Design for the Distance Measuring System Based on Binocular Stereo Vision

Yajun Fan [a], Min Wan [b] and Sihan Chen [c], Lingzhi An

School of Mechanical and Electrical Engineering, Southwest Petroleum University, Chengdu 610500, China

[a]18328068786@163.com, [b]18940103@qq.com, [c]1207282603 @qq.com

Abstract

As an important branch of computer vision, binocular stereo vision observes the same scene from two perspectives to get the perception of images under different perspectives, and obtains the three-dimensional scene information by calculating the parallax between image pixels based on the triangle similarity measurement principle. The paper studies the binocular vision distance measuring principle, as well as the technology of camera calibration, rectification and stereo matching. Zhang zhengyou calibration method is adopted to calibrate the camera. Stereo calibration and stereo matching are completed with OpenCV. According to the parallax value, the distance between the camera and the target scene can be solved, so as to realize the distance measurement. The experimental verification shows that the binocular vision distance measuring system achieves the accuracy requirement within a certain distance.

Keywords

Binocular stereo vision, Camera calibration, Stereo matching, Distance measuring.

1. Introduction

Although human eyes have strong capability of stereo perception to judge the order of the depth between multiple objects easily, they can't get accurate distance information of object. Binocular stereo vision simulates the scenery processing way of human eyes. By accurate calibration, it can acquire very precise depth information in the case of correct matching. As an important research direction of distance measuring technology, binocular stereo vision has extensive application prospect in the fields of Robot navigation, three-dimensional measurement of industrial parts , virtual reality and so on[1].

Binocular stereo vision distance measuring acquire the three-dimensional geometry information of objects through two or more two-dimensional images[2]. The key of the distance measurement are camera calibration and matching of right-and-left images. Using Zhang zhengyou calibration method, the right-and-left cameras are calibrated with calibration boxes in Matlab[3]. After acquiring the inner and external parameters of cameras, stereo rectification and stereo matching are completed with OpenCV. According to the position relations of scene points in right-and-left images, the three-dimensional coordinates are calculated, so as to realize the distance measurement.

2. Principle of Binocular Stereo Vision Distance Measurement

The parallax principle of binocular stereo vision is shown in Fig.1. Point P is a spatial point in the scene, whose image point is O. O_L stands for the optical center potion of the left camera and O_R stands for the optical center potion of the right camera. P_L and P_R stand for the horizontal position of the project points. Segment B is the connecting line of the optical center potion of the cameras, which stands for the distance of the baseline. Segment Z is the vertical segment from P to the baseline, which stands for the depth information of point P. The focal length of camera is *f*.

According to principle of similar triangle, the following equation can be deduced from Fig.1.

$$\frac{Z-f}{Z}=\frac{B-(X_L-X_R)}{B}\Rightarrow Z=\frac{B*f}{X_L-X_R}=\frac{B*f}{d} \tag{1}$$

Where d stands for the parallax, $d = X_L - X_R$.

Each parallax of the spatial points can be acquired, so that their depth information are obtained according to the parallax diagrams of the two-dimensional images.

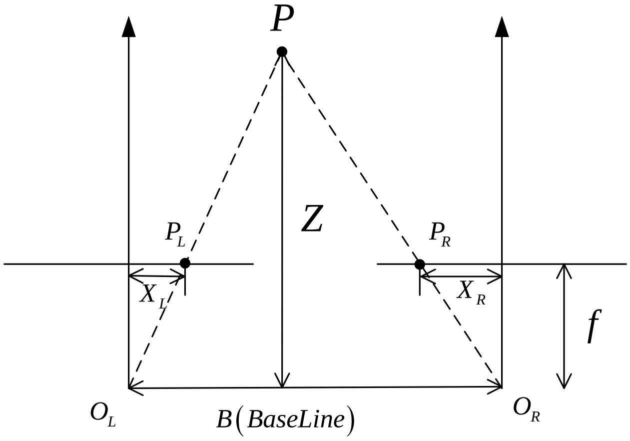

Fig.1 The parallax principle of binocular stereo vision

3. The Geometry Model and Calibration of Camera

The geometrical position relationship between each point in the image and the corresponding point in the surface of the object is determined by the camera geometry model. Their parameters, as called camera parameters, must be determined by experiment and calculation, which is called as camera calibration. Camera calibration plays important role in binocular stereo vision distance measuring system, and the calibration accuracy directly affects the precision of distance measurement.

3.1 The Geometry Model of Camera

The geometry relationship of camera imaging is shown in Fig.2. Point O is the optical center potion of the camera, which is named projection center. Axis X_c and Y_c are respectively parallel to the Axis X and Y in the coordinate system of imaging plane. Z_c is the optical axis of the camera, which is vertical to the image plane. Point O_1 is the intersections of the optical axis and the image plane, which is the main point of image. The rectangular coordinate system, which is consist of O, X_c, Y_c and Z_c, are called the camera coordinate system (CCS, for short). Segment OO_1 is the focal length of camera.

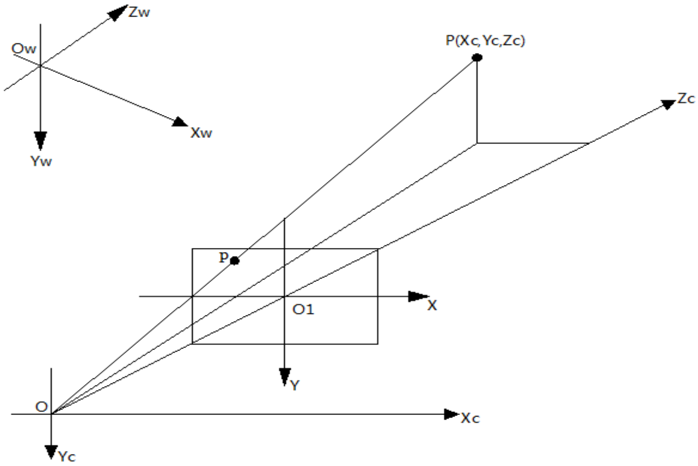

Fig.2 The geometry model of the camera

The world coordinate system (WCS, for short), which is consist of O_w, X_w, Y_w and Z_w, is introduced to describe the position of the camera. The translation vector T and rotation matrix R can be used to show the relationship between CCS and WCS. Assuming (X_c, Y_c, Z_c) is the coordinate of P in CCS and (X_w, Y_w, Z_w) in WCS, then the transformation process from WCS to object coordinate system is shown as Eq.2.

$$Z_c\begin{bmatrix}u\\v\\1\end{bmatrix}=\begin{bmatrix}\frac{1}{d_x} & 0 & u_0\\ 0 & \frac{1}{d_y} & v_0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}f & 0 & 0 & 0\\ 0 & f & 0 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}R & T\\ 0^T & 1\end{bmatrix}\begin{bmatrix}X_w\\Y_w\\Z_w\\1\end{bmatrix}=\begin{bmatrix}a_x & 0 & u_0 & 0\\ 0 & a_y & v_0 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}R & T\\ 0^T & 1\end{bmatrix}\begin{bmatrix}X_w\\Y_w\\Z_w\\1\end{bmatrix}=M_1M_2\mathbf{X}_w=M\mathbf{X}_w \quad (2)$$

Where (u_0,v_0) is the pixel coordinate of O_1, f_x and f_y are pixel focal lengths, M_1 and M_2 are the inner and external parameters of camera calibration.

3.2 The Camera Calibration

Camera calibration is to get the above parameters. Zhang zhengyou calibration method based on checkerboard is adopted to calibrate the camera with Matlab calibration box. Using binocular camera to take photos of 18 pairs of checkerboard image, the inner parameters of left-and-right cameras are obtained by monocular calibrating them. By stereo calibration, the translation vector T and rotation matrix R are acquired. The calibration results is shown as follows.

$$M_1=\begin{bmatrix}719.70 & 0 & 352.95\\ 0 & 718.42 & 231.90\\ 0 & 0 & 1\end{bmatrix}\quad M_2=\begin{bmatrix}727.50 & 0 & 319.20\\ 0 & 726.86 & 224.51\\ 0 & 0 & 1\end{bmatrix}$$

$$D_1=\begin{bmatrix}-0.0742 & -0.2201 & -0.0045 & -0.0037 & 0\end{bmatrix}$$

$$D_2=\begin{bmatrix}-0.056 & -1.0086 & -0.004 & -0.00348 & 0\end{bmatrix}$$

$$R=\begin{bmatrix}1 & -0.0055 & -0.0054\\ 0.0056 & 1 & 0.0062\\ 0.0054 & -0.0062 & 1\end{bmatrix}\quad T=\begin{bmatrix}-86.722\\ 1.4310\\ 0.6950\end{bmatrix}$$

4. Stereo Rectification

The stereo parallax calculation is simple when two image planes are coplanar and row-aligned. But it doesn't happen in practical binocular stereo matching system, which means that stereo rectification is necessary. Rectification functions, such as cvStereoRectify and cvRemap, are available in OpenCV, which can be applied to left-and-right images rectification. When we input the inner parameters acquired by camera calibration, distortion parameters, translation vector T and rotation matrix R, we can make sure the least re-project times and the maximum distortion of the left-and-right images. It brings about more accurate and fast stereo matching and maximum observing area.

The original left-and-right image pair are shown in Fig.3(a), from which we can see they are not row-aligned completely and the same points are not in a row. The image pair after stereo rectification and distortion eliminating are shown in Fig.3(b), from which we can see that the search space of parallax is reduced from two-dimension to one-dimension, and it creates advantage for subsequent stereo matching.

5. Stereo Matching and distance measuring

Stereo matching algorithm searches for the best matching point in the target image based on its projection point in the reference image, and calculate the position relationship between corresponding pixels, thus obtaining parallax figure. Block matching algorithm is a kind of excellent real-time matching algorithm[4-5], which adopts a small window of "*Sum of Absolute Difference*"(SAD, in short) to match the same points of the distortionless image pair. The steps are as follows.

Pre-filtration: image brightness normalization and image texture strengthen.

Sliding SAD window along the horizontal scan lines to match the search.

Filtration and eliminating the wrong matching points.

By calling *cv FindStereo CorrespondenceBM()* function in OpenCV, the stereo matching of the image pair after rectification is achieved, and the parallax figure is obtained. Taking more photos respectively and repeating the above steps, the distance measuring results are shown in Tab.1.

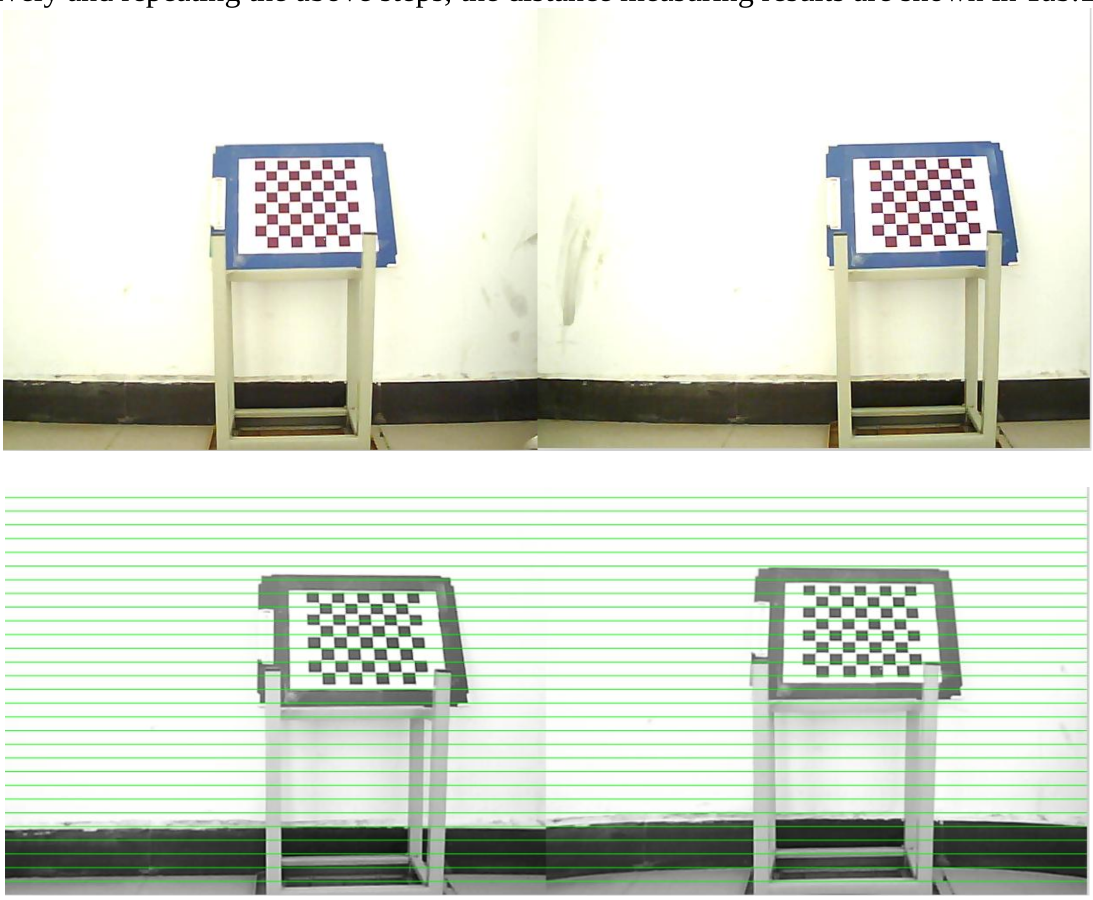

Fig.3 rectification comparison chart

Tab.1 The Distance Measuring Results

No.	Measuring Value (mm)	Actual Value (mm)	Error (%)
1	695.145	700	0.693
2	694.785	700	0.745
3	1287.58	1300	0.955
4	1285.97	1300	1.792
5	2486.78	2500	0.53
6	2483.42	2500	0.663

6. Conclusion

The paper studies the process of acquiring object depth information by using binocular stereo vision and presents the theoretical research and experimental analysis. In order to achieve distance measurement, the key technology such as camera calibration, stereo rectification and stereo matching are also studied. After that the distance measuring system with Matlab and OpenCV based on binocular stereo vision is proposed. The stereo calibration of left-and-right cameras is completed with Matlab, and the stereo rectification and matching are achieved with OpenCV. The experimental verification shows the binocular vision distance measuring system achieves the accuracy requirement within a certain close distance, and it has a certain application prospect in practical application.

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