Study on Image Calibration Method in Automatic Meteorological Observation of Crops

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Abstract. The digital camera was used to collect crop real scene images in automatic observation of crop meteorology, and image processing algorithm was used to extract crop characteristics. Due to the influence of camera distortion parameters, the real images have distortion in different degrees, and there are deviations in the recognition results of the observed area, density and incubation period. According to the results of the crop automatic identification, contrast the distortion parameters of camera was analyzed, and the camera calibration algorithm is studied. Moreover, the accuracy of crop automatic observation was improved, due to the image correction.

1. Introduction
In order to adapt to the requirements of modern agricultural observation, crop meteorological automatic observation stations were established in different regions. Crop meteorological automatic observation stations aimed to provide accurate and reliable data for the development of modern precision agriculture and provide a scientific basis for establishing a reasonable crop model and increasing crop yield [1] [2]. This paper based on the analysis of the observation results of crop meteorological automatic observation stations. According to the error in the observation results, the image distortion was an important factor to cause the inaccuracy of the observation results which was proposed by the analysis of the deviation between crop source data and crop development [3]. Therefore, through the study of the camera imaging model and its distortion parameters, the camera distortion parameters were corrected from the mathematical model. Finally, the internal and external parameters of the camera were calibrated and the acquired images were corrected by the MATLAB toolbox. Through the experiments, it was found that the corrected image can obtain higher accuracy in feature extraction and result recognition.

2. Camera imaging model
There were many types of imaging models for cameras. The common mathematical models were designed according to the principle of small whole imaging. There was a linear relationship between the camera and the image plane, as shown in Figure 1.

There were four coordinate systems in the model, namely a pixel plane coordinate system, an image coordinate system, a camera coordinate system, and a world coordinate system. Supposing there
was a point P in the space, the coordinate was $P_W(X_w, Y_w, Z_w)$ in the world coordinate system, the coordinate was $P_C(X_c, Y_c, Z_c)$ in the camera coordinate system, the coordinate was $p(x_0, y_0)$ was in the image coordinate system and the coordinate was $p(u, v)$ in the pixel coordinate system.

**Figure 1.** Camera and image plane coordinate system model

The relationship between the image coordinate system and the pixel plane coordinate system was shown as follows:

\[
\begin{bmatrix}
    u \\
    v \\
    1
\end{bmatrix} =
\begin{bmatrix}
    1/dx & 0 & u_0 \\
    0 & 1/dy & v_0 \\
    0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
    x_0 \\
    y_0 \\
    1
\end{bmatrix}
\]  

(1.1)

The relationship between the image coordinate system and the camera coordinate system was shown in (1.2), where $f$ was the focal length of the camera.

\[
\begin{bmatrix}
    x_c \\
    y_c \\
    z_c
\end{bmatrix} =
\begin{bmatrix}
    f & 0 & 0 \\
    0 & f & 0 \\
    0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
    X_c \\
    Y_c \\
    Z_c
\end{bmatrix}
\]  

(1.2)

Besides, there were two limiting parameters between the instantaneous spatial position of the camera and the camera coordinate system. The parameters were an external parameter of the camera which was composed of a rotation matrix $R$ and a translation matrix $T$. From these two parameters, the correspondence between the camera space position and the camera coordinate system can be obtained as shown in (1.3).

\[
\begin{bmatrix}
    X_c \\
    Y_c \\
    Z_c
\end{bmatrix} =
\begin{bmatrix}
    R & T \\
    0 & 1
\end{bmatrix}
\begin{bmatrix}
    X_p \\
    Y_p \\
    Z_p
\end{bmatrix}
\]  

(1.3)

When observing crops, especially for automatic identification of maize emergence, the accuracy of the recognition results depended on the accuracy of image feature extraction. The latest research showed that we need to start with camera calibration to improve the accuracy of crop observation and reduce the impact of camera distortion on the recognition results.
3. Camera distortion and correction

3.1. Camera distortions
In ideal conditions, the projection point, the optical center and the object point satisfy the collinear principle during the course of imaging. Due to the structure and technology of the camera, the optical system didn’t work following the ideal imaging principle completely. As a result, there was a distortion error between the ideal image and the actual image in the image coordinate system, which was made by the point in the camera world coordinate system [5] [6]. There were usually three forms of distortion: radial distortion, eccentric distortion, and image plane distortion.

3.1.1. Radial distortion. Radial distortion was the deviation of the image point along the main optical axis, and the radial distortion was symmetric along the main point.

\[
\begin{align*}
\Delta x &= K_1 \overline{x}^2 + K_2 \overline{x}^4 + K_3 \overline{x}^6 + \ldots \\
\Delta y &= K_1 \overline{y}^2 + K_2 \overline{y}^4 + K_3 \overline{y}^6 + \ldots
\end{align*}
\]

(2.1)

Where \(\overline{x} = (x - x_0)\), \(\overline{y} = (y - y_0)\), \(r = (x^2 + y^2)\), \(K_1\), \(K_2\), \(K_3\) was the radial distortion coefficient.

3.1.2. Eccentric distortion. The eccentric distortion was the distortion caused by the deviation of the center of the lens from the main optical axis. The eccentric distortion caused the radial deviation and tangential deviation of the image point [6]. The distortion equation was:

\[
\begin{align*}
\Delta x_d &= P_1 (r^2 + 2 \overline{x}^2) + 2 P_2 \overline{x} \overline{y} \\
\Delta y_d &= P_1 (r^2 + 2 \overline{y}^2) + 2 P_2 \overline{x} \overline{y}
\end{align*}
\]

(2.2)

Where \(P_1\), \(P_2\) was the eccentric distortion coefficient.

3.1.3. Image plane distortion. Image plane distortion was the aberration of image points, which was caused by A/D conversion and signal transfer error caused by asynchronous sampling clock of pixels. The solution method was as follows:

\[
\begin{align*}
\Delta x_m &= q_1 \overline{x} + q_2 \overline{y} \\
\Delta y_m &= 0
\end{align*}
\]

(2.3)

Where \(q_1\), \(q_2\) was the image plane distortion coefficient.

3.2. Distortion correction
Generally speaking, the distortion of the camera was corrected from its mathematical model. Suppose the pixel coordinate of the space point \(P\) was \((x, y)\). Given the influence of the three distortion parameters of the camera on the imaging results, the corrected pixel coordinate was \((x', y')\). The relationship can be expressed by the following equation (2.4).

\[
\begin{align*}
x' &= x + \Delta x + \Delta x_m = x + K_1 \overline{x}^2 + K_2 \overline{x}^4 + K_3 \overline{x}^6 + P_1 (r^2 + 2 \overline{x}^2) + 2 P_2 \overline{x} \overline{y} + q_1 \overline{x} + q_2 \overline{y} \\
y' &= y + \Delta y + \Delta y_m = y + K_1 \overline{y}^2 + K_2 \overline{y}^4 + K_3 \overline{y}^6 + P_1 (r^2 + 2 \overline{y}^2) + 2 P_2 \overline{x} \overline{y} + 2 P_3 \overline{x} \overline{y}
\end{align*}
\]

(2.4)
4. Camera correction

According to different calibration methods, the camera calibration methods were divided into three methods: traditional calibration method, active visual calibration method and self-calibration method. In this paper, the two-dimensional calibration camera calibration method in the traditional calibration method was used [7]. In order to facilitate the calculation, the world coordinate system was defined on the \( Z=0 \) plane. The homogeneous coordinate of the world coordinate point was \( \bar{M} = [X \ Y \ 1]^T \), the homogeneous coordinate of the camera plane coordinate point was \( \bar{m} = [u \ v \ 1]^T \), and the inner parameter matrix was

\[
K = \begin{bmatrix}
\alpha & \gamma & u_0 \\
0 & \beta & v_0 \\
0 & 0 & 1
\end{bmatrix}.
\]

There was:

\[
sm = K[R \ t]\bar{M} = K\begin{bmatrix}
r_1 & r_2 & t
\end{bmatrix}[X \ Y \ 1]^T
\]

(3.1)

Where \( R \) was rotation matrix, \( t \) was translation matrix, \( s \) was scale factor. Simplify (3.1) to:

\[
s\bar{m} = HM
\]

(3.2)

Where \( H = [h_1 \ h_2 \ h_3] = \lambda K[r_1 \ r_2 \ t] \), \( \lambda \) was scale factor, \( r_1 = \frac{1}{\lambda}K^{-1}h_1 \), \( r_2 = \frac{1}{\lambda}K^{-1}h_2 \). According to the nature of the rotation matrix: \( r_1^T r_2 = 0 \) and \( \|r_1\| = \|r_2\| = 1 \), the constraint shown in (3.3) can be obtained for each image.

\[
\begin{cases}
h_1^T K^{-T} K^{-1} h_2 = 0 \\
h_1^T K^{-T} K^{-1} h_1 = h_2^T K^{-T} K^{-1} h_2
\end{cases}
\]

(3.3)

According to the matrix knowledge, when the number of images taken was greater than or equal to 3, the inner parameter matrix \( K \) containing 5 unknowns had a unique solution.

5. Results and analysis

Multiple images with different poses were captured by the camera [6]. The images were calibrated by the MATLAB calibration toolbox. When calibrating, the corners of the calibration board must be extracted firstly as the Figure 2 showed.

![Figure 2. Calibration plate corner extraction](image)

According to the previous formula derivation, the internal parameter matrix of the camera could be obtained by three images. In order to improve the calibration accuracy, 12 different images of different poses were selected to calibrate the camera to obtain the internal parameter matrix of the camera:
The original images were corrected with the camera calibration result, and the correction results were shown in Fig 3.

![Image 1]  ![Image 2]

(a) Before image correction  (b) After image correction

**Figure 3.** Before and after image correction

From the figure, it can be observed that the convex distortion of the edge in the checkerboard had been corrected effectively. Use the obtained camera parameters to correct the measuring image, obtain the geometric relationship between the actual size of the object to be tested and the pixel size, and establish the object-image model. Therefore, the scientificity of test results could be improved. For the automatic identification of the emergence period of corn, the emergence period was the first important development period of corn, which can objectively reflect whether the development of corn was reasonable or not. It was important reference data for scientific management of farmland by farmers.

As literature [3] [4] [8] showed, the current effective corn seedling detection algorithm flow was shown in Figure 4:

![Image 3]

**Figure 4.** Algorithm flowchart

Image segmentation and threshold setting were the most important aspects in the Miao detection algorithm. Yu's illumination was used in image segmentation algorithm, which can effectively reduce the influence of small dynamic range fluctuation of illumination on segmentation results [3] [4]. The threshold value needs to be combined with the seedling characteristics and geometric parameters of the corn seedling stage. Use camera calibration parameters to convert the actual geometric size of maize seedling into pixel size. Counting the confidence of the image segmentation result to be in the threshold interval which was determined whether the seedling has reached the period.

From the experiments, it was found that the results of the identification of the corn seedling stage after calibration of the camera are closer to the actual development and meet the requirements of automatic observation accuracy [1].
6. Conclusion
In this paper, the three types of image distortion were studied by analyzing the automatic observation results and starting from the imaging model of the camera, and the mathematical model was modified. By collecting real images, the camera was calibrated by the MATLAB toolbox, and the camera's internal and external parameters were obtained. Finally, the images were corrected by this parameter. Experiments showed that when the image was corrected, the convex distortion had been effectively corrected, which improved the accuracy of crop automatic observation and recognition results.

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