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Distance Measurement System Based on Binocular Stereo Vision

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Abstract. Binocular stereo vision uses two cameras of the same specification instead of human eyes for measurement and judgment. The basic principle of binocular vision ranging is to simultaneously capture the image of the measured object by using two left and right cameras. The objectmeasuredisdifferent, andthe positions under the different camera screensaredifferent, this difference in position is called disparity. The three-dimensional information of the object is obtained according to the principle of disparity. The binocular stereo vision ranging system, which combines the advantages of high efficiency and high precision, is ideal for non-contact detection and quality control. This paper proposes a method combining MATLAB calibration and OpenCV matching to achieve binocular stereo vision. Using the MATLAB calibration tool to perform stereo calibration of the camera, combined with OpenCV for stereo rectification and stereo matching, the disparity value is obtained, and the distance from the target to the camera is calculated by disparity. Simulations show that this method can satisfy the distance measurement.

1. Introduction

With the continuous improvement of computer image processing capability, computer vision has been widely used in navigation, transportation, military, and logistics, medical and industrial fields [1]. Being one of the important branches, visual ranging has developed into an important research direction, and has played a significant role on UAV vision positioning, robot automatical navigation, non-contact measurement and other fields, it also has great development potential. Different from active ranging such as ultrasonic and laser, binocular stereo vision ranging receives the optical signal reflected by the measured object itself through the cameras for distance measurement, which is passive measurement.

The binocular cameras replace the human eyes to measure and judge the sensing distance information. The method of measuring distance is simple and reliable, and the cost is low. However, the difficulties in obtaining accurate distance information are that the target needs to have strong feature texture and selecting the appropriate criteria for stereo matching.

The completion of binocular stereo ranging can be decomposed into the following five key parts: image acquisition, stereo calibration, stereorectification, stereo matching and ranging [2]. The methodof calibration is carried out by MrZhang, and the MATLAB toolbox is used to complete the stereo calibration of the left and right cameras. Then the internal and external parameters of the camera are imported into OpenCV.The block matching algorithm is used to complete the stereo matching, and finally the three-dimensional information is calculated by the similar triangle theory [3].

2. Stereo vision system model

The binocular stereo vision system usually consists of two cameras of the same specification, the same focal length, the same aperture and the same sensor area of the camera. Ideally, the left and right cameras remain in the same plane, thus ensuring that the horizontal axes of the left and right camera systems are on the same line and parallel to the imaging plane [4], the imaging model is shown as Figure1.

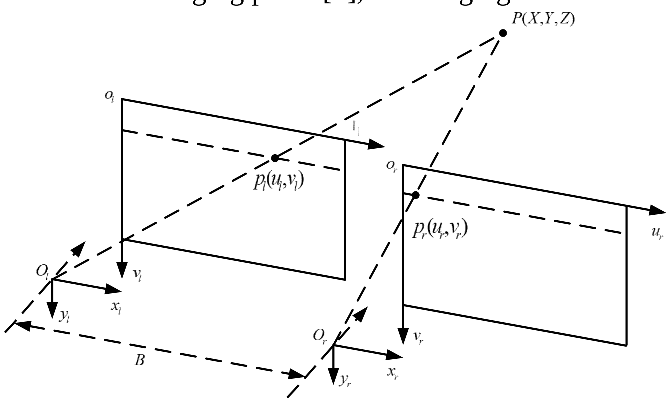

Figure 1. Binocular stereo vision system model

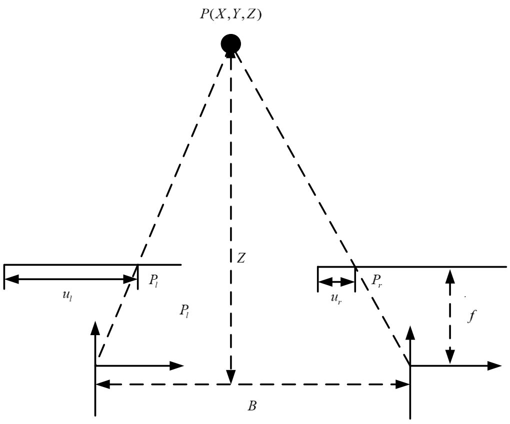

Figure 2. Two-dimensional plane of the ideal model

In the above figure, the distance between the two cameras is B. The $P(X,Y,Z)$ in the imaging images of the left and right cameras are $p_l(u_l,v_l)$ and $p_r(u_r,v_r)$, the left and right camera coordinate systems are respectively displayed as $O_l x_l y_l$ and $O_r x_r y_r$, the image coordinates of the left and right cameras are respectivelydisplayed as $o_l u_l v_l$ and $o_r u_r v_r$. Converting the three-dimensional map into a two-dimensional map is shown in Figure 2.

Figure 2 shows that B is the optical distance of the two cameras. The v coordinates in the left and right image coordinate systems are the same, $v_l = v_r = v$. Triangle $Pp_l p_r$ and triangle $PO_l O_r$ are similar triangles. According to the nature of similar triangles, the ratio of the corresponding edges is equal to the ratio of the corresponding heights. The following relationship can be obtained:

$$\frac{B-(u_l-u_r)}{B}=\frac{Z-f}{Z} \tag{1}$$

In the formula, B is the distance between the optical centers of the two cameras, and v_l and v_r represent the abscissa value of the two camera image coordinate system. Z represents the distance from point P to the camera. f is the focal lengthofthecamera. $u_l - u_r$ iscalleddisparity, let $d = u_l - u_r$, then formula (1) can be written as:

$$\frac{B-d}{B}=\frac{Z-f}{Z} \tag{2}$$

Formula can be turned into

$$Z = f * \frac{B}{d} \tag{3}$$

In formula (3), the distance between the cameras can be measured and found, and we only need to find thedisparityto calculate the distance from the object to the camera.

3. Camera calibration

Since the two camera lenses of the actual camera system are distorted, the imaging planes of the left and right cameras cannot be exactly on the same plane as the ideal model, so the camera needs to be calibrated. The internal and external parameters of a camera are determined by the relationship between the three-dimensional coordinates of a space object point and its corresponding points in the image. [5], through the stereo rectification, the actual binocular stereo vision system is transformed into an ideal binocular stereo vision system, and the depth value can be obtained.

The point $P=[X_W, Y_W, Z_W]^T$ in the three-dimensional space are rotated and translated and the points projected onto the pixel coordinate system is $p=[u,v]^T$, the augmented matrix of P is $\tilde{P}=[X_W, Y_W, Z_W, 1]^T$, the augmented matrix of p is $\tilde{p}=[u,v,1]^T$, and the mapping relationship from the point P in three-dimensional space to the point p intwo-dimensional space is expressed as:

$$\tilde{p} = sAW\tilde{P} \tag{4}$$

s is the scale factor, A is the internal reference matrix of the camera, W is the external parameter matrix of the camera, $W=[R,T]$, and R represents the rotation matrix, T represents the translation matrix. $Z_W = 0$, the mapping relationship from the point P in three-dimensional space to the point p intwo-dimensional space is expressed as:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = sA\begin{bmatrix} r_1 & r_2 & r_3 & T \end{bmatrix}\begin{bmatrix} X \\ Y \\ 0 \\ 1 \end{bmatrix} = sA\begin{bmatrix} r_1 & r_2 & T \end{bmatrix}\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \tag{5}$$

Let $H = A[r_1 \quad r_2 \quad T] = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}$, Repres--enting the Matrix of Point Perspective Mapping on the Calibration Board to Its Image Points

There are three camera methods about calibration currently: manual calibration, MATLAB calibration toolbox, and self-calibration by OpenCV [6]. The method ofcalibration based on MATLAB calibration toolbox is simple and practical, faster than the method of manual calibration and more accurate thanthe method of self-calibration by OpenCV [7], so this paper chooses to use MATLAB calibration toolbox for calibration. Then, importing theresults of calibration into OpenCV for the next imagerectification and matching.

The calibration plate used for calibration is a 12x9 checkerboard, each of which has a size of 20mm x 20mm and is attached to a hard plate. In the image acquisition, it is necessary to constantly change the angle of the chessboard. In order to obtain accurate calibration data, a total of 20 sets of image pairs are collected here, and are imported into the MATLAB calibration toolbox to calibrate the left and right cameras respectively, and then perform stereo calibration. The calibration results are as follows:

$$M_l = \begin{bmatrix} 604.11592 & 0 & 307.87539 \\ 0 & 812.59350 & 253.64088 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$M_r = \begin{bmatrix} 595.45774 & 0 & 317.55949 \\ 0 & 800.63563 & 257.36690 \\ 0 & 0 & 1 \end{bmatrix} \tag{7}$$

M_l is the internal parameter matrix of the left camera, and M_r is the internal parameter matrix of the right camera. The distortion parameter matrices D_l and D_r of the left and right cameras are shown below:

$$D_l = [\text{-}0.46225 \quad 0.36615 \quad \text{-}0.00169 \quad 0.00311 \quad 0.00000] \tag{8}$$

$$D_r = [\text{-}0.42684 \quad 0.20666 \quad \text{-}0.00105 \quad \text{-}0.00049 \quad 0.00000] \tag{9}$$

R is the rotation matrix of the left and right cameras, and T is the translation matrix of the left and right cameras, expressed as follows:

$$R = \begin{bmatrix} 0.99998 & 0.00032 & -0.00351 \\ \text{-}0.00517 & 0.99999 & -0.00019 \\ \text{-}0.00424 & -0.00011 & 0.99998 \end{bmatrix} \tag{10}$$

$$T = [148.25890 \quad \text{-}0.50587 \quad \text{-}1.01811] \tag{11}$$

4. Stereo rectification

The internal and external parameters collected by MATLAB calibration toolbox are imported into OpenCV, using the cvStereoRectify function for stereo rectification. Figure 3 shows the left and right image pairs before stereo rectification. The image distortion is very serious, and the same points are not on the same line. Figure 4 shows the image pair after distortion rectification by stereo rectification. The image distortion is rectificated and the same points are basically on the same line.

Figure 3. Unrectificated left and right images

Figure 4. Rectificated left and right images

5. Stereo matching and ranging

Stereo matching is the process of finding the corresponding points on the target image and obtaining the disparity information of the corresponding points between the reference image and the target image [8].The disparity map can be obtained by stereo matching.

Stereo matching uses a block matching algorithm of "absolute error accumulation" in OpenCV. The basic idea of the algorithm is to sum the absolute values of the differences between the corresponding values of each pixel, and evaluate the similarity of the two image blocks accordingly. Find the matching point between the left and right images. The basic process is as follows:

(1) Pre-filtering, normalizingthe brightness and enhancing the texture;

(2) Create a window and cover the image on the left and right

(3)Subtractthepixel value of the corresponding point of the right image from the pixel value of the left image, take the absolute value and sum it;

(4) Find the window with the smallest SAD value along the polar line.

(5) Filter out the wrong matching points

After the stereorectification, the same point of the measured object is basically on the same line in the left and right images, so the position of the matching point corresponding to the feature point on the left image must be at the same line [9]. Slide the SAD window and search for the right line to complete the matching process. The accuracy of stereo matching depends on whether the feature points of the captured image are obvious. For images with strong texture of feature points, the block matching algorithm can achieve a good matching effect [10].

The disparity map is obtained by matching the left and right images. In OpenCV, the rectificated left and right images are stereo-matched to obtain a disparity map. The picture taken by the right camera is shown in Fig. 5. The disparity map obtained after stereo matching is shown in Fig. 6.

Figure 5. Original image of right camera

Figure 6. Disparity map

If you know the disparity at a certain point, you can use formula (3) to calculate the depth of the object. The experimental results are shown in Table 1.

Table 1. Experimental results of binocular stereo ranging system

number	measured value/mm	actual value/mm	error/%
1	302.32	300	0.77
2	302.23	300	0.74
3	506.74	500	1.33
4	506.89	500	1.36
5	815.41	800	1.89
6	815.99	800	1.96
7	1026.27	1000	2.56
8	1555.05	1500	3.54
9	2099.32	2000	4.73
10	2665.53	2500	6.21

The experimental results show that when the distance of the measured object is closer, the accuracy of the depth information measured by the binocular stereo vision system is higher. As the distance increases, the measurement error also increases, and the measuring accuracy decreases. Comparing the measurement distance and measurement error, within 2 meters, the error does not exceed 5%, meeting the experimental requirements.

6. Conclusion

Computer vision has become a hot topic in current research. Visual measurement will be widely used in the fields of unmanned obstacle avoidance, automobile unmanned driving, automatic logistics sorting, port cargo automatic handling, etc. More and more researchers are engaged in it. The huge development potential is waiting for further digging.

This paper mainly studies the principle of binocular stereo vision ranging and analyzes the key process of achieving ranging. It builds a binocular stereo vision system and performs ranging experiments in VS2013 environment. The results show that within 2 meters, the error is less than 5%, which meets the accuracy requirements of application development. The error mainly comes from the influence of calibration error, human error and illumination texture. When the texture of the measured object is low, stereo matching will have certain difficulties, and the measurement accuracy will be greatly reduced.

References

[1] Chen Lijuan. Research on navigation technology of unmanned helicopter landing based on vision [D]. Nanjing University of Aeronautics and Astronautics, 2013
[2] Huang Songmei, Bi Yuanwei, Liu Diantong, et al. Non-contact measurement of binocular stereo vision[J]. Journal of Yantai University(Natural Science and Engineering), 2017, 30 (4): 323-327.
[3] Li Zhanhai. Research on 3D reconstruction technology based on binocular vision system [D]. Guangxi University, 2014.
[4] Wang Wei. Research on mobile robot positioning technology based on multi-information fusion [D]. 2015.
[5] JinHongyan, Yan Xiaojun. Calibration Implementation of CCD Camera Based on Radial Size Constraint [J]. Automation Technology and Application, 2017, 36 (4): 99-102.
[6] Zhang Bin. Research on key techniques of femur individualized attitude estimation based on DR image [D]. Harbin Institute of Technology, 2013.
[7] Zhang Yingguo. Research and application of contour measurement based on structured light [D]. 2013.
[8] Wang Zhenzhen, Zhao Lianyu, LiuZhenzhong. Binocular stereo vision ranging system based on MATLAB and OpenCV [J]. Journal of Tianjin University of Technology, 2013, 29(1): 45-48.

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[9] Wang Yi. Three-dimensional target reconstruction technology based on aerial photographs of unmanned helicopters [D]. Shanghai Jiaotong University, 2010.
[10] Quiet static. Research on stereo matching algorithm based on binocular stereo vision [D]. North University of China, 2012.