A Novel Method of Preceding Vehicle Detection and Vehicle Distance Measurement Based on Monocular Vision

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Abstract
To solve the problem of high precision preceding vehicle detection and distance measurement of driver assistant system, a novel method based on monocular vision is proposed. In the process of preceding vehicle detection, a two steps method that includes vehicle hypothesis area extraction and vehicle verification is designed. In order to improve the accuracy of vehicle detection effectively, feature vectors of ULBP (Uniform Local Binary Pattern) texture histogram and a k-nearest neighbor classifier are adopted to verify whether there are vehicles in the hypothesis area. In the process of distance measurement, the camera off-line calibration and on-line distance calculation method is effectively guarantee the distance measuring precision. Experimental results show that the vehicle detection accuracy of the proposed method is 98.13%, which is 5.73% higher than that of traditional shadow-based method, and the rate of false positives is reduced significantly. And the distance measuring average absolute value of error of only 0.8058 m, the method has higher measuring accuracy than the traditional methods.

Key words: Monocular vision, Preceding vehicle detection, Vehicle distance measurement, Feature vectors of ULBP texture histogram.

1. INTRODUCTION
With the increase of vehicle penetration, the traffic environment deteriorated and the traffic accident rate continued to rise. Statistical data show that the proportion of rear-end accidents accounts for the first of all kinds of road traffic accidents. Especially the consequences of rear-end on the highway are mostly large or significant vicious incidents, resulting in the huge casualties. Therefore, the preceding vehicle distance measurement and timely warning of traffic safety is of great significance. It has become a hot issue in today's vehicle-assisted driving system. Studies have shown that one second pre-warning time can prevent 90% of the car rear-end accident and 60% of the vehicle front collision accident (Sun and Zhou, 2013).

At present, the vehicle discovery and distance measurement technology are mainly based on laser radar, ultrasonic ranging, RFID (Radio Frequency Identification), satellite navigation and vision-based methods. The laser radar (Yin, et al., 2014) and ultrasonic ranging (Zhu, 2013) methods are easy to mistakenly detect the roadside facilities as vehicles and send false alarm. This mistake is particularly serious in turn corners. RFID-based technology and satellite navigation technology (Wang, et al., 2011) require vehicles to install RFID radio and GPS modules. Vehicles that do not have GPS and RFID modules installed cannot be measured, which greatly limits the application of the system. The vision-based approach has the advantages of low installation...
cost and abundant information, but the traditional visual distance measurement based on binocular vision method (Seo, et al. 2013; Zhang, et al., 2011) need to install two cameras. The application is inconvenient and the algorithm is complicated. In recent years, some literatures (Yu and Zhang, 2012; Wu, et al., 2012) proposed single camera- based distance measurement method, but mostly dependent on the lane line detection. They do not apply to unstructured roads and their application is limited. In this paper, a novel method of vehicle detection and distance measurement based on monocular camera is proposed. The algorithm has the advantages of high precision, easy application and wide application.

2. DESIGN OF THE PROPOSED METHOD

The method is divided into three parts: camera off-line calibration, preceding vehicle detection and vehicle distance measurement. The flow chart is shown in Figure 1. In the off-line calibration procedure, the camera homography model is established. A homography matrix from the roadbed to the image plane is calculated based on four known coordinate points. In the preceding vehicle detection step, two steps of vehicle hypothesis area extraction and vehicle verification are designed, which can effectively improve the accuracy of vehicle detection. In the step of vehicle distance measurement, the accurate distance is defined as the distance between the shadow point of the rear of the preceding vehicle and the projection point on the vehicle head on the road.

3. OFF-LINE CALIBRATION OF THE CAMERA

First, the camera calibration is used to calculate the camera's internal and external parameters, so that the actual distance of the vehicles in the subsequent step can be calculated. According to the pinhole imaging model (Chi, et al. 2015), the imaging geometry model of the vehicle-mounted camera used in the proposed method is shown in Figure 2.

For any point \((X, Y, Z)\) in the world coordinates, the transformation to the image plane coordinates \((u, v)\) uses the formula (1),

\[
\begin{align*}
X &= f_X u \\
Y &= f_Y v \\
Z &= f_Z \frac{v}{u}
\end{align*}
\]
where $z$ is the scale factor, $M$ is a $3 \times 4$ perspective transformation matrix, which consists of camera internal and external parameters.

$$M = \begin{bmatrix}
f_x & 0 & u_0 & 0 \\
0 & f_x & v_0 & 0 \\
0 & 0 & 1 & 0
\end{bmatrix} \begin{bmatrix}
R \\
t \end{bmatrix}$$

In formula (2), $f_x$ is the focal length in pixels, $(u_0, v_0)$ is the pixel coordinate at the origin of image plane, $R$ is $3 \times 3$ rotation matrix, and $t$ is $1 \times 3$ translation vector.

If the camera is calibrated using the above model, the algorithm is complex. In this paper, the vehicle distance is the distance on the road between the shadow area of preceding vehicle on the road surface and the projection point of the vehicle-mounted camera. So we only need to focus on the points on the road plane. Under this constraint, the $X-O-Y$ plane of the world coordinate system is selected on the roadbed, and the $Z$-axis can be eliminated. Therefore, the camera homography model is derived and formula (3) is given,

$$z \begin{bmatrix}
u \\
v \\
1
\end{bmatrix} = H \begin{bmatrix}
X \\
Y \\
1
\end{bmatrix}$$

where $H$ is a homography matrix from the road plane to the image plane. In the calibration process, the $h_{33}$ is normalized, and only the remaining 8 parameters are solved. If the world coordinates $(X_Q, Y_Q)$ and its pixel coordinates $(u_q, v_q)$ of a point $Q$ in space are known, the result can be calculated by formula (3). The results are shown in formula (4),

$$\begin{align*}
z u_q &= h_{11}X_q + h_{12}Y_q + h_{13} \\
z v_q &= h_{21}X_q + h_{22}Y_q + h_{23} \\
z &= h_{31}X_q + h_{32}Y_q + 1
\end{align*}$$

After eliminating the scale factor $z$, two solutions to the constraint equation are obtained. The results are given in formula (5),

$$\begin{align*}
u_q &= \frac{h_{11}X_q + h_{12}Y_q + h_{13}}{h_{31}X_q + h_{32}Y_q + 1} \\
v_q &= \frac{h_{21}X_q + h_{22}Y_q + h_{23}}{h_{31}X_q + h_{32}Y_q + 1}
\end{align*}$$

According to the previous method, this paper chooses four calibration points to obtain eight solving constraint equations, and the 8 parameters in the homography matrix $H$ are calculated.

4 PRECEDING VEHICLE DETECTION

The purpose of preceding vehicle detection is to detect the vehicle in front and to determine the position of the vehicle in the image. In this paper, the location of the vehicle may be extracted according to the shadow area at the bottom of the vehicle (The latter is called the vehicle hypothesis area). And then calculate the texture symmetry matrix in each vehicle hypothesis area. Due to the vehicle's view is texture of axisymmetric, thus can judge whether there is vehicle in the hypothesis area.

4.1 Extraction of Vehicle Hypothesis Area

For vehicles on the roadbed, shadow areas are often formed on the roadbed due to light shielding. This
method is based on the detection of vehicle shadow area to complete the extraction of vehicle hypothesis area. Because the brightness of shadow pixels is dim, the adaptive threshold method is used to extract the suspected shadow pixels in the video gray image, and the results are shown in Figure 3(a). The black pixels in the figure satisfy the condition of formula (6),

\[ g(x, y) \leq \delta \] (6)

where \( g(x, y) \) is the gray value at the pixel \( (x, y) \), and the \( \delta \) is an adaptive threshold, which can be calculated by the method in the document (Zhang and Zhang, 2008). It can be seen from the figure that the detected pixels contain not only the real shadow pixels of the vehicle, but also the background pixels such as the tree contour. Obviously, the real vehicle bottom pixels are located in the roadbed, while the other interference pixels are mainly distributed in the background area outside the road. So this paper filters out most of the interference through road constraints. In this method, the camera is installed at the driver's point of view, and the roadbed area is located below the field of view. The image edge information is detected by using Roberts cross gradient operator. Then the area of the roadbed is determined, as shown in Figure 3(b). Taking the shadow area of the vehicle as the lower boundary, the projection of the edge of the image is calculated to complete the extraction of the vehicle's hypothesis area. The principle is shown in Figure 3(c), and the extraction result is shown in Figure 3(d). It can be seen that the vehicle area can be detected more accurately, but there are still a small number of interference areas. This method eliminates these disturbances by the following vehicle verification to achieve accurate preceding vehicle detection.

4.2 Vehicle Verification

For the extracted vehicle hypothesis area, a variety of methods can be used to determine whether there is a vehicle in the area. In this paper, the detection method of the existing literature has been improved. By calculating the left and right sub-area of the hypothesis area edge image, ULBP (Uniform Local Binary Pattern) (Ojala and Harwood, 1996) texture histogram features, and the k-nearest neighbor classifier is used to classify the hypothesis area with car and carless. We verify the existence of the vehicle or not by this method. Before applying the k-nearest neighbor classifier, the hypothesis area is filtered through the symmetry of the left and right texture of the vehicle’s view to improve the efficiency of the algorithm. The calculation of ULBP texture histogram feature and filtering the hypothesis area are as follows:

**Step 1:** The vehicle rear hypothesis area shown in Figure 4(a) is divided into left and right detection partitions, labeled L and R, respectively;

**Step 2:** The detection partitions L and R are divided into six sub-partitions, respectively, as shown in Figure 4(b) labeled L1 ~ L6 and R1 ~ R6;
Step 3: Each pixel in each sub-partition is compared with the gray values of the 8 adjacent pixels, and the ULBP texture of the pixel is calculated, as follows,

$$ULBP_{p,r} = \begin{cases} \sum_{i=0}^{P-1} (S(g_c, g_i) \times 2^i), & U(LBP_{p,r}) \leq 2 \\ \xi, & \text{others} \end{cases}$$

(7)

where $g_c$ is the current point, $g_i$ is the i-th neighborhood, $P$ is the number of neighborhood points, $R$ is the radius of the neighborhood circle, $\xi$ is the uniform constant, $U(LBP_{p,r})$ is the decision function of the number of bitwise transformations. $U(LBP_{p,r})$ is calculated using the following formula (8),

$$U(LBP_{p,r}) = \left| S(g_c, g_{p-1}) - S(g_c, g_R) \right| + \sum_{i=1}^{P-1} \left| S(g_c, g_i) - S(g_c, g_{i-1}) \right| .$$

(8)

Step 4: For each sub-partition, the ULBP texture histogram of all pixels is calculated and normalized, denoted as $H_{L1}, H_{L2}, H_{L3}, H_{L4}, H_{L5}, H_{L6}$ and $H_{R1}, H_{R2}, H_{R3}, H_{R4}, H_{R5}, H_{R6}$.

Step 5: Construct the ULBP texture feature vector $S$ is constructed as follows,

$$S = [S_1, S_2, \cdots, S_6]^T$$

(9)

where $S_i$ is a similarity degree of $H_{Li}$ and $H_{Ri}$, it is calculated using the following formula (10),

$$S_i = \left| H_{Li} - H_{Ri} \right|, i = 1, 2, \cdots, 6 .$$

(10)

Take $S$ as the eigenvector, and the k-nearest neighbor classifier is used to determine whether there are vehicles in the hypothesis area or not.

Figure 4. Calculation of the ULBP texture histogram feature of vehicle rear view

5. VEHICLE DISTANCE MEASUREMENT

In a vehicle-assisted driving system, the vehicle distance is the exact horizontal distance from the rear of the preceding vehicle to the head of the vehicle. In this paper, the vehicle distance measurement method shown in Figure 5. The vehicle distance is defined as the distance from B to A, where B is the shadow point of the preceding vehicle on the road and A is the midpoint of the projection line of the vehicle head on the roadbed. The vehicle distance $d$ is calculated by formula (11),

$$d = d_1 + d_2$$

(11)

where $d_1$ is the straight line distance between A and Q, $d_2$ is the straight line distance between Q and B, the Q point is the closest point of view of the horizontal roadbed in the video image. Because of the block of view of the head of this vehicle, Q generally does not coincide with A. However, when the camera is mounted, $d_1$ can be obtained by manual measurement, and $d_1$ remains unchanged on the horizontal road. The calculation method of $d_2$ is as follows,

$$d_2 = \sqrt{(X_Q - X_B)^2 + \left( Y_Q - Y_B \right)^2}$$

(12)

where $(X_B, Y_B)$ and $(X_Q, Y_Q)$ are the world coordinates of point B and point Q, respectively. Since these two points are on the road plane, so the coordinates of the Z-axis are 0. The world coordinates of each point are calculated by their image coordinates and camera calibration parameters.
6. EXPERIMENTAL RESULTS AND ANALYSIS

In order to verify the effectiveness of the algorithm, we conducted a large number of experiments on the secluded campus. The vehicle at 0.5m interval parked within the 5~75m distance ahead of the vehicle equipped with a video camera. The actual vehicle distance is recorded accurately and compared with the result of the algorithm.

Figure 6 shows the absolute error data of the proposed algorithm for measuring the distance between vehicles at different positions, and compared with the absolute error data using lane line method. The lane line method calculates the vehicle distance based on the disappearance of the lane mark in the image, which is a typical technique of monocular vision measurement. Analysis show that the average absolute error of lane line based method is 1.2194m, and the measurement error of the proposed algorithm is in the range of [-1.0, 1.0]m. The average absolute value of the error is only 0.8058m. It can be seen that the proposed algorithm of this paper has higher measurement accuracy.

![Figure 5. Calculation of the distance from the preceding vehicle rear to the vehicle head](image)

![Figure 6. Experimental results of vehicle distance measurement](image)

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Table 1. The experimental results of vehicle distance measurement

In this paper, we use the two-step method of hypothesis area extraction and vehicle verification. Compared with the traditional vehicle verification based on the shadow area at the bottom of the vehicle, the new algorithm has higher vehicle detection rate and lower false alarm rate. Table 1 shows the comparison of two methods. Among them, the video 1~4 were collected on unstructured roads of suburbs, urban structured roads, highways and urban expressway respectively. The number of actual vehicles in each video is obtained by means of manual...
detection. Analysis shows that the new algorithm effectively ensures the accuracy of vehicle detection, and can significantly reduce the probability of false alarm.

7. CONCLUSIONS

This paper presents a novel method based on monocular vision for preceding vehicle detection and vehicle distance measurement. The proposed method including two steps is used to detect the preceding vehicle effectively by vehicle hypothesis area extraction and vehicle verification. In the proposed method, the feature vectors of the ULBP texture histogram is used to improve the accuracy of vehicle detection. We designed an off-line calibration method of camera and on-line calculation of vehicle distance, built the camera homography model and calculated the exact vehicle distance from the rear of the preceding vehicle to the head of the vehicle via a midpoint, which is defined as the projection point. The experimental results verify the high accuracy of the algorithm in vehicle detection and vehicle distance measurement. The application of the algorithm can significantly reduce the false alarm rate of the preceding vehicle detection and vehicle distance measurement error, can also improve the reliability of the vehicle-assisted driving system, and has great value.

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REFERENCES