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Mathematical model of nonlinear distortion and linear error correction for soccer robot vision system

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ABSTRACT

For the soccer robot vision system this paper conducts distortion and error analysis, for the linear part and non-linear part of the system' distortion and error it conducts the principle research, uses the geometric similarity theory to establish a linear error correction model, uses the K value selected and the least squares principle to establish the nonlinear distortion correction model, and then uses the linear error correction model and nonlinear distortion correction model in this text to correct the coordinate values for soccer robot vision system. The results show that the kicked rate after a simple linear error correction has increased 18.04% than that before correction, the kicked rate after a simple linear distortion correction has increased 14.32% than that before correction, the kicked rate after composition of linear error correction and linear distortion correction has increased 30.77% than that before correction, showing that the effect of simple linear error correction is stronger than that of simple nonlinear distortion correction, but the superimposed correction effect is the best.

KEYWORDS

Visual system;
Linear error;
Nonlinear distortion;
Least squares method;
Kicked rate.

INTRODUCTION

For vision-based soccer robots, vision subsystem is the sole information source of decision-making subsystem. Its main task is to collect real-time image of the competition venue, and then automatically process, analyze and understand the images. Thus obtain the location, movement direction, speed and other information of the field's moving objects (the robot car, the ball of both sides), and this information is provided to the decision-making subsystem for analysis and decision-making. Vision subsystem as the testing organization of the whole soccer robot system is its "eyes." Therefore, the accuracy of the soccer robot vision system greatly affects the process and results of the game, which is necessary for the error correction of the visual system.

The visual system is very important in the development of the robot, similarly also the requirements in the ball game are relatively high. For the accuracy research of the visual system and its error correction many people have made efforts and it constantly updates accompanied by the continuous increasing of robotics technology. The vision system of soccer robot is consisting of the camera placed above a certain height of the football court and related hardware. Its task is to rapidly gather and process the game image by a certain cycle, then sent the processing results to the decision-making system, but in the practical application of the visual system the image distortion will appear.

In this paper, on the basis of previous research, it introduces the linear error and nonlinear distortion of the soccer robot vision system and for the two types of errors establishes a corresponding correction model, and finally applies the two correction algorithms to the practical game to verify the kicked rate after correction.

CORRECTION MATHEMATICAL MODEL OF THE VISUAL SYSTEM

Soccer robot vision system will appear distortion and error. The error of soccer robot vision system is divided into linear error and nonlinear error. Linear error means that the vision image has geometric similarity, while nonlinear error lost the geometric similarity which is called as distortion. Here we analyze the linearity error and nonlinear distortions for the image, study its correction methods, and establish the mathematical model.

Linear error analysis of the visual system

Soccer robot vision system usually obtains a two-dimensional flat image by using a camera. If it is often difficult to achieve the accurate coordinates of the three-dimensional target based on the flat image, but the field size, camera height and the geometry size of the other targets are known, so you can get accurate coordinates of the target through these known geometry sizes.

As shown in Figure 1, MN means the ball courts, P indicates the location of the camera, Q indicates the project point of P in court MN, $ABA'B'$ means the robot car; point E' means the projection of central point E of the robot car's upper plane on the court MN, which represents the actual position of the car body; point E'' means the projection of point E' along the ray PE on the court, namely the location of the car that the host gets by the image.

Figure 1 shows, there is an error between the position obtained by the host machine and the actual position. The obtained coordinate of E in the image treating process is, the position coordinates of the actual point is E'', thus we can see that the error in the direction of E' pointing Q is $E''E'$, and formula (1)can be obtained by a similar principle:

$$\frac{PQ}{QE''} = \frac{EE'}{E'E''} \qquad (1)$$

Thus obtain $E''E'$ shown by the formula (2) below:

$$E''E' = \frac{QE'' \times EE'}{PQ} = 0.03QE'' \qquad (2)$$

In Formula (2) $EE' = 7.5, PQ = 250$, **when the robot soccer has the largest distant from the court, we have the maximum.**

Similarly, the actual coordinates of the ball also have errors, i.e. $E_1''E_1' = 0.00852QE_1''$ in Figure 1; when the ball has the farthest distant from the site $E_1''E_1'$ reaches the maximum $E''E'$.

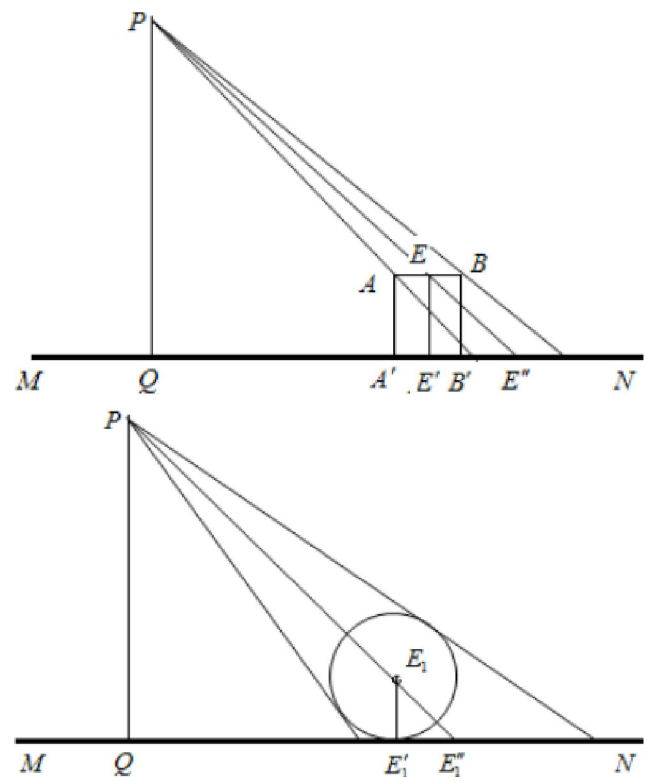

Figure 1 : Linear coordinate error

When $E''E'$ and $E_1''E_1'$ reach the maximum value at the same time, it may result in consequences that the robot cannot kick the ball.

Linear error correction model

Based on the linear error analysis of the visual system, the error will appear a fatal error that cannot kick the ball at a certain moment, so correction on it is necessary.

By the captured image the coordinates (x_0, y_0) of point Q can be obtained, the coordinates of the center point E of the robot is $E''(x_1, y_1)$, and EE'' because is much smaller than PE we can draw formula (3):

$$QE'' = QE' = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2} \qquad (3)$$

The direction angle $\cos\alpha, \cos\beta$ can be concluded as formula (4) below:

$$\begin{cases} \cos\alpha = \dfrac{x_1 - x_0}{QE'} \\ \cos\beta = \dfrac{y_1 - y_0}{QE'} \end{cases} \qquad (4)$$

Combing formula (2) (3) (4) we can be obtain the current real position of soccer robot as formula (5) below:

$$\begin{cases} x_1' = x_1 - E'E''\cos\alpha = x_1 - 0.03QE'\cos\alpha \\ y_1' = y_1 - E'E''\cos\beta = y_1 - 0.03QE'\cos\beta \end{cases} \qquad (5)$$

Similarly, the ball's correction method is same as above.

Nonlinear distortion analysis of the visual system

Nonlinear distortion is mainly caused by barrel-shaped distortion of the wide-angle lens. Because football court is relatively larger to other sports venues, which is more difficult to meet the paraxial conditions, therefore the image magnification of various parts refracted by a lens is not identical to the extent that the object and the image lost the geometric similarity. In addition, wide angle lens consist of a group of lens, and the curvature of each lens has an error, so that the center axis cannot completely overlap, this can also cause distortion of the visual system; when the edge portion of the image is enlarged and less than the central portion is known as negative distortion, otherwise it is known as positive distortion.

Nonlinear distortion correction model

The mathematical description of the distortion is shown in formula (6) below:

$$\begin{cases} \Delta x_r = kx(x^2 + y^2) \\ \Delta y_r = ky(x^2 + y^2) \end{cases} \qquad (6)$$

In Formula (6), (x, y) means the plane's coordinate in no distortion case, Δx_r indicates the distortion amount in the x axis direction, Δy_r indicates the distortion amount in the y axis direction, thus we can obtain the coordinates (x_d, y_d) of the distortion image plane as shown in the formula (7):

$$\begin{cases} x_d = x + kx(x^2 + y^2) \\ y_d = y + ky(x^2 + y^2) \end{cases} \qquad (7)$$

In formula (7) when $k > 0$, it is positive distortion, when $k < 0$, it is the negative distortion.

Based on the above analysis, we can achieve the correction of the coordinate by selecting k; if the selected k is appropriate, it can be very easy to straight the bent line and the correction effect is good.

Using the method of least square fitting to conduct distortion correction, which means mapping the point before correction to the given point by a certain mapping tables through selecting the control point; if (x, y) is any point of the image before the correction, the corresponding point of the image after correction is, the relationship between the two coordinates is in the formula (8) below:

$$\begin{cases} x = \sum_{i=0}^{n}\sum_{j=0}^{n-i} a_{ij}u^i v^j \\ y = \sum_{i=0}^{n}\sum_{j=0}^{n-i} b_{ij}u^i v^j \end{cases} \qquad (8)$$

In Formula (8), n means the degree of the polynomial, a_{ij}, b_{ij} means the coefficients of the polynomial. In order to obtain coefficients a_{ij}, b_{ij}, first select the L pairs of control points (u_1, v_1), $(x_1, y_1), (x_2, y_2), (u_2, v_2), \ldots, (x_L, y_L), (u_L, v_L)$, in accordance with the principle of least squares make the sum of squared error the minimum, then the formula (9) satisfies formula (10):

$$\begin{cases} \varepsilon_x = \sum_{i=1}^{L}\left(x_L - \sum_{i=0}^{n}\sum_{j=0}^{n-i} a_{ij}u^i v^j\right) \\ \varepsilon_y = \sum_{i=1}^{L}\left(y_L - \sum_{i=0}^{n}\sum_{j=0}^{n-i} b_{ij}u^i v^j\right) \end{cases} \qquad (9)$$

$$\begin{cases} 2\dfrac{\partial\varepsilon_x}{\partial a_{ij}}\sum_{l=1}^{L}\left(\sum_{i=0}^{n}\sum_{j=0}^{n-i} a_{ij}u^i v^j - x_l\right)u^i v^j = 0 \\ 2\dfrac{\partial\varepsilon_y}{\partial b_{ij}}\sum_{l=1}^{L}\left(\sum_{i=0}^{n}\sum_{j=0}^{n-i} b_{ij}u^i v^j - x_l\right)u^i v^j = 0 \end{cases} \qquad (10)$$

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TABLE 1 : The football kicked rate comparison table before and after correction

Status	Statistics kicked times	Kicked times	Kicked rate
Before the correction	120	61	50.83%
	120	83	69.17%
	120	65	54.17%
	120	70	58.33%
	120	72	60.00%
	120	87	72.50%
	120	83	69.17%
	120	74	61.67%
	120	76	63.33%
	120	83	69.17%
After linear error correction	120	95	79.17%
	120	79	65.83%
	120	77	64.17%
	120	95	79.17%
	120	93	77.50%
	120	76	63.33%
	120	97	80.83%
	120	80	66.67%
	120	99	82.50%
	120	99	82.50%
After nonlinear Distortion correction	120	91	75.83%
	120	80	66.67%
	120	89	74.17%
	120	95	79.17%
	120	77	64.17%
	120	84	70.00%
	120	91	75.83%
	120	83	69.17%
	120	78	65.00%
	120	94	78.33%
After Superimposed correction	120	104	86.67%
	120	102	85.00%
	120	101	84.17%
	120	104	86.67%
	120	102	85.00%
	120	91	75.83%
	120	92	76.67%
	120	90	75.00%
	120	98	81.67%
	120	102	85.00%

Then use these obtained coefficients to map the required point to the calibration point, thus the principle of least squares and non-linear distortion correction results can be realized.

EMPIRICAL ANALYSIS

Assumed conditions

1) The data collected in this article is the five on five matches in MiroSot;
2) The height of the camera is 250cm;
3) The venue is a 180cm × 220cm rectangle;
4) Soccer robot is a 7.5cm × 7.5cm × 7.5cm cube;
5) The diameter of the tiny ball is 4.27cm.

The data comparison before and after the correction

Based on the above analysis we know the error correction principle of soccer robot vision system, in accordance with the error correction method conduct the coordinate values ’ correction of soccer robot vision system for the game, obtain the football kicked rate before correction and after linear error correction, the football kicked rate before correction and after non-linear distortion correction, and the football kicked rate before correction and the superposition of linear error correction and nonlinear distortion correction, and the data acquisition is shown in TABLE 1:

TABLE 1 shows the average kicked rate before the correction is 62.83%, the average kicked rate after linear error correction is 74.17%, the average kicked rate after non-linear distortion correction is 71.83%, and the average kicked rate after superimposed correction is 82.83%.

CONCLUSIONS

Data from the paper shows that the kicked rate after a simple linear error correction has increased 18.04% than that before correction, the kicked rate after a simple linear distortion correction has increased 14.32% than that before correction, the kicked rate after composition of linear error correction and linear distortion correction has increased 30.77% than that before correction, showing that the effect of linear error correction is stronger than that of nonlinear distortion correction, and the superimposed correction effect is the best.

The average kicked rate by the correction method in this paper is significantly better than that before correction; The effect of linear error correction to some extent is better than the effect of nonlinear distortion correction, indicating the linear error accounts for bigger proportion in the overall distortion; The effect of two superimposed correction methods is obviously better than a simple error correction, indicating the linear error and nonlinear distortion of the image also accounts for certain part of proportion.

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