Review on Camera Calibration

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Abstract: The camera calibration has become one of the most important parts of computer vision. By doing this, we can obtain the intrinsic and extrinsic parameters of cameras. This paper introduces the widespread application of camera calibration in the robot navigation, the three-dimensional reconstruction, the bio-medical, the virtual reality and the visual surveillance. Then summarizes the methods in different application, such as traditional calibration， the self-calibration and the active vision calibration.

Key words: Computer vision; Camera calibration; Intrinsic and extrinsic parameters

1 INTRODUCTION

In the machine vision, the geometric information of three-dimensional object is obtained from the image information by cameras. In order to get the corresponding relationship between the spatial point and the camera image pixel, the camera calibration is necessary. The relationship between the three-dimensional geometric location of one point and its corresponding point in the image is determined by the geometric model of camera imaging, and these geometric model parameters are the camera parameter. In most condition, these parameters must be obtained through the experiment and the calculation, and this process is known as the camera calibration [1].

Although the theory on the camera calibration is already very mature, and the calibration methods are also many, so far there is not a method to be able to used in a variety of occasions, owing to the camera calibration has the widespread application prospect and the huge economic efficiency in the domain of the robot navigation, the three-dimensional reconstruction and the like, so many scholars and research institutions are still engaged in the researching on it.

2 Applications of camera calibration

The camera calibration has widespread application prospect, such as the followings.

2.1 Mobile robot navigation

With the rapid development of robot technology, to ensure the robot complete complex task, there is an urgent need to develop a robot which has a stronger ability to interact with the outside world tasks, so that we can carry out the interaction between the robot and the environment. Among the many navigation methods, the visual navigation method has the advantage in the detection range and the information acquisition, so it has been the major development direction in the future mobile robot navigation [2-7].

In the visual navigation system, the navigation method based on in-car video cameras installed on the mobile robot is the most widely used at home and aboard. Because of the lower installation position of camera and lesser scene range with the used of the navigation method based on local visual, the general calibration method can satisfy the accuracy requirements. However, all computing devices and sensors are mounted on the robot, all the Image recognition, path planning, and other senior decision-making are completed by the board computer. Thus the real-time performance is slightly worse. In order to obtain a larger scene, it needs to layout multiple cameras in the environment. So the method of calculating position coordinates and camera calibration accuracy of an impact on mobile robot become an important factor in navigation and positioning accuracy. And camera calibration method has important research significance and practical value.

2.2 Machine vision

With the development of processing technology, there is an ever-increasing demand in the processing of mechanical opponents, for example, high-speed, high-precision process automation and so on. Literature [8] proposed a detection technique to the round part based on machine vision technology, which achieved the non-contact precision machining to the hole and the round part with a simple calibration method.

2.3 Biomedical

Since the 1980s', the United States, Japan and other countries have already begun to use the robot in medical surgery. With the help of robot and computer, we can formulate a reasonable, quantitative surgical option to improve the precision of surgery as well as reduce surgical trauma. Moreover, we can also complete the surgery and complex diagnosis which is very difficult for the routine method by using the robot. Practice has proved that the development of medical and surgical robotic technology is a reliable way to get rid of the old surgical methods, to improve the efficiency and quality of operation and to reduce the cost of surgery. The neurosurgery robot surgery mentioned in literature [9] is an example of medical applications. It did this by drilling a small hole in the skull,

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and then, leaded the probe or other more sophisticated, complex surgical devices into the brain under the guidance with the help of the robot. Finally, we take actions such as Biopsy Specimen, radiotherapy, resection and so on. At present, because of the calibration accuracy and the other issues, the domestic on the robot-assisted stereo tactic neurosurgery research is still in Inception Phase, it still needs a long way to go.

2.4 Visual surveillance

With the rapid development of China's road construction, road monitoring tends to road network monitoring. We can get a lot of surveillance videos and images during image acquisition equipment to analyst traffic risks and find accident timely that ensure the road smoothly because of retrograde vehicle, rear-end, dropping or blocking other traffic.

As the complexity of road condition and vehicles are more and faster, image acquisition is easy to the impact of the weather and operating personnel. Therefore, how to improve the calibration accuracy of image acquisition devices and image processing speed that become a key link of road monitoring system [10].

What's more the camera calibration has a wide range of applications in the archaeological, architectural, agricultural machinery and other fields.

3 Camera calibration methods

Generally speaking, the camera calibration techniques can be divided into the following three categories: traditional calibration techniques, self-calibration techniques and calibration techniques based on active vision. The following we will introduce the more common methods of each category.

3.1 Traditional calibration method

Traditional method of camera calibration[11] is known as using a calibration piece , which of known structure and high precision processing, as space reference point and through the correspondence between the space points and the image points to establish the constraints of the camera model parameters, then to obtain these parameters by optimization algorithm. The traditional methods can use any camera model and have high precision of calibration, so that when applications required highly accuracy, often use this approach. The typical representatives are as follows: the direct linear transformation method (DLT method), nonlinear optimization method, two-step method, planar template method, dual-plane method and so on.

(1) Direct linear transformation method

Direct linear transformation method is first proposed by Abdel-Aziz and Karara in 1971. In this method, a set of intermediate parameters are defined, and then the intrinsic and extrinsic parameters of camera model could be solved by establishing and solving linear equations without iterative calculations, which is the attraction of the direct linear transformation method. Because of this approach involved few parameters and calculated easily, it is relatively easy to be adopted. However, this approach did not consider the non-linear distortion problems during the camera works. In order to increase accuracy, the direct linear transformation method can be expanded to include these non-linear factors and used non-linear means to solve them [12-14].

(2)Nonlinear optimization technique

Considered the distortion of the camera, nonlinear optimization technique use a large number of unknowns and large-scale nonlinear optimize, which makes the computational cost become larger with the increased accuracy of the nonlinear model. Nonlinear optimization technique's precision is high, but its algorithm is fussy and slow, and the iterative nature of algorithm needs a good initial estimate. If the iterative process of design is not appropriate, especially in high-distortion conditions, the optimization process may be unstable, resulting in instability and even the results of the error, so its validity is not high. The advantages and disadvantages of the distortion calibration method are proposed based on a simple and rapid calibration method of the lens distortion parameters [15]. This method makes use of the perspective projection of the cross-ratio invariance, in the distortion model is a first-order radial distortion of the cases, only needs the space to a total line of the image coordinates of four points and their cross-ratio, for example, the establishment of a quadratic equation distortion parameters can be calibrated. This method algorithm is simple and easy to implement. Literature [16] in its image on the basis of a correction, using linear calibration completed the calibration, to avoid other nonlinear optimization methods may encounter instability.

(3) Two-step method

The direct linear transformation method didn’t considered the distortion of the camera lens, while the non-linear model methodology could take the non-linear factors into account, but it made the calculations much more complicated, and the result even may not be exact solutions. Tsai studied and summarized the traditional calibration method before 1987; there was radial distortion factor of the camera model, on the basis of which a practical two-step calibration algorithm was proposed. First, the perspective matrix transform method was used to solve the camera parameters of the linear systems, and then used the achieved parameters as the initial value, given the distortion factor, and use optimization methods again to improve the calibration accuracy. The advantage of this method was that the model assumed the camera lens distortion was radial and the vector remained unchanged from the image center to the point direction of the image, regardless of changes in distortion. Because of its high calibration accuracy, it significantly reduced the space dimension of parameters, so it was suitable for precise measurements. The disadvantage is that the calibration of the equipment requirements is relatively high, not suitable to use on a simplified calibration.

Generally speaking, we can achieve very good precision considering the second-order distortion which is the same as radial distortion of the camera. Therefore, two-step method only considered the second-order radial distortion, without considering the tangential distortion. Literature [17] referred that Weng considered two kinds of distortion and gave the corresponding algorithm and analytical methods of calibration accuracy. This method is a significant development of two-step calibration method.

(4) Biplane method

The basic difference between biplane model and the pinhole model is that the pinhole model requires all lights projected onto the surface must pass through the optical center of light which is different from biplane model. Given an image point of the image plane, we will be able to calculate the corresponding points between the two calibration planes, and then determine the lights which projects to the image plane to generate the image point.

Martins and others firstly proposed biplane model. This method does not explicitly use the camera model, but uses the "line of sight" of the world coordinate system. The line of sight defined in this method is the line connecting, which is set off from the two flats in the work scene to certain point on the image plane. Given reference points and its corresponding points on the image, we can calculate the two maps by using insertion method. Insertion method is: For each image point, we define two corresponding points between the first plane and the second plane and then to define the vector of line of sight .In this method, we use the local insertion. The three vertex of every triangle which forms the image must be the intersection of the calibration lattices, and then we use spine interpolation in the triangle. Advantage of this method is we could receive relevant parameters by using a linear method of solution. The disadvantage is that it needs to require solution of a large number of unknown parameters and exists a tendency to over-parameterization.

3.2 Self-calibration technology

Since in some situations the camera can not be calibrated by choosing the appropriate calibration object, so it brings a kind of method called camera self-calibration to achieve demarcating, which does not depend on the calibration reference object and is unrelated to the scenes and camera movements, only making use of the self-constraints of camera intrinsic parameters. Such method is suitable for the situation that the intrinsic and extrinsic parameters of camera are not fixed to implement demarcating. At present, self-calibration techniques can be divided into: Based on Active Vision camera self-calibration techniques, using essential matrix and fundamental matrix self-calibration method, using the absolute conic and polar transform the nature of camera self-calibration method, using blanking points or blanking line camera calibration method and calibration method under considering the case of non-linear distortion of camera.

Compared with traditional methods, camera self-calibration approach only requires the establishment of the correspondence between the image .it is flexible, but the calibration process of the self-calibration method is complex, it does not apply to the in-time Updating occasion, and is only applicable to the situation that calls for less precision ,such as virtual reality, owing to the non-linear calibration of self-calibration method, relying on good initial estimates and lacking of robustness.

3.3 Calibration technique based on active vision

In order to overcome the cumbersome process of traditional calibration method, then there is the active calibration method in controlling camera movement, for example, rotation around the optical center and movement on flat. Active calibration method has the advantage of simple algorithm and the disadvantage of that the camera movement can not be applied beyond the control of unknown or occasion.

Camera Self-Calibration Method based on active vision is an important branch. The active vision system is that camera have been precise installed in the controllable platform, through the active control of the camera for a special campaign to obtain multiple images, using images and the controllable camera motion parameters to determine the camera intrinsic reference and extrinsic reference parameters. Ma songde and Hu zhanyi have done a great deal of research in this system [11,18-21].

It should be noted that the research focus of this method is the linear solution of the camera model parameters while minimizing camera movement restrictions. If there is no camera movement constraints, calibration process is essentially a multivariate nonlinear optimization problem, and the calibration based on active vision returns to the scope of self-calibration. On the basis of Tsai, Gao used the distance between the actual 3D point in the world coordinate system and the 3D point of the theory as the cost function. At the same time, he optimized the camera parameters and distortion factors, and achieved a better accuracy in his experiment.

3.4 Other calibration methods

(1)Plane pattern method

Graphic template is first proposed by Dr. Zhang Zhengyou, which requires precise positioning to draw a dot matrix template, and then makes the template and the camera mutual move and obtains three or more template images from different orientations. By matching the determined image with the template, homography matrix can be calculated, and using linear solution with homography matrix we can get the parameters of camera at last. This method has the advantage of solving the lens distortion factors; the disadvantage is that the process of calibration is complex, and needs to extraction the corner point and the opposite corner point and matches them which makes the algorithm need manual intervention and is not conducive to automated calibration.

On this basis, Literature[22] proposed a calibration template can be used in improving SUSAN algorithm, completing the matching corner point coordinates and taking into account a case of first-order radial distortion model for the establishment of the camera; Literature [23] proposed to use the center of a circle as the calibration points of the 2D planar template. Wu Fu-Chao, Wang Guang-hui, Hu Zhan-Yi used two non-parallel rectangles as a template; Quan Hong-yan, etc. used the square and the midpoint of its the edge as a template to complete the camera calibration. On this basis, Literature [24] proposed a calibration based on a single flat rectangular template; Literature [25] proposed achieving calibration by two intersecting circular template with the center point and unknown radius. Meng and others used a circle and straight lines through the center of the circle as the calibration templates to achieve calibration. Literature [26] had proposed a calibration plate using a two-dimensional gray-modulated sinusoidal fringe pattern. According to Fourier fringe analysis， the truncated phase distribution of two orthogonal directions can be calculated, and extract the phase feature points as 2D calibration data. We can use the 2D coplanar reference point calibration method to achieve calibration. Literature [27] proposed to have two similar planar graph templates to achieve calibration procedure. These new developed methods provide more new targeted direction for camera calibration.

（2）Neural network、genetic algorithm etc

With the development of technologies such as neural networks, more and more people are aware of the applications of neural network in solving nonlinear models. Literature [28] proposed a traditional camera calibration algorithm based on single adaptive neuron. He used a simple structure, strong anti-interference ability of individual neurons adaptive algorithm instead of the usual non-linear optimization algorithm for camera calibration. Experimental results show that the algorithm without calculating the Jacobian matrix, and high precision, simple and feasible. for the complex imaging and distortion models in process of calibration, Literature [29] calibrated implicitly the camera of attitude measurement system, using the error back-propagation neural networks' powerful approximation ability to complex non-linear mapping, so that attitude measurement system need not complex camera calibration, directly restore the three-dimensional information of the target feature points, then acquire the objective attitude information.

Artificial neural network can achieve accurate approximation of complex non-linear mapping. It provides an effective method to model the attitude visual measurement system. It Simple, Practical and Less computational compared with variety traditional of optimization algorithms, there are still many problems. Learning algorithm is inefficient, slow to learn, easy does not converge. The learning process is easy to fall into local optimal solution. Therefore using neural network to camera calibration is often obtaining larger error due to trapped into local optimal solutions. For this reason, combining the nonlinear fitting ability of neural networks and good global search capability of genetic algorithm, literature [30] further proposed a method of single camera calibration.

4 Conclusions

The traditional calibration method must use the constraint relation between the standard reference and their images in order to solve the intrinsic and extrinsic parameters of camera model, and if you want to improve the calibration precision, you need to further enhance the accuracy of camera model, so the camera's distortion must be considered. In fact, introducing the distortion will make the entire camera model become a nonlinear model. Therefore how to success for solving the parameter of nonlinear model under the guarantee precision's condition has become an important issue. The solution that obtained from camera self-calibration is not unique and even instable at times. So how to enhance the nonlinear solution's stability and robustness has become one of the most difficult problems. Artificial neural network can achieve accurate approximation of complex non-linear mapping. It provides an effective method to model the visual measurement system. Combining the nonlinear fitting ability of neural networks and good global search capability of genetic algorithm， calibration by neural network will be more and more attractive.

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