Chapter 46
The Vehicle Distance Measurement System Based on Binocular Stereo Vision

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Abstract Vehicle distance measurement is the basis of intelligent navigation and secondary navigation which plays an important role in traffic safety. Based on the machine vision technology, a vehicle distance measurement system is designed and realized. Two digital images of the tested vehicle are obtained by binocular camera. On the basis of camera calibration, the technologies of feature point detection and matching are used. According to the principle of parallax, the three-dimensional geometric information of the vehicle's feature point is reconstructed and the distance between vehicles is obtained. The system can provide a basis for visual navigation and vehicle monitoring, improve road safety, and reduce traffic accidents which has certain practical value.

Keywords Binocular stereo vision · Vehicle distance measurement · Camera calibration · Corner detection · Image matching

46.1 Introduction

With the rapid increase of car ownership and driving speed, the traffic accident rate is getting higher and the issue of traffic safety is more prominent. The vehicle distance measurement technique can ensure traffic safety and improve the intelligence level of vehicles. In critical situations, through an alarm or automatically pre-set operation,

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Y. Qin et al. (eds.), *Proceedings of the 2015 International Conference on Electrical and Information Technologies for Rail Transportation*, Lecture Notes in Electrical Engineering 378, DOI 10.1007/978-3-662-49370-0_46

such as emergency braking, some accidents which are caused by the drivers' fatigue or negligence can be avoided based on the measured vehicle distance [1, 2].

Today, the commonly used vehicle distance measurement methods mainly include ultrasonic ranging, millimeter-wave radar ranging and laser ranging, etc. These methods have their advantages and disadvantages.

The technology of vision measurement is to use image sensors to detect the three-dimensional coordinates of certain space object and then get the size, shape, and motion of the tested object [3]. It originated from the computer vision technology in the 1950s. After decades of research and development, various theories and techniques become more mature and perfect. Now, many techniques about machine vision are really applied to people's daily life, such as production automation, vehicle identification [4], and so on.

Based on the technologies of binocular stereo vision technology and image processing, a vehicle detecting and distance measurement system is designed. The principle of binocular stereo vision is analyzed and the corner detection and matching methods are used to compute the actual vehicle distance, which can provide essential information to vehicle safe driving.

46.2 Design of Vehicle Distance Measurement System

The binocular stereo vision system can measure the distance by the simulation of human eyes. Two images of the same object are captured by using two cameras, and the coordinates of certain points can be obtained by corner extraction and matching, and then the distance between cameras and target can be obtained.

46.2.1 Principle of Binocular Stereo Vision Measurement

In binocular stereo vision, using two cameras simultaneously at different locations to shoot two pictures of the same target vehicle [5]. According to the coordinates of same points in their two image coordinate systems, based on feature points detection and matching, the coordinates of certain points in the world coordinate system can be obtained. The principle of three-dimensional measurement is given, as shown in Fig. 46.1.

Assuming that the left camera coordinate system $oxyz$ is made as the world coordinate system, the left image coordinate system is $X_lO_lY_l$, and the effective focal length is f_l; the right camera coordinate system is $o_rx_ry_rz_r$, the corresponding image coordinate system is $X_rO_rY_r$, and the effective focal length is f_r. The point

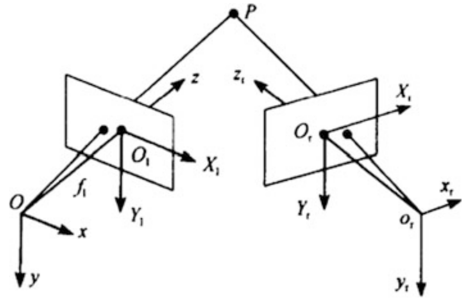

Fig. 46.1 The spatial point reconstruction of binocular stereo vision

P is target, according to the camera perspective transformation model, the expression can be obtained as in

$$s_l\begin{bmatrix}X_l\\Y_l\\1\end{bmatrix}=\begin{bmatrix}f_l&0&0\\0&f_l&0\\0&0&1\end{bmatrix},\quad s_r\begin{bmatrix}X_r\\Y_r\\1\end{bmatrix}=\begin{bmatrix}f_r&0&0\\0&r_l&0\\0&0&1\end{bmatrix}\begin{bmatrix}x_r\\y_r\\z_r\end{bmatrix}\tag{46.1}$$

The mutual positional relationship between the world coordinate system and the right camera coordinate system can be obtained as in

$$\begin{bmatrix}x_r\\y_r\\z_r\end{bmatrix}=M\begin{bmatrix}x\\y\\z\\1\end{bmatrix}=\begin{bmatrix}r_1&r_2&r_3&t_x\\r_4&r_5&r_6&t_y\\r_7&r_8&r_9&t_z\end{bmatrix}\begin{bmatrix}x\\y\\z\\1\end{bmatrix}\tag{46.2}$$
$$M=[R|T]$$

where, $R=\begin{bmatrix}r_1&r_2&r_3\\r_4&r_5&r_6\\r_7&r_8&r_9\end{bmatrix},\quad T=\begin{bmatrix}t_x\\t_y\\t_y\end{bmatrix}$, they are the rotation matrix and translation transform vector between the world coordinate system $oxyz$ and the right camera coordinate system $o_rx_ry_rz_r$ respectively.

For the spatial point in the world coordinate system, the correspondence of a certain point in the two image plane can be obtained as in

$$\rho_r\begin{bmatrix}X_r\\Y_r\\1\end{bmatrix}=\begin{bmatrix}f_rr_1&f_rr_2&f_rr_3&f_rt_x\\f_rr_4&f_rr_5&f_rr_6&f_rt_y\\r_7&r_8&r_9&t_z\end{bmatrix}\begin{bmatrix}z\frac{Y_l}{f_l}\\z\frac{Y_l}{f_l}\\z\\1\end{bmatrix}\tag{46.3}$$

Thus, the three-dimensional coordinate can be obtained as in

$$\begin{cases} x = z\dfrac{X_l}{f_l}, \quad y = z\dfrac{Y_l}{f_l} \\ z = \dfrac{f_l(f_r t_x - X_r t_z)}{X_r(r_7 X_l + r_8 Y_l + r_9 f_l) - f_r(r_1 X_l + r_2 Y_l + r_3 f_l)} \\ \quad = \dfrac{f_l(f_r t_y - Y_r t_z)}{Y_r(r_7 X_l + r_8 Y_l + r_9 f_l) - f_r(r_4 X_l + r_5 Y_l + r_6 f_l)} \end{cases} \tag{46.4}$$

Therefore, if the focal lengths f_l, f_r and the coordinates of left image and right image of the spatial point are known, as long as rotation matrix R and translation transform vector T are obtained, the three-dimensional coordinates of the object point can be obtained.

46.2.2 Vehicle Distance Measurement Based on Binocular Stereo Vision

In the vehicle distance measurement system, it is based on machine vision technology; the two images of the tested vehicle are captured and processed. Using the binocular vision technology, the distance between two vehicles can be computed.

The realization process of vehicle distance measurement is given, as shown in Fig. 46.2.

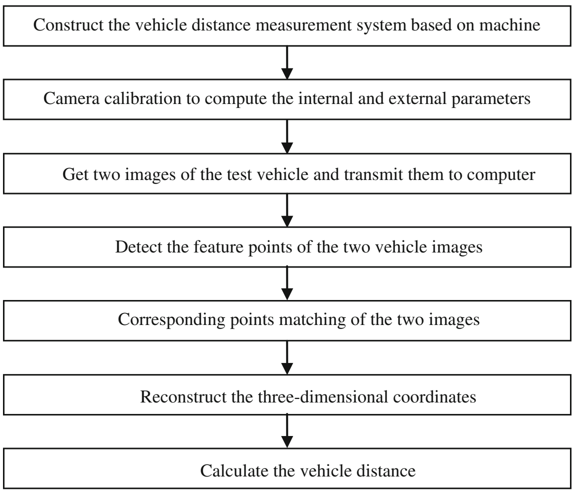

Fig. 46.2 The process of vehicle distance measurement based on binocular stereo vision

46.3 Realization of Vehicle Distance Measurement System

46.3.1 Camera Calibration

The camera calibration means to build the relationship between image pixel position and actual scene location of certain feature points. Its approach is to analyze the model parameters of cameras by image coordinates and world coordinates of some known feature points based on camera model [6, 7]. The model parameters of camera are divided into two parts: internal parameters and external parameters. The camera imaging model has two types: linear model and nonlinear model. Wherein, the linear camera model is based on the principle of pinhole imaging, and the nonlinear camera model adds the distortion amendment on the basis of linear model which improves the camera calibration accuracy effectively.

Tasi gives a two-step calibration method based on radial constraint. The first step is to use the least square method to solve an over-determined linear equation, so the external parameters can be obtained. The second step is to solve the internal parameters. If the camera is not distorted, they can be solved by an over-determined linear equation, but if there are radial distortion in the camera, these parameters can be obtained by combining the nonlinear optimization method. The method has moderate calculating amount and high precision. In this project, in order to compute the internal and external parameters, the two cameras are calibrated by the two-step method.

46.3.2 Corner Detection of Vehicle Images

In the process of computer image processing, the corners can reflect the essential characteristics of the original image [8]. There is no exact definition of corner. In general, the corner means a point where the brightness changes strongly. As the important feature of original image information, the corner can effectively reduce the data amount and the corner detection is particularly important in image processing and machine vision.

Harris algorithm extracts corners based on gray scale information of image pixel. The method has excellent detection result and it is used widely. It uses autocorrelation matrix and computes the threshold value to decide a corner. In this project, the Harris method is adopted to detect the image corners of the tested vehicle.

46.3.3 Stereo Matching of Vehicle Images

The stereo matching is the key technology to machine vision application system. It is to get the correct corresponding feature points in the two images of the same target [9, 10]. On the basis of corner detection and image matching, the vision system can quickly get the coordinates of the object in the world coordinate system.

In order to improve the accuracy rate of the image matching, certain constraints are used. For the detected corners by the Harris algorithm, the gray scale similarity is used to construct the initial matching relation. The matching method based on gray scale distribution is to use correlation function to evaluate the similarity of the two images and to determine the corresponding feature points. The parallax theory is used to remove some false matched corners. According to the camera calibration, the fundamental matrix is found to eliminate some false matching. Then, the final corresponding corners in the two images of the tested vehicle can be obtained.

46.3.4 Measurement of Vehicle Distance

In the vehicle distance measurement system, based on binocular stereo vision, two images of the same target vehicle are captured simultaneously at different locations by two cameras. Based on the camera calibration technology, Harris corner detection algorithm, stereo matching technology, and the three-dimensional reconstruction theory, the vehicle distance can be computed.

In the actual test, the two cameras are set with a moderate angle, the left and right images of the tested vehicle are captured, and the corners are detected and matched, as shown in Fig. 46.3.

According to the matched corners and the results of camera calibration, the vehicle distances are measured, as shown in Table 46.1.

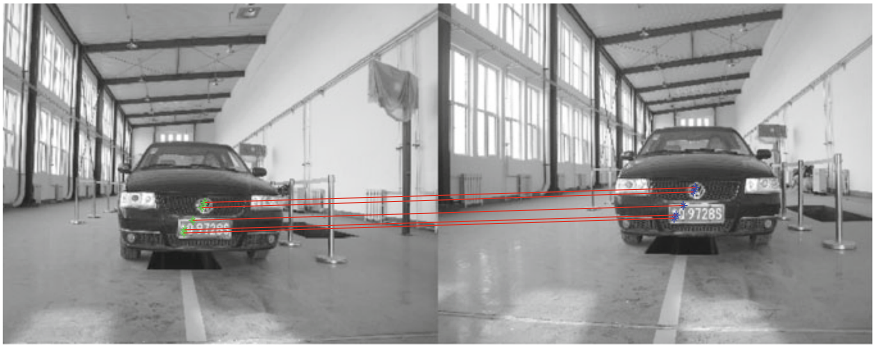

Fig. 46.3 The matched corners of the tested vehicle images

Table 46.1 The measurement results of vehicle distance

No.	Coordinates in left camera image	Coordinates in right camera image	World coordinates	Vehicle distance/m	Actual distance/m	Relative error (%)
1	(1194.4763, 1165.0427)	(1525.8455, 1079.4907)	(−180.31609, −202.23938, −2434.7925)	2.4498	2.454.9	−0.21
2	(1091.0814, 1290.8289)	(1424.7415, 1206.8273)	(−4.4261856, −352.28821, −2430.7969)	2.4562	2.454.9	0.05
3	(1206.764, 1138.7637)	(1538.672, 1052.4248)	(−217.42348, −186.19931, −2450.8438)	2.4675	2.454.9	0.51
4	(1135.3666, 1240.5409)	(1467.2797, 1156.5664)	(−74.991882, −286.10071, −2421.0759)	2.4391	2.454.9	−0.64
5	(1081.2616, 1309.0554)	(1415.4536, 1225.1615)	(21.507919, −367.56281, −2434.4548)	2.4621	2.454.9	0.29

46.4 Conclusions

The binocular stereo vision system has the special function of simulating human visual system. It can get outside information effectively and quickly, and it is an online, non-contact information exchange platform. Vehicle distance measurement is important in intelligent vehicle and safe driving. The vehicle distance measurement system based on machine vision is designed and realized. By the corner detection and stereo matching for the two images of the tested vehicle, based on the camera calibration, the three-dimensional information of the target vehicle is reconstructed. The vehicle distance measurement model is established based on principle of parallax. The system can automatically measure the distance between two vehicles to provide driving information for drivers and ensure driving safety.

Acknowledgment This study is sponsored by the National Undergraduate Training Programs for Innovation and Entrepreneurship (No. 201410452031) and the Science and Technology Development Planning Project of Shandong Province (No. 2013YD05004), People's Republic of China.

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