A distortion image correction method based on machine vision

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Abstract. As autopilot becomes a hot spot in the field of automobile, machine vision is widely used in autopilot technology, and calibration of camera parameters is the basic work of obtaining driving environment by using vision. In this paper, based on camera parameters and machine vision technology, the monocular camera image distortion correction algorithm is studied. Based on the perspective transformation principle, the method of controlling transformation point is used to correct the image. The black-and-white checkerboard is taken as the object of image acquisition, and the results obtained in this paper are compared with those obtained by the calibration toolbox camera calibrator of matlab camera. The algorithm proposed in this paper is used to correct the images collected in traffic environment, which lays a foundation for the subsequent recognition of traffic signs. The experimental results show that the distorted image correction results are good, the accuracy is higher, and it is practical and effective.

1. Introduction
In the process of acquiring images, the auto-driving technology has a certain angle between the camera and the road surface due to factors such as the shooting angle, which causes the images to have different degrees of distortion. In this case, the direct use of image information to formulate the vehicle control strategy will cause serious errors and even lead to the deviation of the driving track. Therefore, calibration of camera parameters as the key prerequisite for correcting distorted images, which plays a great significance role for automatic driving to obtain accurate driving environment [1].

At present, there are two kinds of image distortion correction: one is the non-measurement distortion corrected method, which does not need calibration template, and the distortion parameter solving process and camera calibration process are independent of each other [2-4]; and the other is to calibrate the camera to obtain the inside parameters, outside parameters and the distortion parameters of the camera. Camera parameter calibration can be divided into traditional camera calibration method and camera self-calibration method [5].

The traditional calibration method needs high precision calibration object as a spatial reference, and can be used in any camera model with high calibration accuracy. The most typical is Zhang Zhengyou's calibration method based on plane target and Tsai[6]two-step method. But in the special working environment, the selection and maintenance of the calibration object are complicated and difficult to realize. The camera self-calibration method does not need to establish calibration template in the process of parameter calibration, but only depends on the relationship between the corresponding points of multiple pictures taken by the camera in the natural environment. This method is flexible and useful, but it is sensitive to initial value and noise, and its robustness is not high.
Under the influence of various methods, this paper uses the advantage of the self-calibration method of the camera to correct the radial distortion produced in the automatic driving process. Using the principle of perspective transformation, the position of the selected control point is improved by using the black-and-white checkerboard as the image acquisition object.

2. Camera model

2.1. Pinhole imaging model

In order to determine the relationship between the position of a point in three-dimensional space and its corresponding position in a two-dimensional image, the geometric model of camera imaging should be established. The model parameters are internal and external parameters of the camera. The imaging model includes the world coordinate system, the camera coordinate system, the image coordinate system and the pixel coordinate system. P(X_W, Y_W, Z_W) is the coordinate of P in the world coordinate system, and the coordinate of this point in the camera coordinate system is P(X_C, Y_C, Z_C), in the image coordinate system of the ideal pinhole model the coordinate of P(x, y), in the pixel coordinate system is P(u, v). The camera geometry model established in this paper is shown in Figure 1.

![Figure 1. Camera geometry model](image)

Set the coordinates of the image center to be (u_0, v_0). The physical dimensions of each pixel in the camera are dx * dy, so the relationship between (u_0, v_0) and dx * dy is expressed as:

\[
\begin{bmatrix}
    x \\
    y \\
    1
\end{bmatrix} =
\begin{bmatrix}
    dx & 0 & 0 & u_0 \\
    0 & dy & 0 & v \\
    0 & 0 & 0 & 1
\end{bmatrix} +
\begin{bmatrix}
    -u_0 dx \\
    -v_0 dy \\
    1
\end{bmatrix} =
\begin{bmatrix}
    dx & 0 & -u_0 dx \\
    0 & dy & -v_0 dy \\
    0 & 0 & 1
\end{bmatrix}
\]

(1)

According to the position of each point in the model, the following equation can be obtained:

\[
\frac{O_iO_c}{O_iA} = \frac{O_cA}{AB} = \frac{PC}{AB} = \frac{O_cC}{O_cA}
\]

(2)

Where the distance between O_i and O_c is camera focal length f, there is the following relationship:

\[
\begin{cases}
    Y_c = \frac{yZ_c}{f} \\
    X_c = \frac{xZ_c}{f}
\end{cases}
\]

(3)

Rewriting to a matrix can be expressed as:

\[
\begin{bmatrix}
    x \\
    y \\
    1
\end{bmatrix} =
\begin{bmatrix}
    f & 0 & 0 & X_c \\
    0 & f & 0 & Y_c \\
    0 & 0 & 1 & Z_c
\end{bmatrix}
\]

(4)

The equation (1) and (4) are as follows:

\[
\begin{bmatrix}
    u \\
    v \\
    1
\end{bmatrix} =
\begin{bmatrix}
    f & 0 & 0 & X_c \\
    0 & f & 0 & Y_c \\
    0 & 0 & 1 & Z_c
\end{bmatrix}
\]

(5)
\[ M = \begin{bmatrix} \frac{f}{dx} & 0 & 0 \\ 0 & \frac{f}{dy} & 0 \\ 0 & 0 & 1 \end{bmatrix} \] is the internal parameter matrix of the camera.

### 2.2. Distortion type

The distortion can be divided into radial distortion and tangential distortion. As shown in the Figure 2, \( d_r \) is radial distortion and \( d_t \) is tangential distortion. The radial distortion is caused by the change of radial curvature of the optical lens. The farther away from the optical center, the larger the deformation of the image point moving along the radial direction. Radial distortion can be divided into barrel distortion, pillow distortion and beard distortion. Tangential distortion is caused by the fact that the lens itself is not parallel to the image due to the defects in the manufacture of the lens. Tsai[6] has proved that tangential distortion can be ignored for most computer vision applications, so only radial distortion is considered in this paper.

![Figure 2. Distortion principle diagram](image)

![Figure 3. Perspective collineation](image)

### 3. Distortion correction

#### 3.1. Perspective transformation principle

Two-dimensional perspective transformation is the projection of objects in three-dimensional space on two-dimensional plane, which is composed of translation transformation, affine transformation and rigid-body transformation. Finally, perspective transformation is formed[7-8]. From the point of view of E, the rectangle on plane \( P' \) is observed. When the line of sight reaches the P plane through the \( P' \) plane, there is perspective distortion between the rectangular \( A'B'C'D' \) and the new rectangular \( ABCD \) projected to the \( P \) plane because of the angle between the two planes. As shown in the Figure 3.

If the \( P \) plane is regarded as the front view plane of the object, then the \( P' \) plane can be seen as the plane of the camera to obtain the image. The perspective transformation is the process of transforming the image pixel on the \( P' \) plane into the corresponding pixel on the front view. In order to correct image distortion, the mathematical model of two-plane perspective transformation must be established.

\[
\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}
\]

(6)

(\( x, y \)) is the coordinate of the original image, and \((X, Y)\) is the coordinate of the transformed image.

The transformation matrix \( A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \) can be decomposed into four parts, \( \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \) for linear transformation, \( \begin{bmatrix} a_{31} \\ a_{32} \end{bmatrix} \) for translation, and \( \begin{bmatrix} a_{13} & a_{23} \end{bmatrix}^T \) for perspective transformation. Use \((X', Y', Z')\) to represent a point on the image:

\[
X' = \frac{X}{Z} = \frac{a_{13}X + a_{12}Y + a_{13}}{a_{31}X + a_{32}Y + a_{33}}
\]

(7)

\[
Y' = \frac{Y}{Z} = \frac{a_{21}X + a_{22}Y + a_{23}}{a_{31}X + a_{32}Y + a_{33}}
\]

(8)
Make $a_{33} = 1$, eight equations can be obtained by four points, and the transformation matrix can be solved.

\[
\begin{bmatrix}
 x & y & 1 & 0 & 0 & -x'X' & -X'y' \\
 0 & 0 & x & y & 1 & -x'Y' & -y'Y' \\
 \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
 \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
 \end{bmatrix}
\begin{bmatrix}
 a_{11} \\
 a_{12} \\
 a_{13} \\
 \vdots \\
 \vdots \\
 \vdots \\
 \end{bmatrix}
= 
\begin{bmatrix}
 X' \\
 Y' \\
 \vdots \\
 \vdots \\
 \vdots \\
 \end{bmatrix}
\tag{9}
\]

Therefore, determining the position of these four pairs of control points is very important for the realization of perspective transformation. In this paper, the method of Hough transform is used to detect straight lines and simultaneous linear equations, so as to determine the four corners of detecting lines intersecting as control points. Then, the coordinate position of the control point in the corresponding face view diagram is also determined. In engineering application, it is hoped that the corrected image can keep up with the size of the actual photographed image as much as possible.

3.2. Distortion correction flow

In this paper, the principle of perspective transformation is used for image correction, the process of the algorithm is shown in the following Figure 4:

![Figure 4. Algorithm flow](image)

Firstly, the original image is inputted, secondly, the line is detected based on the principle of Hough transform, and then the original image control point is determined according to the line intersection, then the improved orthographic coordinate is defined as the control point. Then, according to the perspective transformation principle, four groups of points are brought into the equation to obtain the transformation matrix. Finally, the transformation matrix is applied to the preprocessed original distortion image to achieve distortion correction.

4. Experiment and result analysis

4.1. Camera calibration

In a uniform light environment, the same camera is used to shoot the calibration from different angles. Camera calibration uses an application program of MATLAB, to calibrate the camera. And the camera internal parameter matrix and distortion vector are obtained as follows:

\[
M = \begin{bmatrix}
330.21 & 0 & 167.79 \\
0 & 377.06 & 226.16 \\
0 & 0 & 1 \\
\end{bmatrix}, \quad \text{distortion vector} = [0.1794 \quad -0.3893].
\]

4.2. Distortion image correction

The method presented in this paper is compared with the calibration method of MATLAB toolbox. The comparison between the original distorted image and the corrected image is shown in the Figure 5. So the method proposed in this paper is used to carry on the simulation experiment in the MATLAB environment. The contrast between the original distorted image and the corrected image is shown in Figure 6.
It can be seen from the image of the correction effect that the correction effect of this method is obviously better. Based on the quantitative analysis of the experimental error results, the correction algorithm uses 10 valid images from 20 images, and gets the average pixel error of each effective image as shown in Table 1.

We can obtain that the average error of pixels in the calibration results of this algorithm is about $S = 0.1897$. Under the same conditions, the average pixel error of the calibration results of the MATLAB camera is $S' = 0.58$. It can be seen that the image correction method proposed in this paper can correct the distorted image better, and the error is smaller and the accuracy is higher.

| Image number | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
|--------------|----|----|----|----|----|----|----|----|----|----|
| Pixel average error | 0.3697 | 0.2113 | 0.0986 | 0.0911 | 0.1256 | 0.2458 | 0.1796 | 0.1642 | 0.2017 | 0.2103 |

### 4.3. Distorted traffic sign image correction

Due to the camera shooting angle problem, traffic signs have different degrees of deformation. To solve this problem, the principle of perspective transformation is used to correct the image. Through the actual collection of a large number of traffic signs pictures for the experiment, the correction results are shown in the Figure 7.
In order to reflect the improvement of traffic sign recognition rate after image correction, the original image and the corrected image are recognized in this paper. The image recognition environment adopts the image recognition module in Baidu AI open platform, and the recognition rate of traffic signs is obtained by analyzing, as shown in the Figure 8.

In this experiment, 10 images with traffic signs were selected for recognition, and the recognition probability of traffic signs before and after correction was counted as shown in table 2.

| Image number | 01   | 02   | 03   | 04   | 05   | 06   | 07   | 08   | 09   | 10   |
|--------------|------|------|------|------|------|------|------|------|------|------|
| Original image | 0.275 | 0.534 | 0.471 | 0.257 | 0.562 | 0.478 | 0.395 | 0.296 | 0.588 | 0.584 |
| Corrected image | 0.677 | 0.696 | 0.652 | 0.493 | 0.764 | 0.706 | 0.688 | 0.553 | 0.690 | 0.759 |

Through data comparison, the average recognition rate increased by 0.224%. It is proved that the correction algorithm proposed in this paper is of great significance to the improvement of image recognition accuracy in the process of intelligent driving and lays a foundation for the follow-up research of self-driving.

5. Conclusion
In this paper, the principle of image distortion and the type of distortion are analyzed, and the camera imaging model and camera internal and external parameters are studied. According to the principle of
perspective transformation, the control point is selected, and the distortion image correction is realized by applying the transformation matrix to the global image. A series of simulation results show that the method proposed in this paper solves the problem of image distortion, and the method in this paper is obviously better than the calibration result of MATLAB toolbox. Finally, the algorithm is applied to traffic sign recognition, and the result shows that the recognition rate is improved. It shows the effectiveness of this method and has certain application value for intelligent driving to obtain road environment information.

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