ISSN: 2414-1895 DOI: 10.6919/ICJE.201911_5(12).0004

Research and Design of 3D Reconstruction System Based on Binocular Vision

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Abstract

Binocular vision is one of the most popular and important technologies in computer vision. It is a stereoscopic reproduction of the external environment in the natural light state in the human visual system. Due to the equipment requirements simple, easy to operate, strong adaptability and other advantages,this technology has broad application prospects in the fields of navigation, mapping, medical imaging, military and industrial testing. In this paper, a three-dimensional reconstruction system based on binocular vision is designed. The experimental results show that the three-dimensional reconstruction has better effect and higher precision.

Keywords

Binocular vision, camera calibration, stereo matching, 3D reconstruction.

1. Introduction

Binocular stereo vision uses a computer to process a floor plan based on the principle of parallax to get three-dimensional information about the scene， and the most important process is stereo matching. At present, the stereo matching algorithm is mainly divided into two categories: local algorithm and global algorithm. And the local algorithm is adopted in this paper, because its algorithm structure is clearer and easier to improve. And we improved the algorithm. The binocular camera was used to take pictures of the scene, and the obtained image was restored by using the stereo matching algorithm. The obtained three-dimensional information is basically in line with reality.

2. Binocular Vision

Binocular Stereo Vision is an important form of machine vision. It is based on the parallax principle and uses the imaging device to acquire two images of the measured object from different positions by calculating the positional deviation between the corresponding points of the image to obtain the three-dimensional geometric information of the object and to restore the image in three dimensions. It mainly includes camera calibration, image correction, stereo matching and 3D reconstruction.

The standard binocular camera model is shown in Figure 1:

In the standard binocular camera model, the two camera coordinate systems differ by only one translation in the x-axis direction, and the two optical core connections O_lO_r are called the baseline B [1]. The image coordinate system of the two cameras coincides with the u-axis, the v-axis is parallel to each other, and the two image planes are aligned. The pixel coordinate of the intersection of the camera’s optical axis and the image plane are (u_0, v_0), Superimpose the left camera coordinate system with the world coordinate system (original coincidence), the coordinates of the spatial point are (X,Y,Z), The pixel coordinates of the projection point p_l are (u_l, v_l), The physical coordinates are

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(x_l, y_l), the pixel coordinates of the projection point are (u_r, v_r), and the physical coordinates are (x_r, y_r).Where $y_l = y_r$.

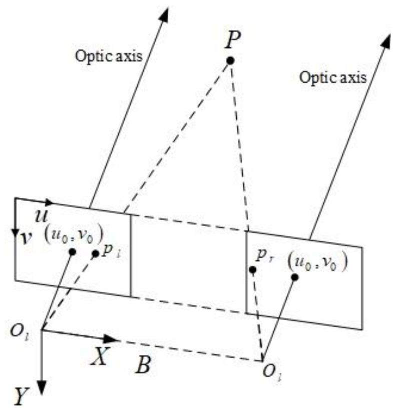

Figure 1 The binocular camera vision model

2.1 Camera calibration

In the image measurement process, in order to determine the relationship between the three-dimensional geometric position of a point on the surface of the space object and its corresponding point in the image, a geometric model of the camera imaging must be established. These geometric model parameters are camera parameters. In most cases， these parameters must be obtained through experiments and calculations. This process of solving parameters is called camera calibration[2].

Purpose: To obtain the camera's internal parameters and external parameter matrix (also get the rotation matrix and translation matrix), the internal parameters and external parameters can be corrected for the images taken by the camera, and the images with relatively small distortion are obtained.

Input: calibrate the image coordinates of all inner corner points on the image, and coordinate the spatial three-dimensional coordinates of all inner corner points on the image of the plate (assuming the image is on the Z=0 plane)[3].

Output: camera internal parameters, external parameter matrix (rotation matrix and translation matrix).

Using Matlab software for camera calibration, Matlab2017a comes with the Camera Calibrator toolbox, which is used to calibrate the prepared chessboard[4]. Export the obtained camera parameter data to a .mat file.

Use the checkerboard calibration board as shown in Figure 2.

Figure 2 Checkerboard calibration board

The final calibration results are shown in Figure 3 below.

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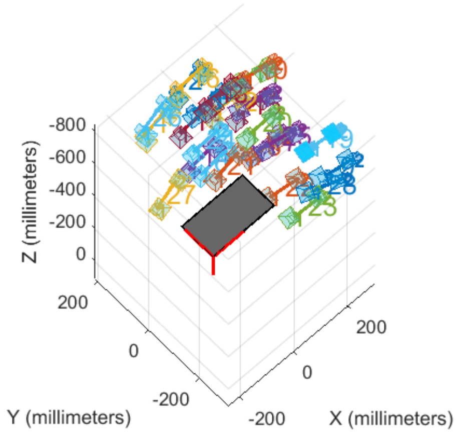

Figure 3 Final calibration results

2.2 Stereo correction

Image correction is an important step before stereo matching. After obtaining the polar line relationships of the two cameras, the polar line constraints can be used to find matching points, thereby speeding up the matching and improving stability. However, in the real world, due to many reasons such as assembly, imaging, etc., the camera can't achieve parallel alignment strictly, which makes the matching search still take a considerable part of the time [1]. The image correction can correct the polar line pairs into parallel directions. The two images only have horizontal parallax, and the search of the corresponding points only needs to be translated on the same scan line, which greatly reduces the search time. Figure 4 is a description of the position of two cameras in reality, and the parallel alignment state after correction.

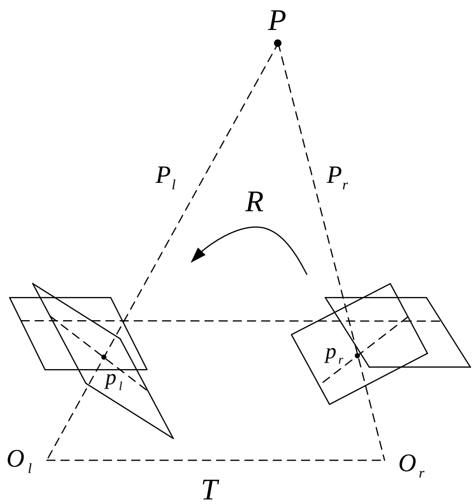

Figure 4 Stereo correction

Moreover, due to the shape of the camera lens, significant radial distortion is always produced at the edge of the imaging plane. Due to the assembly accuracy of the camera, the lens cannot be parallel to the imaging plane, resulting in tangential distortion. The mathematical model of the physical coordinates (x,y) of the projection point on the imaging plane affected by radial distortion is as follows.

$$\begin{cases} \bar{x} = x\left(1+k_1r^2+k_2r^4+k_3r^6\right) \\ \bar{y} = y\left(1+k_1r^2+k_2r^4+k_3r^6\right) \end{cases} \tag{1}$$

affected by tangential distortion is as follows.

$$\begin{cases} \bar{x} = x + \left[2p_1 y + p_2 \left(r^2 + 2x^2 \right) \right] \\ \bar{y} = y + \left[p_1 \left(r^2 + 2y^2 \right) + 2p_2 x \right] \end{cases} \tag{2}$$

k_1, k_2, k_3, p_1, p_2 are distortion parameters, $r^2 = x^2 + y^2$, $(\bar{x}, \bar{y})$ are the corrected ideal coordinate value.

2.3 Stereo matching

Stereo matching is a key part of stereo vision research, and its goal is to match corresponding pixel points and calculate disparity in two or more viewpoints. According to Schrstein's and Szeliski's summary, binocular stereo matching can be divided into four steps: matching cost calculation, cost aggregation, disparity calculation, and disparity optimization.

The purpose of the matching cost calculation is to measure the correlation between the pixel to be matched and the candidate pixel. Each pixel will often specify a parallax search range D($D_{\min} \sim D_{\max}$) before searching for the same name point. In the parallax search, the range is limited to D, and a three-dimensional matrix of size W×H×D (W is the image width and H is the image height) is used to store the matching value of each pixel in each parallax in the parallax range. There are many ways to calculate the cost of matching， we use the method of Sum of Absolute Differences (SAD) to calculate the matching cost of two pixels[5].

The fundamental purpose of cost aggregation is to enable generational values to accurately reflect correlations between pixels. Matching cost calculations tend to only consider local information, so this generation value may not accurately reflect the correlation between pixels. Cost aggregation is to establish the connection between adjacent pixels, and to optimize the cost matrix globally with certain criteria. The new generation value of each pixel under a certain parallax will be in the same disparity value or near its neighboring pixels. The generation value under the disparity value is recalculated to obtain a new parallax matrix.

The parallax calculation determines the optimal disparity value of each pixel by the disparity matrix after the cost aggregation, and is usually calculated using the Winner-Takes-All algorithm (WTA, Winner-Takes-All)[6].

The purpose of parallax optimization is to further optimize the disparity map obtained in the previous step to improve the quality of the disparity map.

2.4 3 D reconstruction

According to the binocular vision model of Figure 1 and the triangulation principle of Figure 5, the depth Z of the spatial point P can be easily obtained[7]:

$$\frac{Z-f}{Z} = \frac{B-(x_l - x_r)}{B} \Rightarrow Z = \frac{B \cdot f}{x_l - x_r} \tag{3}$$

The conversion relationship between the pixel coordinate system and the physical coordinate system:

$$x_l = \left(u_l - u_0 \right) d_x \tag{4}$$

$$x_r = \left(u_r - u_0 \right) d_x \tag{5}$$

Generation (3):

$$Z = \frac{B \cdot f}{\left(u_l - u_r \right) d_x} \Rightarrow Z = \frac{B \cdot a_x}{d} \tag{6}$$

$u_l - u_r = d$ is called parallax, The correspondence between the projection points of the representative points on the two image planes. P is the value of the focal length in pixels, and a_x is the internal parameter[8] of the camera.

ISSN: 2414-1895 DOI: 10.6919/ICJE.201911_5(12).0004

After obtaining Z, the X and Y coordinate values of point P can also be determined accordingly.

$$\frac{X}{x_l} = \frac{Z}{f} \Rightarrow X = \frac{B(u_l - u_0)}{d} \tag{7}$$

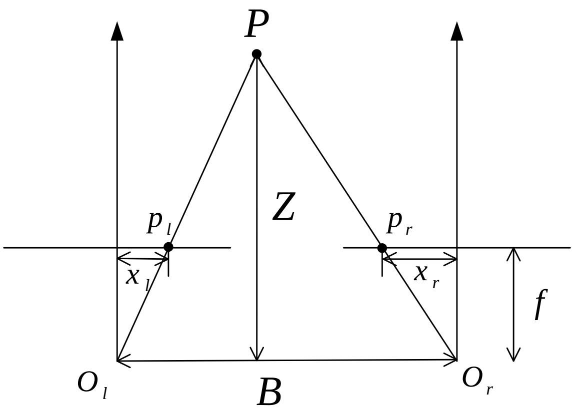

Figure 5 Triangulation

3. Experimental results and analysis

The binocular camera captures an original picture as shown in Figure 6.

Figure 6 Original image captured by a binocular camera

The corrected image is obtained using the rectifyStereoImages calibration function as shown in Figure 7.

Figure 7 Parallax map

The corrected picture is processed by the disparity function to obtain a parallax map, and then the parallax map is simplified and post-processed to obtain a parallax depth map, as shown in Figure 8.

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Figure 8 Disparity diagram

The parallax map is converted into a depth map by a parallax-depth conversion relationship program to obtain three-dimensional information of the original image.

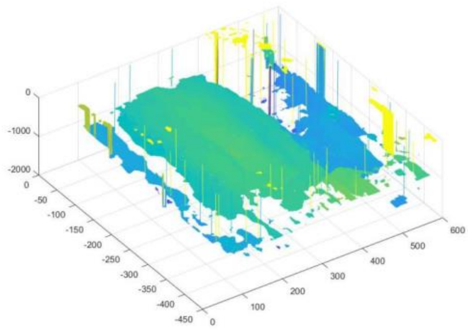

Figure 9 3D information of 3D reconstruction recovery

4. Conclusion

Based on the analysis of the popular problems in binocular vision, based on the analysis, this article designs a simple and reliable 3D reconstruction system, which lays a foundation for the establishment of a more complete 3D reconstruction system. The system has low requirements on camera hardware and low cost, and does not require special transmitters and receivers. The ordinary RGB camera can be satisfied; the adaptability is strong, and the image can be directly collected according to natural light, and can be applied indoors and outdoors; 3D reconstruction The three-dimensional coordinates can be obtained for positioning, and the SAD algorithm is faster in operation, and can feed back three-dimensional scene information in real time; based on these advantages, the system is widely used in robot navigation, unmanned driving systems, agricultural picking and so on.

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ISSN: 2414-1895 DOI: 10.6919/ICJE.201911_5(12).0004

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