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Study on Method of Detecting Preceding Vehicle Based on Monocular Camera

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Abstract-**This article describes systemically the method of detecting preceding vehicle based on monocular camera. The main contents are as following: First, a primary area of interesting is found by the lane borderlines that are identified in a camera image, and a likelihood target vehicle is searched by the gray difference between the target vehicle and background. Second, an identifying area of interesting is found again based on the area of likelihood target vehicle, a target vehicle is affirmed by a symmetry character of the vehicle outline and a position of the vehicle symmetrical axis is ascertained. Third, the object vehicle is tracked by Kalman forecast principle in the sequence images. Fourth, a method of detecting distance in a frame of image is introduced, and the calibration of camera's interior parameters and the results of some experiments are given.**

I. INTRODUCTION

The image can be obtained simply and conveniently by CCD camera now, availability information is contained in the image and can be processed by different methods, so that computer vision technique is a very important to obtain information for vehicle autonomous driving. The applications of image information in identifying lane, detecting obstacle, tracking object and detecting distance have received more and more attention.

The information can be obtained from two kinds of image form. One is to process only a frame of image once, another one is to process continually the sequence image. The exploring path, identifying obstacle and detecting distance can be finished in a frame of image, and the tracking object can be implemented by the sequence image. The sequence image can be used also to detect a relative distance between the host vehicle and the obstacle, and to improve the real time and availability of detecting obstacle [1][2]. In practice, two kinds of method for processing image are used at same time.

The approaches to acquire information around a host vehicle by camera image are as following: First, to identify the object, it is to discover and validate whether the object is in a frame of image. Second, to track the object, it is to affirm continually the position of object in the sequence image. Third, to detect the distance, it is to ascertain the distance between the host vehicle and object by a model of detecting distance. The algorithm of identifying and tracking object impact on the real time to acquire information in the image, the model of detecting distance affect the results of measuring the distance. In this paper, the methods about acquiring information of preceding vehicle by monocular camera are introduced, a kind of detecting distance model is discussed and validated by some experiment.

II. IDENTIFYING AND TRACKING THE PRECEDING VEHICLE

A. Characters of target vehicle

In a frame of gray image, the characters of target vehicle are as following:

(1) Gray characteristics There are different grays between the vehicle and background in the image.

(2) Boundary characteristics There are some level and vertical borderlines on the vehicle, the gray change of the boundary between the vehicle and background or the vehicle and road is evidence.

(3) Symmetry characteristics The figure of the vehicle is symmetry on the center axis of level or vertical direction.

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Wherefore, the algorithm of identifying object based on characteristic model has three steps:

(1) The primary area of interesting is found by the lane borderlines that are identified in a camera image, the possible object is detected by the gray characteristic.

(2) Then the identifying area of interesting is found in the area of possible object, the object is ascertained and located in the image by the symmetry characteristic.

(3) The object is tracked continually in the sequence images.

It is very important to find a target vehicle as soon as possible when the vehicle is running in a high speed. But the object is smallness in the image when the preceding vehicle is far, so some characteristics of the object are not evidence. The primary detecting is done only by a part of characteristics.

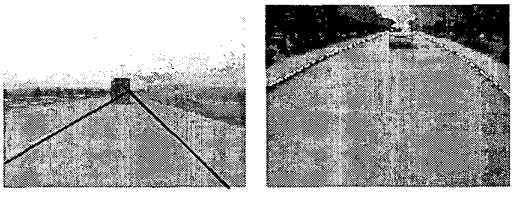


Fig.1 The primary area of interesting found by two lane borderlines

B. Detecting possible object

1. Primary area of interesting

It is supposed that the host vehicle and preceding vehicle are running in same lane. The preceding vehicle is the identifying object in the image. The area of detecting object is a triangle area in Fig.1, it is formed by two lane borderlines that have been identified in detecting navigation path. The triangle area is called the primary area of interesting. In the area of interesting, the time to detect preceding vehicle can be reduced. The method of detecting lane borderline or road margin has been introduced in other paper of our group [3].

2. Primary detecting preceding vehicle

There are some level configurations on the tail of the preceding vehicle, for example, a shadow line bottom the vehicle, the rear window, bumper and license plate etc. When the preceding vehicle is far, the level line between the vehicle and ground is evidence. The line is a clew for primary detecting object. The method of detecting preceding vehicle is as following:

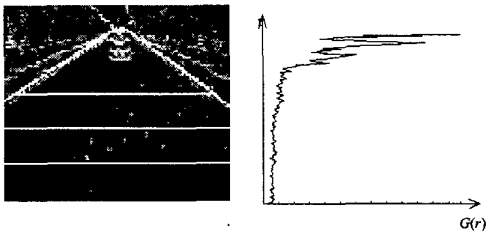
(1) According to the characteristics of level line in the image, the image is processed in the level direction based on Sobel transform, the margin of the object is clear.

(2) In the primary area of interesting, the mean value of the pixel gray for each row is calculated, shown as Fig.2 (a). On r row, the formula for the mean value of the pixel gray is as following:

$$G(r)=\frac{1}{rb(r)-lb(r)+1}\sum_{c=lb(r)}^{c=rb(r)}g(r,c) \qquad (1)$$

In the formula, lb(r) is the coordinate of pixel on left end of r row in the primary area of interesting, rb(r) is the coordinate of pixel on right end of r row in the primary area of interesting, g(r, c) is a gray of pixel (r, c) on r row, $G(r)$ is the mean value of the pixel gray on r row.

(3) In primary area of interesting, the position of the mean value break of the pixel gray is the bottom margin of the preceding vehicle, so that the preceding vehicle may be considered to have been found, shown as Fig.2 (b).



(a) (b)

Fig.2 The primary detecting for target vehicle

The lane is divided into two parts by the row of gray mean value break in the primary area of interesting, shown as Fig.3. The underside is the road, and the upside may be the preceding vehicle. The gray of pixel is a type of information. If the distribution of the gray is uniformity, the information is a few in the image. By contraries, if the distribution of the gray is complex, the information is abundance in the image.

$p(x_k)$ is probability of the gray value x_k ,the

entropy shows a uncertainty of the gray value in the image, then, mean value of information x_k is measured as following:

$$E(x_k) = -\sum_{k=1}^{n} p(x_k) \log p(x_k) \qquad (2)$$

The values of entropy in the upside and underside divided by the row of gray mean value break are shown in Fig.4, that curves are formed by 200 frames of image. The entropy values are difference between the upside and underside of the primary area of interesting, so the threshold should be given. If the entropy value is higher than the threshold, it is possible for the preceding vehicle to be in primary area of interesting.

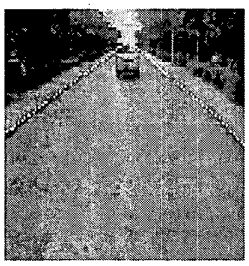


Fig.3 The two areas divided by gray mean value break in primary area of interesting

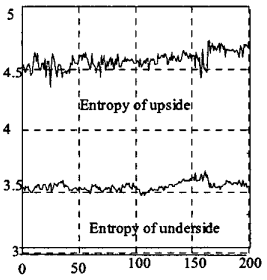


Fig.4 The entropy of upside and underside

C. *Affirming preceding vehicle*

It is a hypothesis that the preceding vehicle is running in frontage of the host vehicle, but the object must be affirmed in the identifying area of interesting. Generally, the figure of a vehicle is symmetry. The concept of series symmetry is used to affirm the preceding vehicle in the lane.

1. Identifying area of interesting

In order to affirm the position of the preceding vehicle, the identifying area of interesting should be found. The identifying area of interesting is a rectangle. The area of rectangle is larger than the image of the preceding vehicle. The steps to build the identifying area of interesting are as following:

(1) The bottom line of the identifying area of interesting is selected on row k under the row of mean gray value break, and two points of intersection between the bottom line and the margins of lane can be found.

(2) Two vertical lines are set at left and right points of intersection, they are two margins of the identifying area of interesting..

(3) The top line is set by the transcendental knowledge of the vehicle height, the image of preceding vehicle is as possible as in the identifying area of interesting.

According to above steps, a rectangle area can be formed, it is called the identifying area of interesting.

2. Measure of symmetry

The gray value of a row in the image is shown by the one dimension function of level pixel coordinates (x), it is g (x). Any function is the sum of odd function $g_o(x)$ and even function $g_e(x)$, the symmetry is shown by their weights. If the weight of even function is larger than the odd function, the figure is symmetry.

To set x_s is the level position of symmetry axis, w is the width of symmetry area. If x_s is origin, new coordinates $u\ (-w/2 \le u \le w/2)$ is found, the transform of u and x is as following:

$$u = x - x_s \qquad (4)$$

When x_s and w are affirmed, the odd and even functions are as following:

$$e(u, x_s, w) = \frac{g(x_s + u) + g(x_s - u)}{2} \qquad (5)$$

$$o(u, x_s, w) = \frac{g(x_s + u) - g(x_s - u)}{2} \qquad (6)$$

The energy function is used to compare the weights between the even function and odd function. The formula of energy function is as following:

$$E(f(x)) = \int f^2(x) dx \qquad (7)$$

Therefore, their energy functions of even function and odd function can be expressed as following:

$$E_e(x_s, w) = \sum_{u=-w/2}^{w/2} e^2(u, x_s, w)$$

$$E_o(x_s,w)=\sum_{u=-w/2}^{w/2}o^2(u,x_s,w) \qquad (8)$$

According to the rule of statistics, the mean value of odd function is zero, the mean value of even function is positive number. The above results are not compared, so that the even function should be transformed and the mean value of the function is also zero.

$$e'(u,x_s,w)=e(u,x_s,w)-\frac{1}{w}\sum_{v=-w/2}^{w/2}e(v,x_s,w) \qquad (9)$$

$$E'_e(x_s,w)=\sum_{u=-w/2}^{w/2}e'^2(u,x_s,w) \qquad (10)$$

The measure of symmetry described with the energy function is as following:

$$s(x_s,w)=\frac{E'_e(x_s,w)-E_o(x_s,w)}{E'_e(x_s,w)+E_o(x_s,w)} \qquad (11)$$

The range of symmetry measure is (-1,1), when s = 1, it is a full symmetry, when s= -1, it is no symmetry. The symmetry depends on parameters xs and w.

In the identifying area of interesting of Fig.5, the symmetry measure of row 168 is shown in Fig.6. Because the width of object vehicle is unknown, the mean value of

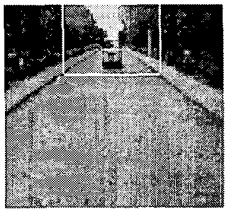


Fig.5Theidentifying area of interesting

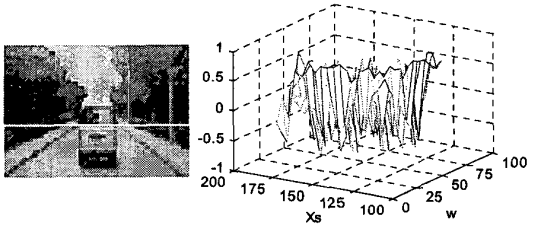


Fig.6 The symmetry measure on row168

symmetry measure on the symmetry axis xs of object vehicle may be calculated by the formula 12. The results are shown in Fig.7.

$$\mu(x_s)=\frac{1}{n_{x_s}}\sum_{w}s(x_s,w) \qquad (12)$$

Commonly, the symmetry of preceding vehicle is evidence in the identifying area of interesting and the value of symmetry measure is maximum on the symmetry axis. But the mean values of symmetry measure calculated by one row are many peak value points, shown as Fig.7, the results is not used to affirm the symmetry axis. If the values of symmetry measure about every row in the identifying area of interesting are calculated and the mean value of symmetry measure is also counted,

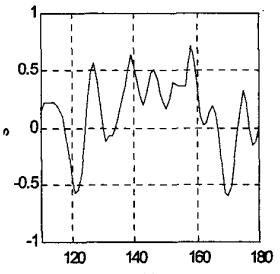


Fig.7 The mean value of symmetry on row 168

the result show maximum value of symmetry measure on symmetry axis, shown as Fig.8. A threshold of symmetry measure should be selected correctly. If the value of symmetry measure is higher than the threshold, the preceding vehicle can be affirmed and the position of the level symmetry axis is found at the same time. Otherwise, the preceding vehicle is not considered in the frontage lane.

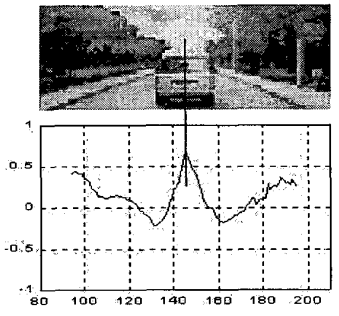


Fig.8 The symmetry axis of Preceding vehicle

3. Vehicle figure in rectangle area

Based on the margin image enhanced by Sobel transform in the perpendicularity, Hough transform detected on two sides based on the symmetry axis of the object, two margins of the preceding vehicle in perpendicularity is finished in the identifying area of

interesting. The perpendicular lines are can be drawn. According to the transcendental knowledge of the vehicle height, Hough transform in level is finished in the identifying area of interesting, the top margin of he preceding vehicle can be drawn. The vehicle figure in rectangle is shown in Fig.9.

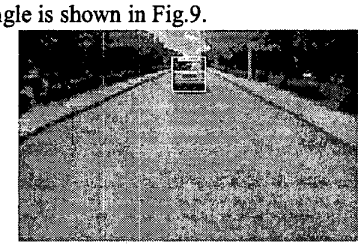


Fig.9 The area of vehicle figure

D. *Tracking the preceding vehicle*

The rectangle of the vehicle figure is as a target, the center of rectangle is the position of the target. It is supposed that the current position of the target is a Gauss distribution based on the previous position [4].

The position of target in the sequence image accords with one rank self-correlation process, so that the position of the target in the sequence image can be forecast by Kalman principle.

E. *Experiment for detecting preceding vehicle*

In order to verify the availability of the detecting the object, some experiments is finished on the JLUIV-4 intelligent vehicle. At the same time, the sequence images of the preceding vehicle are obtained in highway, the images are processed by the off-line detecting, shown as Fig.10.

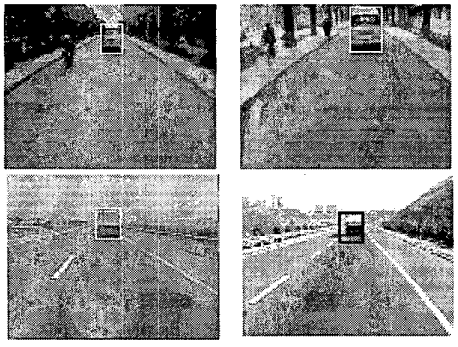


Fig.10 The images of detecting preceding vehicle

The results of the experiments are as following: when the algorithm of tracking the object is not used,the overall detection rate was only 90% and false alarm rate was13%,the mean time of detecting object is 82 ms. Then, when the algorithm of tracking the object is used, the overall detection rate was 94% and false alarm rate was 6% ,the mean time of detecting object is 68ms.

III. DETECTING DISTANCE BASED ON MONOCULAR CAMERA

A. *Model of detecting distance in image*

The geometrical relation of point P imaging in two dimensions plane of CCD camera is shown in Fig.11.

The level distance between point P and the center of camera is described in the following formula:

$$d = h / \tan(\alpha + \arctan((y - y_0)/f)) \quad (13)$$

In the formula 13, f is the focus of CCD camera. αis the incline angle of CCD camera. h is the height of CCD camera to ground. The coordinate (x0, y0) is the point of intersection about optical axis and image plane, it is a origin of image plane and set (0, 0). The coordinate (x, y) is the point P projection in image plane.

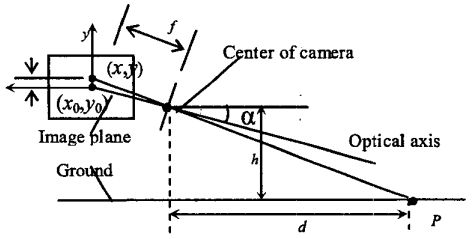


Fig.11 The geometry model of detecting distance in image

B. *Analysis of model parameters*

In the formula 13, h and α are the known parameters when the CCD camera is installed. f is the focus of CCD camera and belongs to interior parameter of CCD camera. y is a coordinate, that is the projection of point P on y axis of image plane, and it is called the image plane coordinate and the unit of coordinate is millimeter. Because the digital image is stored in the memorizer of computer, the coordinate (u, v) of image data is used only in the image processing, it is called the store frame coordinate and the unit of coordinate is pixel. In the detecting distance, the store frame coordinate must be transformed into the image plane coordinate.

u0, v0 are the store frame coordinate of intersection point (x0, y0) of CCD camera optical axis and image plane, it is in the center of frame store image. The transforms between the store frame coordinate and image plane coordinate are as following:

$$u = \frac{x}{dx} + u_0, \quad v = \frac{y}{dy} + v_0 \qquad (14)$$

In the formula 14, dx and dy are the length and width of each CCD pixel. v can be obtained in above the identifying vehicle, it is a coordinate of intersection point about the symmetry axis of the vehicle and the projective line of the vehicle on ground in the image. The dx, dy, u0 and v0 are the interior parameters of CCD camera. After the calibration of parameters is finished in off-line, the detecting distance can be carried out in real time.

The following formula is transformed from the formula 14:

$$\begin{cases} x = (u - u_0)dx \\ y = (v - v_0)dy \end{cases} \qquad (15)$$

In the fomula15, the values of u and v are obtained by the image proceeding.

$$x_0 = y_0 = 0 \qquad (16)$$

The formula13 is transformed by the formulae 15 and 16, then

$$d = h / \tan(\alpha + \arctan((v - v_0) / a_y)) \quad (17)$$

a_y=f / dy.

C. *Verifying model*

The calibration of the interior parameters is carried out in 50 points of space, the results are as following:

u0=151.4,v0=94.27,ax=252.67,ax=234.60

The store frame coordinate of intersection point about optical axis and image plane is (151,94), but the sizes of frame store image are 288×216, its center coordinate is (143,107). The two centers are different. The detecting distance is carried out by above the method, the range of detecting distance is 4m-25m. The gray images are shown in Fig.12.

IV. CONCLUSION

The method of detecting preceding vehicle by the characteristic of object is as following: First, the primary area of interesting is found by the lane borderlines that are identified in a camera image, and a likelihood target vehicle is searched by the gray difference between the target vehicle and background. Second, identifying area of interesting is found again based on the area of likelihood target vehicle, a target vehicle is affirmed by a symmetry character of the vehicle outline and a position of the vehicle symmetrical axis is ascertained. Third, the object vehicle is tracked by Kalman forecast principle in the sequence images. Above method can be used to identify the preceding vehicle and the results of the experiment are preferably in the some conditions. The information of processing image and the calibration of camera's interior parameters can be used to detecting the distance of object.

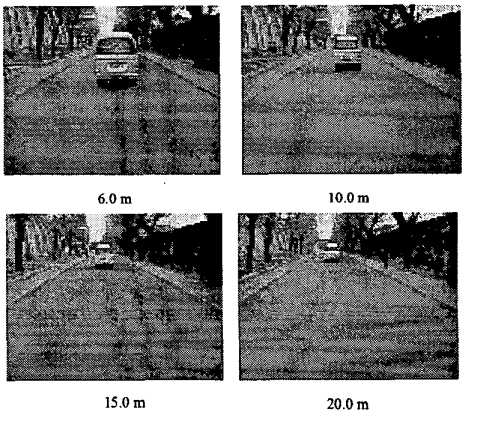


Fig.12 The gray images used in detecting distance

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