Using Binocular Stereo Cameras for Object Positioning

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1 Introduction

With binocular stereo cameras, we can take stereoscopic pictures, which allow us to calculate the position of the target object. In recent years, this technology has been widely applied to autonomous navigation, engineering surveying and other areas [1]. Actually, the position is obtained by **calculating the distance** from the camera(s) to the chosen object within the picture [2] [3]. Therefore, we will focus on how to measure distance in the rest of this report.

2 Distance Measurement Based on Binocular Stereo Vision

Generally, distance measurement is performed according to the steps of **Camera Calibration→Image Matching→ Geometric Calculation**. That is, use two cameras on the same scene from different locations to obtain stereo images, through a variety of matching algorithms to find out the corresponding point in order to calculate the parallax, and then the distance from the scene can be calculated by triangulation methods and parallax theory.

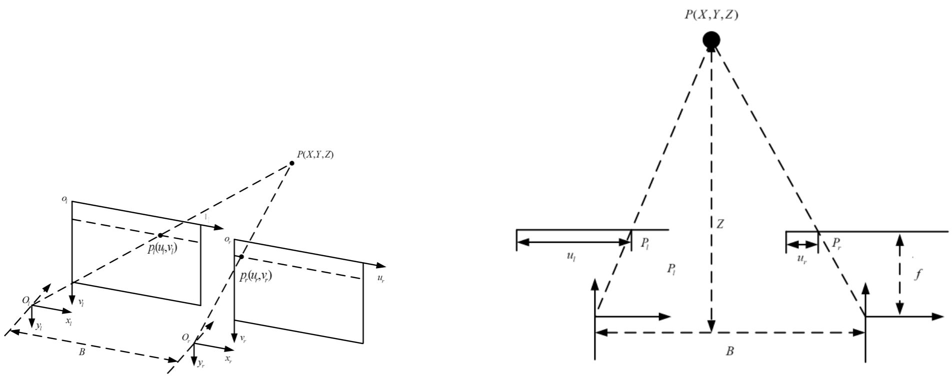
The process of geometric calculation is as follows [4]: in the ideal model, two cameras have the same specification, the same focal length, the same aperture and the same sensor area. In addition, the two cameras remain in the same plane, as shown in Fig. 1a. Then, we **convert 3D model to 2D picture** for better illustration, as shown in Fig. 1b, where z stands for the distance we want to know, f is the focal length and B is the baseline. $P(X, Y, Z)$ stands for the target point and it's coordinates in the picture of the left and right camera are $p_l(u_l, v_l)$ and $p_r(u_r, v_r)$ respectively. We write the parallax of point P as $d = u_l - u_r$. According to **the parallax theory and triangulation methods**, we can easily get that:

$$Z = z = \frac{B \times f}{d}$$

$$X = Z \times \frac{u_l}{f}$$

$$Y = Z \times \frac{v_l}{f}$$

Therefore, the remaining questions are how to ensure that the two cameras



(a) 3D (b) 2D

Figure 1: Ideal model

meet the requirements of ideal model and how to match the imaging p_l and p_r of P on the left and right cameras.

2.1 Camera Calibration

Camera calibration are critical for non-ideal model, in which two camera lenses are distorted, and the imaging planes of the left and right cameras cannot be exactly on the same plane, as shown in Fig. 2. To guarantee the accuracy of matching algorithm, we must do calibration to correct this case to ideal model as much as possible. We can use tools in OpenCV[1] to calibrate directly or manually calibrate.

In the case of using binocular stereo camera, this step can be **skipped** unless the experimental results are terrible, which means the device is too rough.

[1] `https://docs.opencv.org/3.1.0/dc/dbb/tutorial_py_calibration.html`

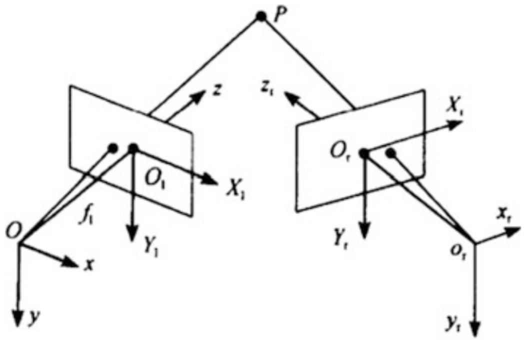
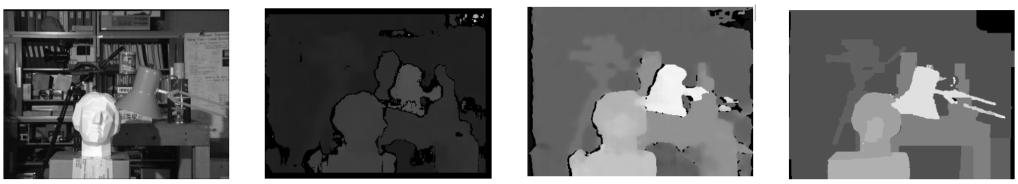


Figure 2: Non-ideal model

2.2 Image Matching Problem

Image matching is the most important step in distance measurement and we take **stereo vision algorithms** to solve this problem. These stereo vision algorithm can be divided into two categories [5]: local methods (area-based, such as BM, SAD and so on) and global methods (energy-based, such as SGBM[2], GC and so on). The former is faster, while the latter is more accurate.

In [6], the performances of BM, GC and SGBM have been evaluated in terms of speed and quality of disparity map, the results are shown in Fig. 3 and Fig. 4. We can easily say that in terms of accuracy, GC is the best and BM is the worst, while in terms of efficiency, the opposite is true.



(a) Original (b) BM (c) SGBM (d) GC

Figure 3: Disparity map

After obtaining the correspondence between points p_l and p_r, calculate the coordinates of $p_l(x_l, y_l)$ in the left camera's coordinate system x_lOy_l and $p_r(x_r, y_r)$ in the right camera's coordinate system x_rOy_r. Then the parallax[3] d **equals to** $x_l - x_r$.

[2]strictly speaking, SGBM is semi-global method that uses both local and global approach

[3]always use **disparity** stands for the estimated parallax

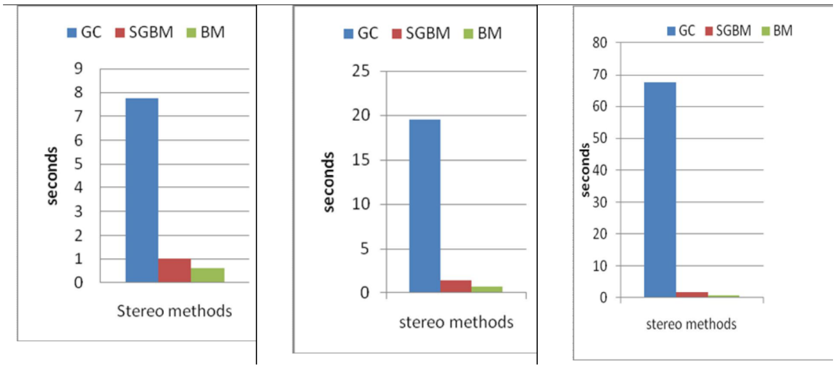


Figure 4: Efficiency

3 Results

In this section, we list the methods used in [1,3,7,8] and their experimental results.

In [1], Zhengzhen Liu et al. first use smooth filter to the images in order to reduce the noise influence. Then take Canny edge detection and Harris corner detection to find the initial candidate match relations. Then delete impossible match relations according to polar line restraint and gray values' similarities. The result is shown in Table. 1.

In [7], Dhaval K. Patel et al. use traditional method to solve the matching problem. They identified the object in two pictures according to its color, and obtained its centroid through geometric calculations. Then directly match the centroids. The disadvantage of this method is apparent: we can only get one pair of matchings and cannot get whole depth information. The result is shown in Table 2.

Table 1: *Results of [1]*

The actual distance(m)	The measured distance(m)	Error
0.7	0.661	5.57
1.0	0.998	1.2
1.5	1.513	0.87
3.0	2.996	1.13
5.0	5.062	1.24
6.0	6.078	1.30
7.5	7.784	3.79

In [3], Yongjie Li et al. use binocular camera to take pictures of a tested vehicle and calculate the vehicle distance. Specifically, they first do camera

Table 2: *Results of [7]*

The actual distance(cm)	The measured distance(cm)	Error
12	12.34	2.83
18	18.28	1.56
24	24.35	1.46
30	30.63	2.10
36	36.75	2.08
40	41.30	3.24
50	51.95	3.90
100	104.91	4.91
130	134.20	3.23
150	147.62	1.59

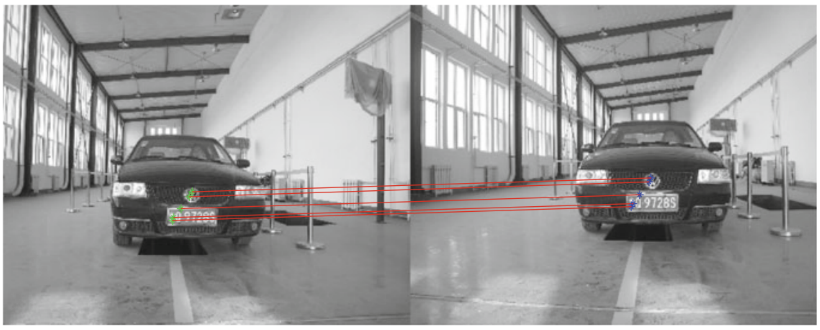


Figure 5: The matched corners

calibration and then, they take Harris algorithm to extract image corners of the tested vehicle based on gray scale information and then use gray scale distribution to evaluate the similarity of the two images. The matching result is shown as Fig. 5. And Table. 3 shows the experimental results.

Table 3: *Results of [3]*

The actual distance(m)	The measured distance(m)	Error
2.4549	2.4498	0.21
2.4549	2.4562	0.05
2.4549	2.4675	0.51
2.4549	2.4391	0.64
2.4549	2.4621	0.29

As for [8], an area-based matching algorithm of "absolute error accumulation" has been used. The basic idea of this 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. This method is called **SAD**. Table. 4 shows the experimental results.

Table 4: *Results of [8]*

The actual distance(mm)	The measured distance(mm)	Error
300	302.32	0.77
300	302.23	0.74
500	506.74	1.33
500	506.89	1.36
800	815.41	1.89
800	815.99	1.96
1000	1026.27	2.56
1500	1555.05	3.54
2000	2099.32	4.73
2500	2665.53	6.21

3.1 Error Analysis

Measurement error is mainly from the following two reasons:

- fabrication error: it is difficult to strictly ensure that the optical axes of two cameras are parallel, the focal length are the same and so on [10].
- image match error: we still need to improve the accuracy and robustness of existing matching algorithm.

References

[1] Zhengzhen Liu and Tianding Chen. Distance measurement system based on binocular stereo vision. In *2009 International Joint Conference on Artificial Intelligence*, pages 456–459. IEEE, 2009.

[2] CVlife. How to use binocular stereo camera to measute distance. `https://zhuanlan.zhihu.com/p/32199990`. Accessed Feb 7, 2020.

[3] Yongjie Li, Peijiang Chen, and Mei Zhang. The vehicle distance measurement system based on binocular stereo vision. In *Proceedings of the 2015 International Conference on Electrical and Information Technologies for Rail Transportation*, pages 437–444. Springer, 2016.

[4] Stefano Mattoccia. Stereo vision: Algorithms and applications. *University of Bologna*, 22, 2011.

[5] Nalpantidis Lazaros, Georgios Christou Sirakoulis, and Antonios Gasteratos. Review of stereo vision algorithms: from software to hardware. *International Journal of Optomechatronics*, 2(4):435–462, 2008.

[6] Rachna Verma and AK Verma. A comparative evaluation of leading dense stereo vision algorithms using opencv. *International Journal of Engineering Research and Technology (). issn*, pages 2278–0181.

[7] Dhaval K Patel, Pankaj A Bachani, and Nirav R Shah. Distance measurement system using binocular stereo vision approach. *Int J Eng Res Technol*, 2(12):2461–2464, 2013.

[8] Xiyan Sun, Yingzhou Jiang, Yuanfa Ji, Wentao Fu, Suqing Yan, Qidong Chen, Baoguo Yu, and Xingli Gan. Distance measurement system based on binocular stereo vision. In *IOP Conference Series: Earth and Environmental Science*, volume 252, page 052051. IOP Publishing, 2019.

[9] Lu Yang, Baoqing Wang, Ronghui Zhang, Haibo Zhou, and Rongben Wang. Analysis on location accuracy for the binocular stereo vision system. *IEEE Photonics Journal*, 10(1):1–16, 2017.

[10] Liu Wenyao. Photoelectric image processing. *Publishing House of Electronics Industry, Beijing*, 2002.