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Research on Camera Calibration in Football Broadcast Videos

Shouzhong Zhang

Physical Education Department, Harbin Engineering University,
Harbin 150000, China
Zhangshouzhong03@163.com

Abstract

A novel continuous camera calibration algorithm is proposed, which can address the calibration for non-goal area of soccer video. By considering the fact that the position of main camera is stable, a novel continuous camera calibration algorithm is proposed for soccer video analysis. There are two stages for calibration: the first stage addresses the calibration only for goal area and the position of camera is computed and recorded, and then the second stage can address calibration for any area including non-goal area where the camera position is given at first stage. Thus, the proposed algorithm can address the calibration for non-goal area of soccer video, which cannot be addressed by traditional calibration algorithms since the inadequate of calibration objects.

Keywords: *Video content analysis, Soccer videos, Tactic analysis, Camera Calibration*

1. Introduction

The semantic analysis of physical sports videos featuring with football videos is always research focus. Of it, one important task is to extract low-level features which are helpful for semantic parsing. Football match broadcast videos are recorded generally by one camera. In the course of shooting, the camera usually needs simple and continuous adjustment as to capture highlights in the competition. Camera alignment can be depicted by the variations of the involved parameters, for example, horizontal rotation of camera being expressed by Pan parameters; vertical rotation by Tilt parameters and focal distance setting by Zoom parameters. Changes of all those parameters contain plenty of information, which can be used as low-level features for semantic parsing [1-5].

Recently, some algorithms have been developed to deal with mid-court area scenes by using kick-off circle as marker [6-8]. For the scenarios of midfield area in the football videos, Luo [9-10] demarcated it with the information of kick-off circle, centerline and two end lines. The method required sufficient information of midcourt line. Zha [11] made use of vanishing points to calibrate with the help of only kick-off circle and incomplete centerline. However, the two algorithms need complete information of kick-off circle and are highly complicated. For numerous scenes in the midcourt area, front court area and sideways area in match videos, both methods are incapable to reach accurate calibration of the camera [12-13].

For the above reason, the paper introduces a new method to fetch adequate calibration information based on a new football field model and the related mark line pick-up algorithms. Then with full advantage of the Priori knowledge that the camera's physical location is unchanged, it develops a two-stage camera calibration method. In the first stage, it uses existing DLT method to calculate the coordinate of camera location; then in the second stage, it employs the coordinate to simplify camera projection equation. Instead of computing homography matrix, it uses directly Levenberg-Marquardt (LM) nonlinear algorithm to get camera parameters [14]. Since in the second stage camera location parameters are known, those pending for calibration are becoming fewer and thus the number of required markers are reducing. The calibration is effected only when there are

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only two fixing points. The proposed method is simple and efficient, appropriate for real-time computation.

2. Camera Calibration in Non-goal Mouth Areas

2.1Football Pitch Model with Offside Auxiliary Lines

The premise for the court calibration system is to create a football pitch model. At present, the common model is based on court lines, which are composed of white lines like sidelines, base lines, major penalty area lines, minor penalty area lines and kick-off circle lines. But, for the image frames which don't have dense court lines, it's impossible to calibrate with court lines. With upgrading of football ground, modern playfields provide other information apart from court lines, such as offside auxiliary lines helping referees determine if there is offside position (see joint lines between medium grey area and white area in Figure 1). With those marking lines (like court lines and offside auxiliary lines) containing distinctive semantic information, we develop a more subtle court model, a model with offside auxiliary lines (Figure 1).

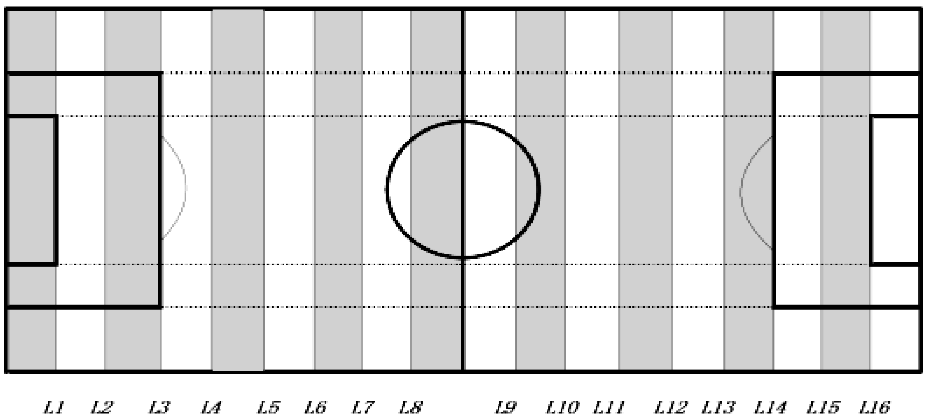


Figure 1. Football Field Model with the Offside Auxiliary Line

2.2. Camera Model and DLT Calibration Algorithm

Camera shooting is actually a projection process from the world coordinate system to image coordinate system, as shown in Figure 2.

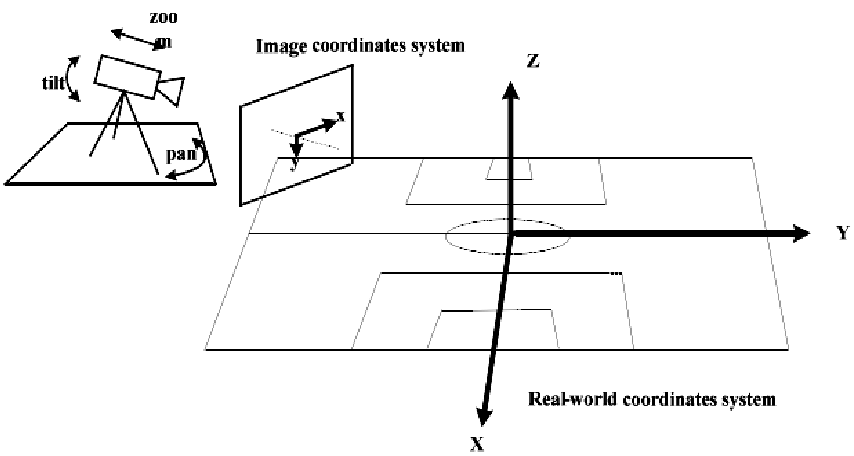


Figure 2. The Relationship between the Camera and the Projection Coordinates

Set the world coordinate of the calibration point $O = (X_w, Y_w, Z_w)^T$, it is in the image coordinate system for point projection $o = (x, y)^T$. There is the following relationship:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \mu K [R \mid -RT] \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} with \ K = \begin{bmatrix} pf & s & x_0 \\ & f & y_0 \\ & & 1 \end{bmatrix} \tag{1}$$

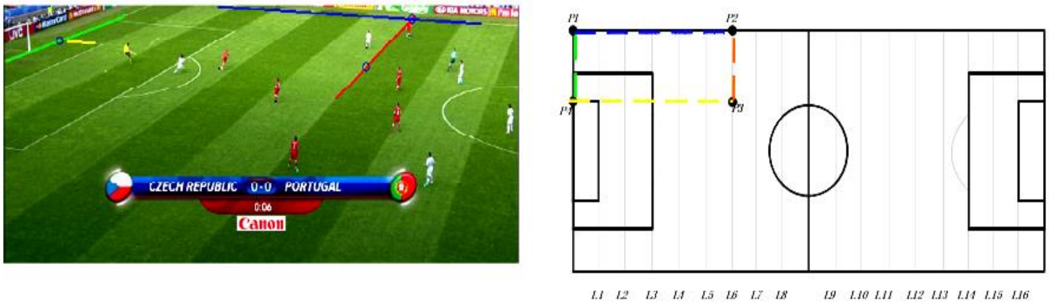
Where, ρ said aspect ratio, s said (skew), (x_0, y_0) said the main optical center, f said focal length, μ said scaling factor. $T = [T_x, T_y, T_z]^T$ is the translation vector of world coordinate system and camera coordinate systems, R is a rotation matrix of world coordinate system and camera coordinate systems. The rotation matrix can also use the Euler angle representation.

$$R = [r_1 \ \ r_2 \ \ r_3] = \begin{bmatrix} \cos(\beta)\cos(\gamma) & \sin(\alpha)\sin(\beta)\cos(\gamma) - \cos(\alpha)\sin(\gamma) & \cos(\alpha)\sin(\beta)\cos(\gamma) + \sin(\alpha)\sin(\gamma) \\ \cos(\beta)\cos(\gamma) & \cos(\alpha)\cos(\gamma) + \sin(\beta)\sin(\alpha)\sin(\gamma) & \cos(\alpha)\sin(\beta)\sin(\gamma) - \sin(\alpha)\cos(\gamma) \\ -\sin(\beta) & \cos(\beta)\sin(\alpha) & \cos(\alpha)\cos(\beta) \end{bmatrix} \tag{2}$$

For the football match, playground is a planar structure. So camera calibration can be seen as a matter of fixing a two-dimensional calibrator. As usual, we set fixing point $Z_w = 0$ based on the selection of world coordinate system. In general, we set main optic center (x_0, y_0) in the center of images. When only one image is used to make camera calibration, the hypothesis that $\rho = 1, s = 0$ is rational, because the actual precision of camera calibration is affected by those parameters far less than the coordinate errors of calibration points. So for a full consideration of both intrinsic and extrinsic parameters, we can use homography matrix H to represent the transformation of the world coordinate system to image system.

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \mu H \begin{bmatrix} X_w \\ Y_w \\ 1 \end{bmatrix} with \ H = \begin{bmatrix} f & & x_0 \\ & f & y_0 \\ & & 1 \end{bmatrix} [r_1 r_2 \mid -RT] \tag{3}$$

DLT calibration algorithm calculates homography matrix H with least squares algorithm according to the world coordinates O = X Y i = N and image coordinates o = x y i = N of N calibration points; then it decomposes H to acquire seven parameters of the camera. Apparently, in order to get homography matrix H, DLT calibration method requires the coordinate data of at least four fixing points and they are not collinear. Like shown in Figure 3, it needs only to detect such four court lines as red, blue, yellow and green line to obtain four calibration points (P). Because of those requirements, DLT calibration method is limited to some extent for the application for football video calibration. To be specific, for long shots in non-goal mouth areas and most medium shots, there may be no four calibration points or such points are collinear (Figure 4), as a result, the calibration can’t be effected.



(a) Calibration Field Lines in the Image (b) Calibration Field Lines in the Field Model

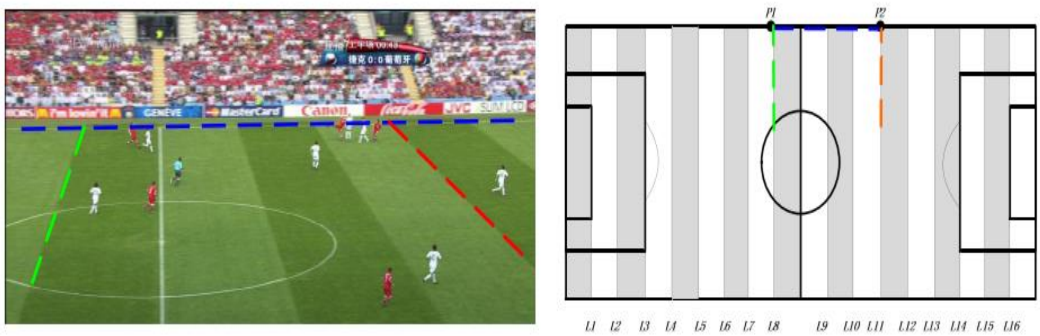
Figure 3. Four Field Lines of Goal Area Wire and Four Point

2.3. Pan-tilt Camera Calibration Algorithm (PCC)

Long shots in the football match videos are taken by one main camera, which is the primary source for us to acquire information regarding camera calibration and player tracking. The position of main camera is standstill in the course of the competition. Normally, the camera is fixed in one place on the rostrum, being set to make movements like pan, tilt rotation and zoom. Therefore it's fine to use Pan-tilt model to describe camera adjustment.

Set calibration point $O = (X_w, Y_w)^T$. The image coordinates in the i of the image is $o = (x, y)^T$. The equation can be listed as follows

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \mu_i \begin{bmatrix} f_i & & x_0 \\ & f_i & y_0 \\ & & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\beta_i) & \sin(\alpha)\sin(\beta_i) & -(\cos(\beta_i)T_x + \sin(\alpha_i)\sin(\beta_i) + \cos(\alpha_i)\sin(\beta_i)T_z \\ 0 & \cos(\alpha_i) & -(\cos(\alpha_i)T_y - \sin(a_i)T_z \\ -\sin(\beta_i) & \cos(\beta_i)\sin(\alpha_i) & -(\sin(\beta_i)T_x + \sin(\alpha_i)\cos(\beta_i)T_y + \cos(\alpha_i)\cos(\beta_i)T_z \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ 1 \end{bmatrix} \quad (4)$$



(a) Calibration of Field lines in the Image (b) Calibration field lines in the filed model

Figure 4. Three Field Lines of Non-goal Area and Two Point

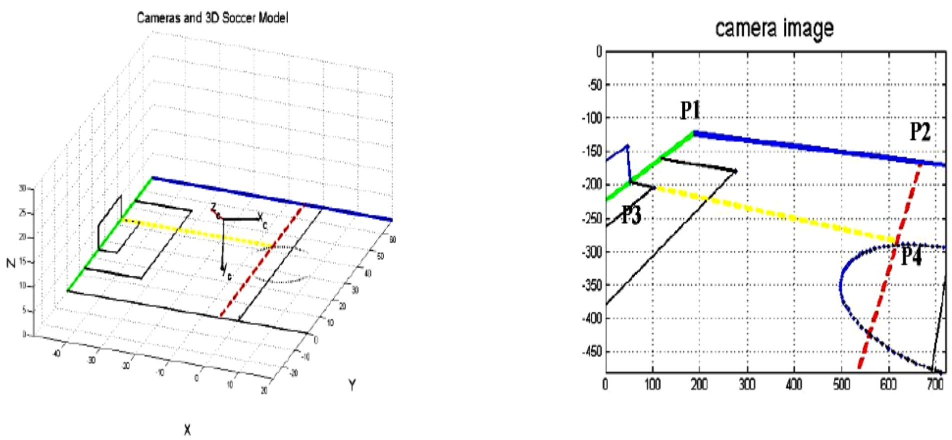
That means when the camera position parameter (T_x, T_y, T_z) is known, the unknown parameters are reduced to 3 (f, α, β) with scaling factor μ . Then we can realize the calibration with the use of coordinate information of only two calibration points. We call it Pan-tilt camera calibration algorithm, PCC in short. In Figure 4, we only need to detect red, blue and green line to have two calibration points. Hence, the method is capable to cope with camera calibration in the non-goal mouth areas. With calibration points lessening, it's not probable to acquire camera's homography matrix H only based on two calibration points and thus unable to get the closed-form solution of camera parameters. In this case, we adopt LM algorithm to solve equation (4).

3. Experiment Results and Discussion

The proposed camera calibration method has two stages, with the second stage based on PCC method, which is key to our method. Next we make tests with comprehensive data to examine the accuracy and robustness of PCC, as well as PCC dependence on camera status.

3.1 Robustness Comparison between PCC and DLT

To find out by what factors the method calibration accuracy is much affected, we should make tests with comprehensive data. Specifically, by using the camera shooting process of 3-dimensional scenes, we can simulate camera imaging procedure with the aid of computer. The imaging is sensitive to camera parameters. By setting different camera parameters, we can get different simulation camera images. In accordance to FIFA rules, we set football field model 99×68 meter. The camera position parameter is known as ($T_x = 5, T_y = 60, T_z = 30$) meters; with f=1000 pixels, tilt rotation angle α = 100°, pan rotation angle β = 38°. The image resolution is 720×480. The model is displayed in Figure 5: (a) the position of the field model and camera in the 3-dimensional world coordinate system (X-Y-Z), where (Xc-Yc-Zc) refers to camera coordinate system; (b) camera images generated by computer simulation when camera parameters are given.



(a) Three-dimensional Real Scene (b) Camera

Figure 5. Diagram of Generating Synthetic Data of DLT and PPC Algorithm Performance Analysis

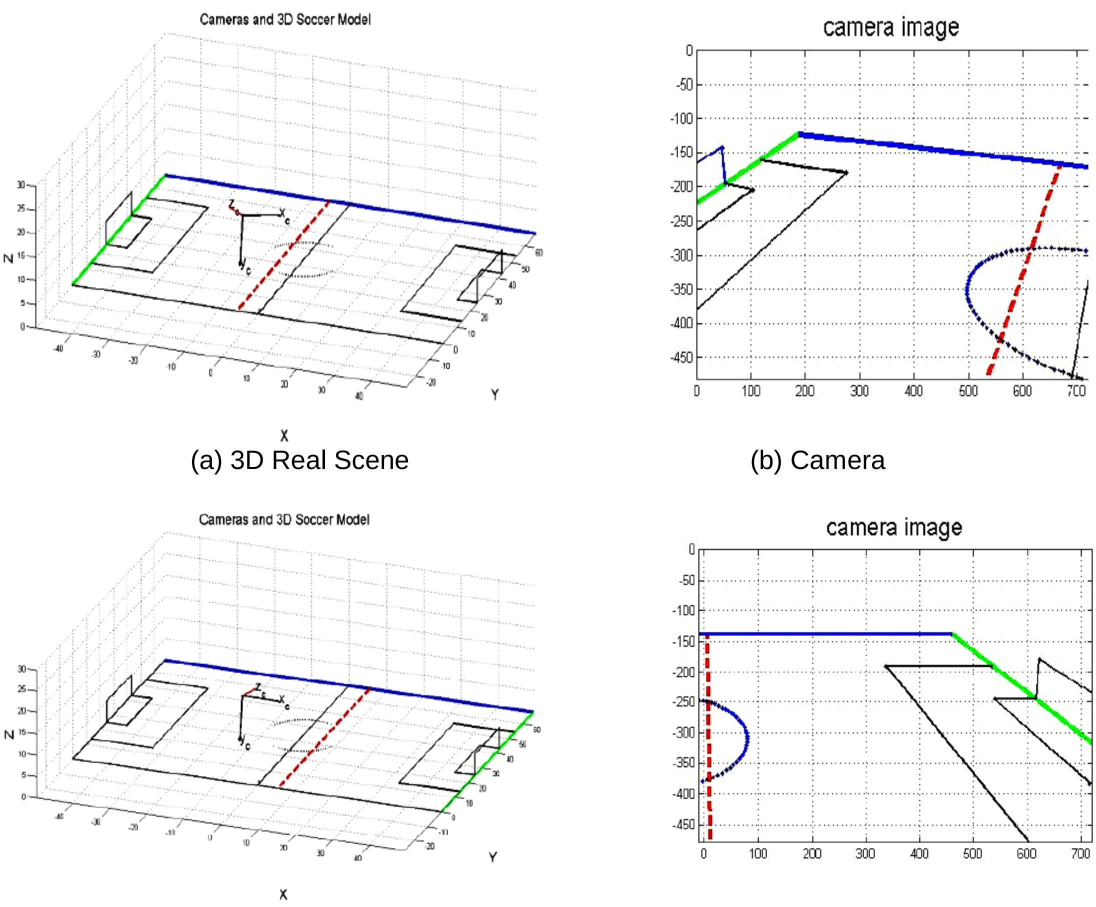
DLT algorithm requires at least four points to execute the calibration. PCC method requires only two calibration points for that purpose. For a full consideration, we examine the performance of PCC when there are two and four points and that of DLT when there are four calibration points. For DLT, we choose green, blue, yellow and red line in picture x. The four lines' intersection point $P_1 : (X_w = -49.5, Y_w = 34)$, $P_2 : (X_w = -5.5, Y_w = 34)$, $P_3 : (X_w = -49.5, Y_w = 25)$, $P_4 : (X_w = -5.5, Y_w = 25)$ is used as calibration point. For PCC, we choose far-distance P_1 and P_2, which are both used as calibration points; and P_1,

P_2 , P_3 , P_4 , which are all used as calibration points. The four points are relatively dispersing, good for us to get satisfactory calibration precision.

3.2 PCC Method's Dependence on Camera Status

During the football competition, the camera makes pan-tilt-zoom movements in a continual way. So the related calibration algorithm needs to accommodate all camera movements. Now we need examine the calibration effect of PCC method when camera is of different statuses (i.e. f , a , β are changing).

Firstly, we validate the performance when the camera makes pan movements. Still we make simulation tests. In Fig. 6, (a) and (c) both show the positional relationship between football field model and the camera in the world coordinate system (X-Y-Z), where, (Xc-Yc-Zc) is camera coordinate system; except of different pan angles (β =0, 30), other camera parameters in the two scenes are same with the above experiment; (b) and (d) shows respectively camera images generated by computer simulation when all camera parameters are given. For different scenes and camera images, the observable court lines are not similar. So the court line and calibration points should be selected according to changing scenes. PCC method needs three or more court lines (or two/more calibration points) to perform the calibration. Green, blue and red line in the figure represents calibrated court line in different scenes.



(a) 3D Real Scene (b) Camera

(c) 3D Real Scene (d) Camera

Figure 6. Diagram of Comprehensive Data under Different Pan

When the coordinates of calibration points are affected by Gaussian noises, and camera pan angle β is separately 0, 10, 20, and 30 degrees, camera parameter errors are subject to calibration point errors. For the noise of different intensity, we perform 500 tests to calculate the mean value and variance of respective f, α and β (Figure 7). The result suggests that the mean values of zoom f and two rotation angles α and β are not associated with noise intensity; their calibrated variances aggrandize along with increased camera position variance, which occurs in a consistent manner. To sum up, PCC method is less affected by the camera status and can calibrate the frame sequence recorded by the camera under different states.

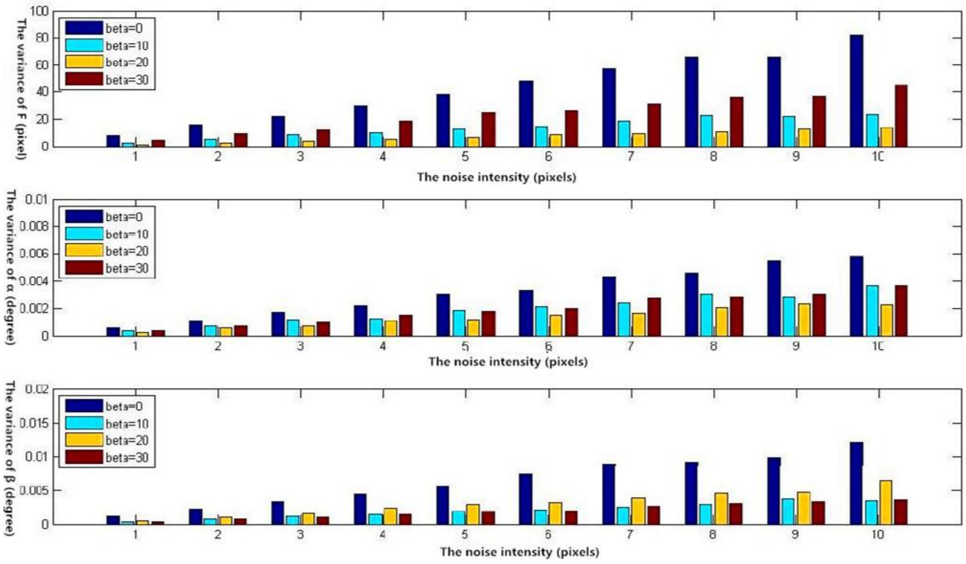


Figure 7. On the Pan of Camera Angle Dependent in PCC Algorithm

Secondly, we prove the calibration performance under different zoom movements. When calibration point coordinate is affected by Gaussian noises and zoom f is respectively 500, 1000, 1500 and 2000 pixels, camera parameter errors are influenced by calibration point coordinate errors. For the noise of different intensity, we perform 500 tests as to estimate the mean value and variance of respective f, α and β. Results are shown in Figure 8. It's observed that the mean values of all three parameters are not correlated with noise intensity; their calibration variances become bigger with increased calibration point coordinate variances, with f's increased variance independent from the focal distance. However, if the focal distance becomes longer, variances of α, β tend to grow slowly. That is because the bigger the zoom f is, the distance of the image coordinate of calibration points becomes longer, with weaker noise interference and smaller calibration errors. So we can learn that the calibration performance for bigger f is better than for smaller f.

4 Conclusions

In the football broadcast videos, there are plentiful non-goal mouth scenarios like midcourt or front court or sideways. Owing to inadequate calibration information, the existing algorithms are not able to realize accurate calibration of the camera. To solve the problem, it introduced a two-stage camera calibration method. The proposed method used a new pitch model and related court mark line pick-up algorithms. Then on that basis, it employed fully the information of the unchanged physical position of the camera in the ball match to accomplish the calibration when there are only two calibration points. The experiment was made with comprehensive data and confirmed that when the camera positional information is accurate, PCC is superior over DLT in terms of precision and robustness. Furthermore, PCC is less affected by the camera status. Also, despite the camera position has influences on the precision of PCC method, calibration errors are controlled in the second stage thanks to information accumulation in the first period.

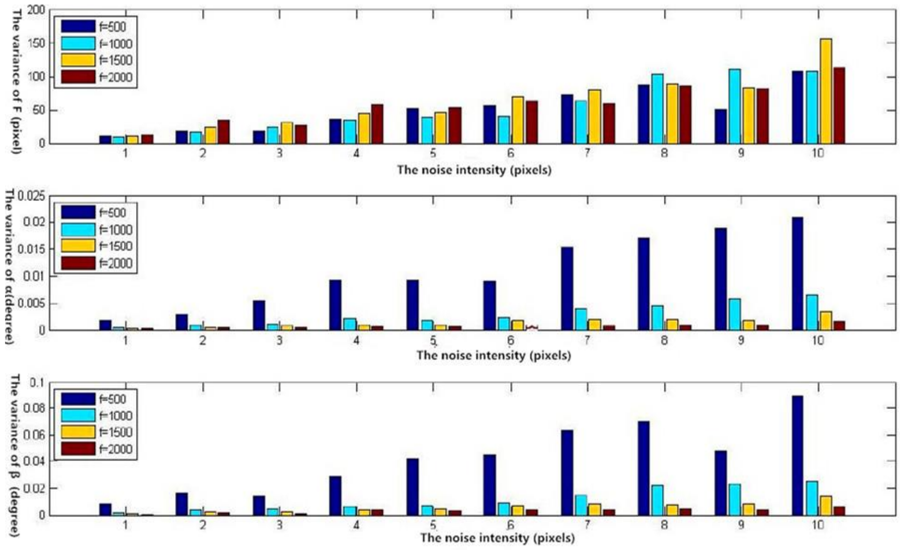


Figure 8. On the Camera Focal Dependent in PCC Algorithm

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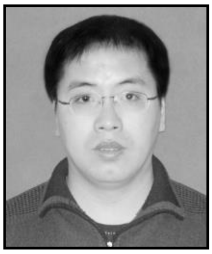

Shouzhong Zhang, he received his B.S degree in physical education from Jilin Institute of Physical Education. He received his M.S degree in physical education from Chengdu Sport University. He is a lecturer in Physical Education Department of Harbin Engineering University. His research interests include physical education and training.