Review of Common Problems and Solutions of Camera Calibration

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Abstract: In recent years, computer vision has been widely studied and applied. Camera calibration is the first step in image processing and an indispensable step to obtain three-dimensional information from two-dimensional images. The quality of the calibration results directly determines the quality of the image and the system accuracy of computer vision. Therefore, the study of camera calibration methods has important theoretical significance and practical application value. Aiming at the problems of camera calibration, and combined with the research results in recent years, several common problems and improvements of camera calibration are summarized and compared, and their advantages and disadvantages are briefly analyzed here in this paper.

1. Introduction

The computer vision technology obtains the two-dimensional information of the object in the space through the camera. It combines the internal and external parameters of the camera to restore the three-dimensional information of the space object, including the size, position and motion state of the object. The geometric model of the camera determines the relationship between the world coordinates and the image coordinates of the object point, which is of great significance in the research of three-dimensional reconstruction and computer vision. In this process, camera calibration must be carried out first. Camera calibration is the basis for three-dimensional reconstruction. Camera calibration is to calculate the parameters of the camera, including internal parameters (also called optical parameters) and external parameters (also called geometric parameters, including rotation matrix and translation vector).

At present, the commonly used calibration methods can be classified into three categories: traditional calibration methods, self-calibration methods and calibration methods based on active vision [1]. The traditional calibration method is to use a reference object whose geometric parameters are known and accurate in size as a camera calibration object, processing the captured image, comparing them, and obtaining parameters through mathematical transformation and calculation. The parameters obtained by this method have high accuracy, but they are not easy to achieve because it is difficult to obtain accurate calibration objects in reality. Precise calibration objects are not required in the self-calibration method. It only needs to know the relationship between the photographed image and the corresponding points of the calibration objects to obtain the camera parameters. This method is simple and easy to operate, but its robustness and accuracy are not very high because it needs to use the geometric information in the scene. The calibration method based on active vision is to solve the camera parameters through autonomous control of the camera. To calibrate the camera, only some parameters of the camera are demanded here. The model calibrated by this method can be solved linearly, so better robustness and higher accuracy of the algorithm could be gained compared with the former two methods. But this method needs a high-precision active vision platform which can get accurate translation information, and needs considerable investment to get it. In 2000, Zhang Zhengyou[2] proposed a camera calibration based on a checkerboard template, which is between the traditional calibration method and the self-calibration method. The method avoids the shortcomings of the above two methods, meanwhile absorbing advantages of them. As a classic work of camera calibration research, it is widely used. In order to obtain higher precision, many scholars have improved the Zhang's calibration method.

For camera calibration, the accuracy of parameters directly determines the image effect and the system accuracy of computer vision. In order to improve the accuracy of camera calibration, this paper summarizes some improvements and research achievements in recent years.

2. Internal parameters

2.1 Accurate Extraction of Pixel Coordinates

In camera calibration, it can be achieved with a specific target with a marker point, the accurate extraction of the pixel coordinates of the marker has an important impact on the high-precision calibration of the camera. When determining the position of the point, the camera focuses the paper and other materials in different levels of high-light areas, which will lead to the loss of image texture information, resulting in inaccurate corner extraction, thus reducing the accuracy. The polarizer can effectively remove part of the highlight area. Therefore, Zhu Zhenmin[3] proposed a method to obtain the checkerboard calibration image at the optimal polarization Angle in different spatial positions by means of Stokes variable linear feedback through a CCD camera equipped with a polarizer. The sub-pixel level detection algorithm and Gaussian fitting are used to determine the image position of the corner points, and the two-dimensional pixel coordinates of the corner points in each board image are taken out to perform camera calibration. The slope of the fitted parallel lines of the method is closer, which meets the high precision calibration requirement of camera.

Huang Wanting and Hu Xiaoping[4] proposed an improved calibration algorithm for monocular camera based on Zhang's calibration method. On the basis of Zhang's calibration, the image preprocessing, Harris corner detection and sub-pixel precision are carried out on the directly collected chessboard images, and then the accuracy of the calibration results is evaluated by re-projection method. This method corrects the distorted image effectively and is applicable to many camera sensors. It has high validity and stability. However, instead of considering other distortion factors, this method only takes radial distortion into account. In order to further improve the accuracy of the calibration algorithm, a distortion model should be established and a variety of distortion be considered.

2.2 Distortion problem

The distortion coefficient in the internal parameters obtained by camera calibration is the key factor affecting the calibration accuracy. The ten-parameter model can better compensate for various foreseeable distortion differences. It is the most widely used camera aberration model at present. However, there is an approximate linear relationship between distortion parameters and the parameters of the camera station, that is, over-parameterization. To solve the problem of correlation between camera parameters, Wang Junwei[5] et al. proposed a camera calibration method based on robust ridge estimation. After obtaining the initial values of interior and exterior orientation elements, they calculate the coefficient matrix of the equation and judge whether it is ill. If it is ill-conditioned, the method of robust ridge estimation is used; if it is not ill-conditioned, the method of robust estimation is used. This method can effectively solve the problem of parameter correlation in calibration model structure, but also effectively resist the influence of observation gross errors and further improve the camera calibration results. In addition, Wu Fang[6] proposed a camera plane calibration method based on three-line structured light. This method uses BP neural network to correct the distortion model of industrial cameras. Because the image has been corrected, the camera distortion is not considered. The calibration parameters of the corrected camera model can be obtained by using Zhang's plane calibration method. This method has high accuracy and can effectively improve the accuracy and speed of camera calibration within a certain error range.

Furthermore, Liu Yan and Li Tengfei[7] also proposed an improved two-step calibration method to solve the lens distortion. First, the homograph between the template plane and the image is established, then the parameters are revised by the non-linear least squares method, and the calibration parameters are found from the complex model. The tangential distortion is considered as an important factor affecting the calibration results, and the reconstruction effect is improved. Compared with the traditional Zhang’s calibration method, this method improves the accuracy and provides a guarantee for accurate three-dimensional reconstruction.

The above method does not take into account the lens distortion of the fish-eye lens in the improvement of Zhang's calibration method. The angle of view of the fish-eye lens can generally reach 140 degrees or even 180 degrees. Fish-eye camera imaging has large radial distortion. It is difficult to obtain accurate corner points in the image edge area by traditional methods, which leads to the decline of calibration accuracy. If Zhang's calibration is used, the error will be very large. Therefore, Xu Yunze and Zhao Rujin[8] proposed a linear calibration method based on division distortion model. The method uses a stereo target, and utilizes the characteristics of the distortion center, therefore avoiding local minimum interference. First, the camera distortion center is estimated, then the distortion equation is decoupled from the projection matrix. Finally, the camera internal and external parameters and distortion coefficients are solved respectively. The accuracy and reliability are guaranteed, and the computational efficiency is improved.

2.3 Optimization of internal parameters

Zhang's calibration method solves parameters by LM algorithm, therefore there are common limitations of traditional non-linear optimization methods, that is, inappropriate initial value setting can easily make the method fall into local optimum. The combination of differential evolution algorithm and particle swarm optimization algorithm proposed by L Deng can effectively calibrate camera parameters and avoid local optimum solution. But the premature problem of traditional particle swarm optimization has not been solved. The problem of local optimal solutions needs further exploration. Therefore, Qin Ruikang[9] et al. proposed a particle swarm monocular camera internal parameter optimization method based on full parameter adaptive adjustment and mutation mechanism. Firstly, Zhang’s method is used to determine the initial value of camera internal parameters. Then, the full-parameter adaptive mutation particle swarm optimization algorithm is used for nonlinear optimization. In the iteration process, the learning factor is adaptively adjusted with the particle distance, and the mutation rate is adaptively adjusted with the average particle distance according to the different effects of the local optimal particle and the global optimal particle on each particle. Compared with Zhang’s calibration method and traditional particle swarm optimization calibration method, this method has better calibration accuracy and convergence speed.

3. Special Scene

In calibration, it is generally required that the target must be large enough to cover the whole field of view, so as to achieve higher accuracy. However, the use of large targets can cause many difficulties in the calibration process. For this reason, LeiYu[10] proposed a virtual plane target calibration method based on multi small targets virtual composition. On the basis of VLPT-based calibration method, the position and direction of STs are transformed several times to obtain multiple calibration images. Then, virtual points corresponding to STs feature points are searched and VLPT of each calibrated image is generated. Finally, the internal and external parameters of the camera are calculated by VLPT. This method has good stability, can solve the problem of calibration accuracy of large field of view camera, and has better operability.

Aiming at the problem of camera calibration in the field of large-size visual measurement, Gao Yang, Lin Jiarui[11] also conducted research and proposed an efficient and flexible calibration method for large-size measuring cameras based on precision two-axis turntable. The two-axis turntable driving the camera to rotate in two dimensions and shooting the front optical reference points is taken to construct a precise angle reference control field and calibration. The whole process is automatically and efficiently completed by program control. For different cameras, the measuring space and measuring distance can be flexibly configured to ensure that the calibration control field is consistent with the camera measurement field. It has high calibration precision.

All the above methods calibrate the whole image, but the points in different positions will be affected by different degrees of distortion. If the same camera parameters are used to correct, the accuracy of the experiment will be affected. To solve this problem, Ling Hanyu, Peng Binbin[12] proposed a method based on distance weighting for sub-regional camera calibration. This method takes the large distortion area far from the main point as the main object, distributes the image feature points as much as possible, thereby balancing the number of corner points in each area, so as to fully consider the impact of different image angles in different areas. It has higher accuracy and better robustness.

But sometimes, in some special measurement scenes, only the size, position and other information of the object in a region of the field of view need to be measured, therefore the traditional method using the object in the whole field of view will reduce the measurement accuracy of the object. To solve this problem, Liu Xiaolei[13] et al. proposed a close-range large field of view angle sub-area calibration method based on fixed targets. Using the idea of sub-area calibration, the calibration field is divided into several sub-area according to bilaterally symmetry, and then the sub-areas are resectioned to obtain the external orientation elements of the camera. This method reduces the total error and improves the accuracy, and with the increase of the number of segmentation areas, the accuracy will gradually improve. This method is especially suitable for the measurement of large work piece, which can improve the measurement accuracy obviously.

In terms of attitude measurement, Su Jiandong, Duan Xiusheng[14] et al. proposed a method based on Zhang’s calibration method to calibrate the camera, using homograph conditions to solve the external parameter matrix, and combining the Givens method to decompose the external parameter matrix Find the attitude angle, and then conduct test and simulation. The method effectively solves the attitude measurement problem of the planar target. Therefore, having a more accurate result for calibration target measurement. Camera out of focus

In the research of Zhang's calibration improvement, most of them are aimed at the improvement of short-range vision system. For some cameras with special imaging range, only defocus blurred photos of the calibrator can be obtained, generally, the field of view and depth of field are small. In the application of Zhang's calibration method, the calibration plate is required to change its position and posture several times, and the different positions and postures are as parallel as possible and full of the whole field of view. Therefore, the calibration plate is often located outside the clear imaging range of the micro-range camera. In order to solve the defocusing problem, Cai Berlin[15] proposed a method to calibrate three circular gratings generated by phase-shifting method. This method uses the polar-polar relationship and algebraic operations to estimate the image center, and then solves the intrinsic parameters through the circular point constraint. In this way, even if the focus of the camera is not aligned, it can work properly. The whole process does not need to measure the test pattern, so it is very flexible to implement.

Yang Hao, Cai Ning[16] et al. proposed a method to calibrate the defocus camera by using the phase-shift method sinusoidal structured light coding display panel. The method uses floyd-steinberg Dithering algorithm to eliminate the calculation error of structural light phase caused by gamma transform of display panel. The accurate extraction of calibration feature points by camera in defocus state is realized. In this way, the camera can be calibrated by Zhang's method in defocus state. It provides an effective solution for calibration of special imaging range cameras such as macro cameras.

In terms of focusing, Zhou Jiali[17] et al. proposed a high-precision and flexible calibration method for dynamic focusing. This method proposes a dynamic focus process based on the dynamic focus process by adding an angle sensor to the lens focus ring. The camera model with the parameter is able to solve the parameters in the camera under any focus state and distance. Finally, the customized three-plane stereo calibration target is utilized. The method has stronger image correction capability, thereby improving the accuracy of photogrammetry and having higher robustness.

4. Summary and outlook

With the development of science and technology, camera calibration plays an important role in weather prediction, road detection, robot vision and other fields. For example, in the fire scene, the image taken by UAV can be used to calibrate the camera, to restore the fire scene, and making plans to minimize the loss. The use of camera calibration ensures the accuracy of image restoration.

This paper reviews the common problems and improved methods of camera calibration methods. Several common problems affecting the accuracy of camera calibration are summarized, as well as the improvement and solution of each problem, the advantages and disadvantages of each method are also summarized. By improving the accuracy of camera calibration, the shortcomings of traditional calibration methods are constantly improved.

Whether it is the study of parameters or different environments, in the final analysis, it is to make the calibration results more accurate and make the image more restored. Camera calibration, as the basis of image processing, must ensure accuracy in order to reduce unnecessary errors in image processing. The accuracy of internal and external parameters is the key factor to determine the accuracy of camera calibration. Therefore, the to further improve the accuracy of internal and external parameters is the focus of future research.

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