Camera model and parameter calibration

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Abstract. Each camera has its own model and parameters. Accurate calibration of the camera's model parameters can effectively prevent distortion effects and ensure image imaging. In this paper, the three-dimensional space points of the camera model are linked with the two-dimensional image points, and the in-plane distortion parameters of the camera are obtained by using the checkerboard calibration method, thereby distorting the image and restoring the image imaging effect.

1. Introduction

The camera has been around for a long time. However, with the introduction of inexpensive pinhole cameras in the late 20th century, they became common events in everyday life. Unfortunately, this cheap price is: a significant distortion. Fortunately, these are constants, calibrations, and some remapping, which can be used to correct this. In addition, by calibration, the relationship between the natural unit (pixel) of the camera and the actual unit (for example, millimeters) can be determined. In computer vision, a three-dimensional spatial point is associated with a two-dimensional image point using a camera model. Camera calibration methods include: traditional camera calibration, active vision camera calibration, and camera self-calibration [1]. Conventional camera calibration requires the use of a calibration of known size. By establishing a correspondence between the point on the calibration object and its image point, a certain algorithm is used to obtain the internal and external parameters of the camera model [2]. According to the different calibration materials, it can be divided into three-dimensional calibration materials and flat calibration materials. The three-dimensional calibration can be calibrated from a single image, and the calibration accuracy is high, but the processing and maintenance of the high-precision three-dimensional calibration is difficult [3]. The flat type calibration is simpler than the three-dimensional calibration, and the accuracy is easy to guarantee, but the calibration must use two or more images. Conventional camera calibration always requires calibration during the calibration process, and the accuracy of the calibration will affect the calibration results. At the same time, the lack of suitable calibration for some occasions also limits the application of traditional camera calibration methods.

The current self-calibration algorithm mainly uses the constraints of camera motion. The camera's motion constraints are too strong, making it impractical in practice. The use of scene constraints is primarily the use of some parallel or orthogonal information in the scene. The intersection of spatial parallel lines on the camera image plane is called vanishing point, which is a very important feature in projective geometry. Therefore, many scholars have studied the self-calibration method based on vanishing point [4]. The self-calibration method is flexible and allows for on-line calibration of the...
camera. However, because it is based on an absolute quadratic curve or surface method, its algorithm is poorly robust.

Active vision-based camera calibration refers to the calibration of the camera by certain motion information of known cameras. This method does not require a calibration, but it is necessary to control the camera to do some special motions, and the specific parameters of the motion can be used to calculate the internal parameters of the camera [5]. The advantage of camera calibration based on active vision is that the algorithm is simple and often can obtain linear solution, so the robustness is high. The disadvantages are high system cost, expensive experimental equipment, high experimental conditions, and not suitable for motion parameters unknown or Uncontrollable occasions.

2. Introduction of methods

Basically, this article needs to take a snapshot of these patterns using the camera. Each discovered pattern produces a new equation. To solve the equation, this paper requires at least a predetermined number of pattern snapshots to form a well-designed equation. This number is higher for the checkerboard pattern and smaller for the circular pattern. For example, theoretically, a checkerboard pattern requires at least two snapshots. However, there is actually a large amount of noise in the input image, so in order to obtain good results, at least 10 different positions of the input graphic snapshot are required. The flow chart of the method is shown in Figure 1.

![Algorithmic flow chart.](image)

**Figure 1.** Algorithmic flow chart.

2.1. Camera Model

In practice, there are often mathematical models to describe the camera model. There are many camera models, but they are generally divided into pinhole models (linear models) and nonlinear models. For linear models, the pinhole model can be used to approximate the projection position of any point \( P(x_c, y_c, z_c) \) at the image plane, that is, the projection point \( P(x, y) \) of any point \( P(x_c, y_c, z_c) \) is the intersection of the line connecting the OP (the optical center) and the point \( P(x_c, y_c, z_c) \) with the image plane. In the actual imaging process, considering the distortion of the lens, there is generally nonlinear distortion, so the linear model cannot accurately describe the imaging geometry. The nonlinear distortion can be described by the following formula:

\[
\begin{align*}
\tilde{x} &= x + \sigma_x(x, y) \\
\tilde{y} &= y + \sigma_y(x, y)
\end{align*}
\]  

(1)

If nonlinear distortion is considered, a nonlinear optimization algorithm is required for camera calibration. However, studies have shown that the introduction of excessive nonlinear incorporation (such as centrifugal distortion and thin edge distortion) can not only improve the accuracy, but also cause instability of the solution. In general, radial distortion is sufficient to describe nonlinear distortion, which can be expressed as:

\[
\begin{align*}
\tilde{x} &= x(1 + k_1r^2) \\
\tilde{y} &= y(1 + k_2r^2)
\end{align*}
\]  

(2)

From the production point of view, it is easier to make a "spherical" lens than to make a mathematically ideal lens. Therefore, radial distortion is generated. Mechanically, it is also difficult to balance the lens and imager. Therefore, tangential distortion is produced. In this paper, the camera
internal parameters and distortion parameters are calibrated by the checkerboard calibration method, and the image quality is guaranteed by anti-distortion.

2.2. Radial distortion

For radial distortion, the center of the imager (optical center) is distorted to zero, and as it moves toward the edge, the distortion becomes more and more serious. Therefore, we can quantify the description with the first few terms of the Taylor series expansion at r=0. For cheap webcams, we usually use the first two items, where the first item is usually k1 and the second item is k2. For cameras with large distortions, such as fisheye lenses, the third radial distortion term k3 is used here. Usually the radial position of a point on the imager is adjusted as follows:

\[
\begin{align*}
x_{\text{distorted}} &= x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) \\
y_{\text{distorted}} &= y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)
\end{align*}
\]

(3)

There \((x, y)\) is the original position of the distortion point on the imager, and \((x_{\text{distorted}}, y_{\text{distorted}})\) indicates the new position after correction.

2.3. Tangential distortion

Tangential distortion is caused by defects in the manufacture of the lens such that the lens itself is not parallel to the image plane. Radial distortion can be described by two additional parameters \(p_1\) and \(p_2\), as follows:

\[
\begin{align*}
x_{\text{distorted}} &= x + [2 p_1 xy + p_2 (r^2 + 2x^2)] \\
y_{\text{distorted}} &= y + (p_1 (r^2 + 2y^2) + 2p_2 xy)
\end{align*}
\]

(4)

So there are a total of 5 distortion parameters we need. Since 5 parameters are required in the program, they are placed in a distortion vector, which is a \(5 \times 1\) matrix, which in turn contains \(k_1, k_2, p_1, p_2\) and \(p_3\).

\[
\text{distortion\_coefficient} = (k_1, k_2, p_1, p_2)
\]

(5)

Now for unit conversion, we use the following formula:

\[
\begin{bmatrix}
x' \\
y' \\
w'
\end{bmatrix} = 
\begin{bmatrix}
f_x & 0 & c_x \\
0 & f_y & c_y \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix}
\]

(6)

There explain the existence of \(w\) by using the homography coordinate system \((w = Z)\). The unknown parameters are \(f_x\) and \(f_y\) (camera focal length) and \((c_x, c_y)\), which are optical centers expressed in pixel coordinates. If the common focal length for a given \(an\) aspect ratio (usually 1) is used for both axes, then \(f_x = f_y * a\), and in the above formula we will have a single focal length \(f\). The matrix containing these four parameters is called the camera matrix. Although the distortion coefficients are the same, these should be scaled along with the current resolution of the calibration resolution, regardless of the camera resolution used.

3. Experiments

The experimental process is divided into four steps:

1. The checkerboard image of the input camera is shown in Figure 2.
2. Calculate the distortion parameters involved in the camera by checkerboard corner calibration as shown in Figure 3.
In Figure 3, by finding the corner points in the checkerboard to align the position in the camera, the algorithm will find the internal distortion parameters of the camera.

3. The anti-distortion effect of the image taken by the camera through the distortion parameter is shown in Figure 4.

![Figure 4. Image distortion and anti-distortion](image)

Before the image is distorted, the image near the outside of the image, especially the four corners, will be bent and distorted. After the anti-distortion, the image can be repaired to obtain the image of the normal viewing angle, which is also related to the imaging effect of the camera itself.

4. Conclusion
The internal parameters and distortion parameters of the camera are very important for the camera. The camera calibration methods are: traditional camera calibration method, active vision camera calibration method, and camera self-calibration method.

Acknowledgments
This work was financially supported by fund project, that is, Guangzhou Institute of industry and commerce college level research project in 2019”Research and design of S band radio frequency front-end” KA201937.

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