The Method of Detecting Nearest Distance Between Obstacles and Vehicle Tail based on Binocular Vision System

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***Abstract*—In order to provide auxiliary information for car parking, a strategy of detecting the nearest distance between obstacle and vehicle tail was studied based on the binocular vision system and a parking assist system was designed. The captured images were processed and analyzed by using binocular vision system, the image distortion was improved by using the histogram correction method, and the influence of noise in space was eliminated by using Gauss filter. Harris algorithm was used to detect the characteristic points accurately, and the feature points were matched. A kind of strategy about detecting the recent distance between obstacles and the rear of vehicle was put forward. In order to measure the distance, the automobile tail was approximately fitted with a certain polygon. The detection of closest distance between obstacles and the rear of the vehicle was accomplished by using the binocular vision principle. The distance could be used to provide useful parking information to drivers.**

***Keywords*-Binocular distance measurement; Image processing; Stereo matching; Strategy of nearest point.**

I. INTRODUCTION

Machine vision is a hot topic of the engineering application research in recent years. With the rapid development of science and technology, the technology is widely used in industrial automation, intelligent transportation system, and vehicle detection. Outside information is obtained by the machine vision. The vision can be divided into active vision and passive vision according to related technology. The reason why the latter is called passive vision is that the method does not need special light source, rather than computer dealing with the image. In this technology, the camera directly shoots object, restoring the three-dimensional information from parallax. Passive vision can be divided into monocular and binocular and more orders, according to the number of the used cameras. The method of photoelectric sensing is mainly used in active vision. In passive vision, monocular vision must be shot from the different orientations to get three-dimensional information of the object, and accompanied by a larger error. Therefore, choosing the stereo vision of binocular as the research object can obtain three-dimensional information of object accurately, and the system hardware is also much cheap. The detection of closest point of binocular camera objects is put forward on this subject, based on the research of the binocular distance measurement. Reversing image has been widely used in vehicles today, the drivers can see the rear obstacle clearly from it. However, there are also some disadvantages, because the image is plane and the distance of obstacle away from the vehicle can't be clearly seen. Sometimes there is apart from the obstacle, but the scene show in the video display is very close. In this study, by studying the binocular vision and using the principle of binocular vision ranging, a method of distance measurement is put forward and it can measure the distance from obstacles to the rear of the vehicle more accurately.

This study is sponsored by the National Undergraduate Training Programs for Innovation and Entrepreneurship (No. 201510452037), the Science and Technology Planning Project of Higher Education of Shandong Province, China (No. J16LB69).

II. THE PRINCIPLE OF BINOCULAR VISION MEASUREMENT

A. *Basic principle*

The main way of human seeing and cognizing the world is vision. Human perceives the outside world mainly by sensory organs, such as vision, touch, hear, smell and so on. 80% of the information is accessed by the vision [1]. And almost all the creatures have two eyes to see the world. The parallax of binocular also let people observe the world with depth. So, the computer vision system also commonly uses two or more cameras to observe the same scene from two or more perspectives, to obtain a set of images from different perspectives. According to the principle of parallax, the target object's geometry and position in the space is deduced. The binocular stereo vision is based on the principle of parallax for three dimensional measurements.

978-1-5090-3528-1/16/$31.00 ©2016 IEEE

The baseline B is the distance of two camera projection axis. The camera focal length is f. Due to the shortage of the manufacturing process, their focal length is not equal, so there are error in the machine vision application. So it can assume that the two cameras have the equal focal length firstly. Supposing that two cameras shoot space objects of the same feature points at the same time, respectively, the "left" and "right" camera can obtain the image of a little point of P. Their image coordinates are $P_{left} = (X_{left}, Y_{left})$ and $P_{right} = (X_{right}, Y_{right})$, respectively. Now the images of two cameras in the same plane, so the feature points image coordinates are equal, that is $Y_{left} = Y_{right} = Y$, obtained by the triangular geometry relationship. The principle of binocular stereo imaging is given, as shown in Fig. 1.

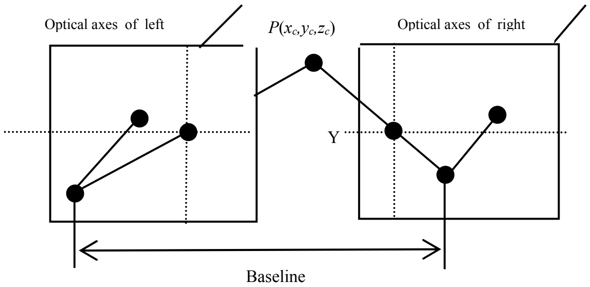

Fig. 1. Principle of binocular stereo imaging

$$\begin{cases} X_{left} = f\dfrac{x_c}{z_c} \\ X_{right} = f\dfrac{(x_c - B)}{z_c} \\ Y = f\dfrac{y_c}{z_c} \end{cases}$$

So parallax as: $Diparity = X_{left} - Y_{right}$.

Thus, it can calculate the coordinates of the feature point P in the 3D coordinates, it is given as follows.

$$\begin{cases} x_c = \dfrac{B \bullet X_{left}}{Disparity} \\ y_c = \dfrac{B \bullet Y}{Disparity} \\ z_c = \dfrac{B \bullet f}{Disparity} \end{cases}$$

B. Image coordinate system and world coordinate system

The image collected by the camera is converted into digital image through the analog-to-digital conversion. For image based on gray value, it is stored in the computer with the form of a $M*N$ matrix, and the value of each element in the image of the N row M column is the gray level of the image point. The definition of Cartesian coordinates in the two-dimensional plane image is on behalf of the pixel, which are columns and rows in the matrix. So, this coordinate system is based on the image coordinate system of the pixel. Because (U, V) only represents the number of columns and rows of pixels in the matrix which does not use a physical unit to show the position of the pixel in the image, therefore, it need to establish the image coordinate system which is expressed by physical unit. This coordinate system defines a point O' as the origin within image, the x axis is parallel to the U axis, and also the y axis is parallel to v axis. The relationship between the two coordinate systems is given, as shown in Fig. 2.

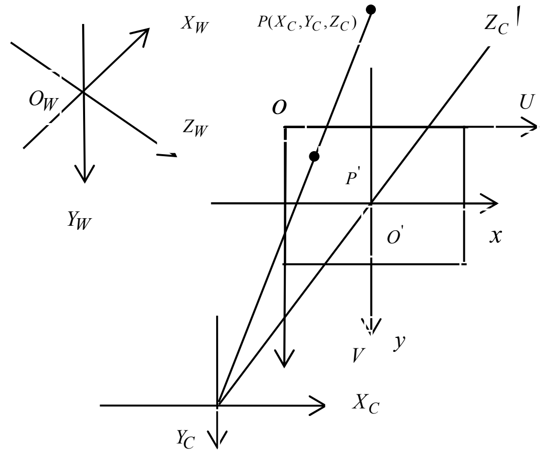

Fig. 2. Image coordinate system and geometry relation

The angle and position of the two cameras can be arbitrary, so the camera coordinate system is not fixed in the environment. It need to choose a reference coordinate system to describe the relative position of the cameras, and then describe the position of any object in the environment. The coordinate system is called the world coordinate system which consists of X, Y and Z axes. The relationship between the coordinate system of image and the coordinate system of world can be described by the rotation matrix R and the translation vector T.

Therefore, if the homogeneous coordinates of a point in the world coordinate system and camera coordinate system are $(X_W, Y_W, Z_W, 1)^T$ and $(X_C, Y_C, Z_C, 1)^T$, then existing

$$\begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix} = \begin{bmatrix} R & T \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X_W \\ Y_W \\ Z_W \\ 1 \end{bmatrix} = M \begin{bmatrix} X_W \\ Y_W \\ Z_W \\ 1 \end{bmatrix}$$

Where, R is a 3*3 orthogonal matrix; T is a three-dimensional translation vector; M is a 4*4 matrix.

So, as long as finding the correspond matching point on the surface of the right camera to any point on the surface of the left camera, then translating the image coordinates into physical coordinates, and using binocular camera calibration translate external parameters into the world coordinates, you can determine the three-dimensional coordinates of the point.

III. THE CAMERA CALIBRATION AND IMAGE PROCESSING

A. The camera calibration

The camera calibration is the first step on the whole system. The camera imaging model describes the relationship between the spatial three-dimensional coordinates of the object and its corresponding points in the camera imaging plane which establishes the geometrical imaging model of camera and describes the relationship between image pixel location and space coordinate midfielder scenic location. Ultimately it determines the camera internal and external parameters, and other information [2]. The camera parameters can be gotten by camera calibration [3]. The basic parameters of the camera imaging, such as focal length, radial distortion and tangential distortion of lens, and so on, they are the camera intrinsic parameters. The traditional camera calibration technique can get the camera model parameters, using the constraint relationship between standard reference and corresponding image. The method need use more than one image to calibrate and the method has been relatively mature [4]. This subject adopts this kind of calibration method, which was put forward by Zhengyou Zhang in 1988. This method is simple, flexible. It is a kind of traditional calibration approach between the traditional calibration methods and self-calibration method. It avoids the high equipment of traditional method, complicated operation, and the self-calibration method is higher accuracy and better robustness etc. [5].

The camera parameters include external and internal parameters. External parameters calibration include rotation matrix T and translation vector R. Internal parameters calibration include camera focal length f, radial lens distortion $k1$,$k2$ and tangential distortion $p1$, $p2$, the main point coordinates (c_x , c_y).

The baseline length B is 384.9 mm, in this subject. The calibration results of two cameras are given, as shown in Table 1 and Table 2.

TABLE I. CAMERA PARAMETERS

Parameters	Left camera	Right camera
f_x	2081.4	2078.7
f_y	2087.8	2075.5
c_x	1179.4	1288.8
c_y	950.4	899.2
k_1	-0.1659	-0.2240
k_2	-0.0768	0.2273
$p1$	-0.0048	-0.0014
$p2$	-0.0006	0.0003
Alpha_c	0	0

TABLE II. ROTATING VECTOR R, TRANSLATION VECTOR T

R1	-0.0030
R2	-0.1456
R3	-0.0593
T1	-384.9
T2	20.1129
T3	40.1122

The two tables show that all parameters of the two cameras are same basically. The calibration coefficient of four distortions and it's error range and calibration results are more accurate. It shows that there is a certain camera angle. Although it is not a standard camera model, the optical axis base on the same plane. The experimental result shows that the distortion coefficient is small, and the distortion of visible and tangential is not particularly evident, especially the tangential distortion.

B. The image feature extraction and stereo matching

1) Image preprocessing

The image preprocessing is a necessary step before exacting image features. Image preprocess aims to reduce the noise of the image signal, increasing noise ratio in digital image data and inhibiting background, so it can facilitate the follow-up image processing, meeting the requirements of system real-time performance. The image pretreatment is related to the subsequent feature extraction and stereo matching directly [6]. Due to information loss caused by image distortion of the image part, the image correction is necessary before for feature extraction. The reasons caused image distortion is the aberration and distortion of imaging system, and the bandwidth limited, etc. Nonlinear geometry distortion is caused by the imaging device profile. The reason of image distortion includes motion blur, radiation distortion, and introduction of noise.

Image correction is mainly divided into two categories, geometric correction and gray-level correction, this subject uses histogram correction in gray level correction, the technology can effectively expand the common brightness, increase the contrast of image, brightness distribute in the histogram better. Then, it can enhance the visibility of the local contrast without affecting the overall effect.

There are external and internal distractions during the process of formation, transmission, receiving and processing the image. The noise makes the image fuzzy, and the characteristic is not obvious, increasing the difficulties of analysis. Therefore eliminating noise and restoring the original image are very important in image processing. It has two purposes, to improve the image quality and to extract object features. The method of the image smooth commonly are carried out by using an average filtering and median filtering. Median filtering is a nonlinear signal processing method, generally using a sliding window contains an odd number of points, the gray value of the specified point is replaced by each point value of the gray in the window.

2) Image feature point extraction

The local characteristics of the image can be reflected by feature points which contain a high amount of information. It indicates the location of the gray level changes dramatically on the two-dimensional, and the surrounding adjacent points also have obvious differences [7]. The Harris operator is used to extract feature point in this study. The extracted feature points are gray-scale transformation sharp points, including the drab background isolated intersection of points, lines and the biggest point of curvature changes on the object contour. The Harris method is simple, less set parameters, small amount of calculation, quick speed, etc. The method is used very widely in machine vision and image processing fields. In this study, it is used to extract the characteristic points of the two captured images of the same obstacle, an automobile, the Harris corners are given, as shown in Fig. 3.

(a) left image (b) right image

Fig. 3. Feature point extracting

3) Image feature point matching

The process of image matching is very import in the machine vision application. It is to recognize the same name point by certain matching algorithm between two or more images. The essence of matching image is to use the similarity and consistency to match the extracted feature points. This study mainly adopts the epipolar constraint theory and disparity theory to match the extracted Harris feature point. In order to increase the matching precision, it uses the match-point function with bilateral matching, the feature points experiment result for the two image of the automobile are given, as shown in Fig. 4.

Fig. 4. Feature points matching

4) Depth recovered and three dimensional positioning

The depth can be recovered after extracting and matching the feature points. According to the results of the interior and exterior parameters of camera calibration, stereo matching, the next task it to restore the 3D information. In this study, it selects the left camera optical center as the origin of coordinates, the 3D information results are given, as shown in Table 3. (unit: mm)

TABLE III. COORDINATES

No.	*X*	*Y*	*Z*
1	882.7	-241.0	2945.9
2	441.7	390.7	3124.8
3	-1729.2	288.3	4918.2
4	-1168.8	-130.5	4405.2
5	890.8	-241.4	2946.0
6	446.6	453.6	3094.0

IV. THE STRATEGY OF MEASURING NEAREST DISTANCE FROM THE OBSTACLES TO VEHICLE TAIL

The system can calculate the world coordinates of obstacles by matching section around the camera. The tail model of the vehicle is simplified with a polygon fitting. According to the values of world coordinate, the nearest distance between obstacle and vehicle tail is calculated. According to the binocular distance measurement principle, the system gets the world coordinates of barriers. Simplifying the vehicle tail can decrease the geometric operation and increase the efficiency. With the above process, the nearest distance from obstacles to the vehicle can be gotten.

As shown in Fig. 5, the automobile tail is approximately fitted with two symmetrical quadrilaterals. The length and the angle parameters are given. The binocular cameras are installed in the middle of the tail position. According to the obstacles of the three-dimensional coordinates, the five vertex distances are computed. The minimum distance can be fended out, which is the approximately nearest distance between the obstacles and vehicle. The quadrilateral fitting of vehicle tail can be used in practice, it can improve the accuracy of measurement. The method can improve the calculation speed by square fitting the tail of vehicle.

The experiment vehicle of this study is Peugeot 308 for 2015, its tail fitting curve is given, as shown in Fig. 5. In this example of the tail fitting curve, the various dimensions are given, which are used to compute the distance.

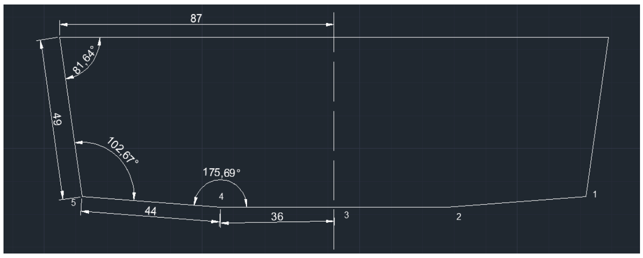

Fig. 5. An example of the tail fitting curve

Based on the information of three-dimensional coordinate of obstacles detected by binocular cameras, the system can find out the five points from the pentagon's nearest point to the obstacles, and calculating the distances.

The measurement result of the nearest distance of an experiment is given, as shown in table 4.

TABLE IV. DISTANCE MEASUREMENT RESULTS

Points	1	2	3	4	5	6
Distance to the	3084.7	3180.0	5221.3	4559.5	3087.2	3158.8

origin						
First point	3068.9	3173.1	5242.7	4576.4	3071.2	3151.8
Second point	3080.0	3177.7	5226.9	4563.8	3082.4	3156.5
Third point	3090.3	3182.7	5215.0	4554.6	3092.8	3161.6
Fourth point	3101.0	3188.1	5203.3	4545.6	3103.6	3167.1
Fifth point	3115.6	3196.3	5190.3	4536.1	3118.3	3175.4

This study designs and implements the nearest distance measurement system by the MATLAB software platform. In the experiment, the first point is nearest from the obstacle, the distance is 3068.9 mm. The strategy for detection nearest distance is put forward in the study for improving the accuracy in the later practice. It can be used to fit the tail of the vehicle rear. Of course, the fitted polygon has more edges, the measurement has higher accuracy, but the calculation is also more complex.

V. CONCLUSIONS

In this study, a nearest distance between the vehicle and the obstacle measurement method is put forward and realized based on machine vision. The system is simple and its hardware is cheap. The experiments show that the designed algorithm is simple and quick, The distance measuring system can work quickly, measurement error is small.

The quadrilateral fitting can meet the system need basically. With the experimental verification, the method proposed in this study has better effect, which provides the information about the distance between carries and parking car for driver and increases the safety of parking or reversing. It can show the position information of obstacles real-time so that the driver can get more information about the rear while backing and increase the safety of reversing.

It is important to note is that the measurement error is mainly caused by less number of fitting edges. In practice, in order to get high measurement accuracy, it can increase the edge number of the fitted polygon. And, it is need to find a compromise between the efficiency and precision of the distance measurement.

ACKNOWLEDGMENT

This study is sponsored by the National Undergraduate Training Programs for Innovation and Entrepreneurship (No. 201510452037), and the Science and Technology Planning Project of Higher Education of Shandong Province (No. J16LB69), People's Republic of China.

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