Camera Pan and Tilt Estimation in Soccer Scenes Based on Vanishing Points

Vahid Babaee-Kashany
Machine Vision Research Laboratory
Ferdowsi University of Mashhad
Mashhad, Iran
V.babaee@gmail.com

Hamid Reza Pourreza
Machine Vision Research Laboratory
Ferdowsi University of Mashhad
Mashhad, Iran
hpourreza@um.ac.ir

*Abstract***— Camera parameters estimation is an important issue in machine vision research area. This paper proposes a new method to find pan and tilt of camera in sport scene on the basis of vanishing points. Vanishing point (VP) of parallel lines is the image of the point at infinity, which corresponds to the projection of the intersection of parallel lines at infinity. According to projective geometry constraint, camera rotation of the projection matrix is computed directly by two vanishing points and pan and tilt of camera extracted from camera rotation matrix. Computer simulation data is carried out to validate our method.**

Keywords- Camera calibration, Soccer, Rotation matrix, pan, tilt, Vanishing points.

I. INTRODUCTION

Soccer is the most popular sport in the world with tremendous amount of video programs produced every year. Automatically analysing soccer videos, such as finding some exciting events for summarizing, is a hot research area which will help professionals to analyse teams' tactics, strengths and weaknesses. Many other researchers have investigated in this field and their researches' topics involve sport event detection, automatic sport video retrieval, augmented reality, virtual advertisement and referee assistant.

In order to calibrate camera, some reference points should be extracted from the given video frame. If the coordinate systems are known, camera calibration is done by solving an equation, whereas the correspondence between reference points in the image coordinates system must be found if coordinates are known.

The aim of this paper is to find the soccer camera pan and tilt parameters when a frame of soccer video is given. We proposed a method which uses geometry of soccer model to find the rotation matrix instead of doing an exhaustive full search over parameter space to find all camera parameters and decompose it.

In recent years, some researchers used correspond between lines to camera calibration. Yu and Jiang [1] proposed an offline method to find external and internal parameters on the basis of frame grouping and Hough like search. Farin et.al. [2], Battikh and Jabro [3] used court model and KLT[1] tracker to release fully automatic method, the last one used a hardware accelerator to achieve real time video content insertion.

Kim and Hong [4] also propose a calibration algorithm for soccer games based on a pan-tilt camera (without roll) but still the inter-frames transformation are estimated by identifying corresponding line between frames and using a non-linear approach to determine the homography matrix that minimizes the Euclidean distance between line pairs.

All these different methods for calculating the camera parameters and focusing area on soccer scenes have a similar characteristic, i.e., they require a number of corresponding points (at least 4 points) to determine the homography matrix for an image. Since the main camera of soccer playfield is free in panning, tilting and zooming, it cannot be guaranteed that every image has sufficient corresponding points. But here we assume that there is a fix focal length and also find variable camera parameters (pan and tilt) without any correspondence.

The rest of paper is organized in three sections: Geometry of vanishing point, Camera calibration using vanishing points, Experiments and Results.

II. GEOMETRY OF VANISHING POINT

A. Camera Model and the Concept of Vanishing Point

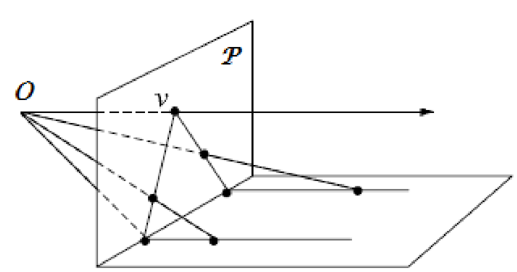

Fig 1. The line connecting the vanishing point with the optical center has the same direction with the corresponding lines in 3D space.

For the classic pinhole model, the basic formula of perspective projection is given by:

[1] Kanade-Lucas-Tomasi feature tracker

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$$\lambda_m . m = K.[R \quad T].M \tag{1}$$

Where:

M denotes a 3D point and m denotes the corresponding 2D point on image. They are both expressed in homogeneous coordinate and λ_m is an arbitrary scale factor.

R is 3 x 3 rotation matrix that describes the rotational mapping from the world coordinate system into the camera coordinate system.

T is a 3 x 1 vector that describes the translational mapping from the world coordinate system into the camera coordinate system.

K is a 3 x 3 matrix describing the internal camera parameters,

$$K = \begin{bmatrix} f & s & u_0 \\ 0 & f & v_0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Where f is scale factor in image u- and v- axes, s is the parameter describing the skew of the two images axes and (u_0, v_0) are the coordinates of the principal point.

As in Fig 1, for the perspective projection, the images of parallel lines meet at a point, if they are not parallel to the image plane. This point is called vanishing point [5]. Vanishing point of the line is the image of the point at infinity, which corresponds to the projection of the intersection of parallel lines at infinity. The line connecting the vanishing point with the optical center has the same direction with the corresponding line in 3D space [6]. That means all parallel lines in space correspond to the same vanishing point.

B. Geometry of Vanishing Point in Soccer Scene

As shown in Fig 2(a), the court model is made of two groups of parallel lines: vertical lines and horizontal lines. We assume that the origin of the world coordinate system coincides with point D and suppose l_1 and l_2 are Length and width of biggest rectangle respectively, and then the homogeneous coordinates of vertexes A, B, C and D are described as:

$$\begin{aligned} X_a &= (0, l_2, 0, 1)^T \quad X_b = (l_1, l_2, 0, 1)^T \\ X_c &= (l_1, 0, 0, 1)^T \quad X_d = (0, 0, 0, 1)^T \end{aligned} \tag{3}$$

The projective image of the court model is shown as in Fig 2(b). v_1 and v_2 correspond to vanishing points of axes X and Y respectively. The perspective relationship between v_1, v_2 and the corresponding 3D points are [5]:

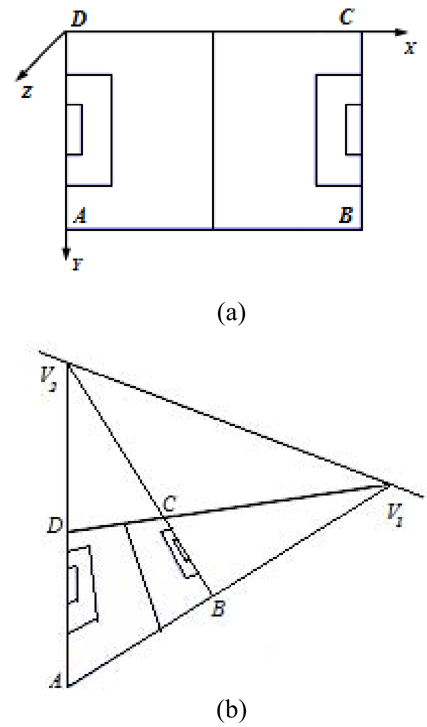

Fig 2. (a) Court model, (b) is perspective image in world coordinate

$$\lambda_1 . v_1 = K[R \quad T]\begin{bmatrix}1\\0\\0\\0\end{bmatrix} = K[r_1 \quad r_2 \quad r_3 \quad T]\begin{bmatrix}1\\0\\0\\0\end{bmatrix} = K.r_1 \tag{4}$$

$$\lambda_2 . v_2 = K[R \quad T]\begin{bmatrix}0\\1\\0\\0\end{bmatrix} = K[r_1 \quad r_2 \quad r_3 \quad T]\begin{bmatrix}0\\1\\0\\0\end{bmatrix} = K.r_2 \tag{5}$$

According to equations (4) and (5), the vanishing points are Independent from Length and width of rectangle.

Because the rotation matrix R is unitary and orthogonal [7], then we have

$$\begin{cases} r_i^T . r_j = 0 \\ \|r_i\| = \|r_j\| = 1 \end{cases} \quad (i \neq j) \tag{6}$$

From (4) to (6), the following equations are satisfied:

$$\lambda_2 K^{-T} v_2^T \cdot \lambda_1 K^{-1} v_1 = 0 \tag{7}$$

$$\left\| \lambda_1 . K^{-1} . v_1 \right\| = \left\| \lambda_2 . K^{-1} . v_2 \right\| = 1 \quad (8)$$

According to (6) and (7), the vectors $\lambda_1 . K^{-1} . v_1$, $\lambda_2 . K^{-1} . v_2$ are mutually orthogonal and have an equal modulus.

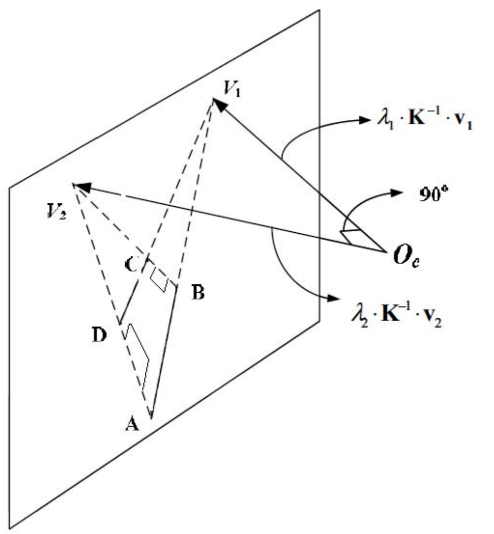

Fig 3. Geometric relationship between vanishing points in the camera coordinates system in sport scene.

As already noted, the line that connects the vanishing point with the optical center, has the same direction with the corresponding line in 3D space and as shown in Fig 3, two vectors Ov_1 and Ov_2 are perpendicular. Thus, these two vectors that is created by two vanishing points, can build a parallel plane to soccer play-field.

III. CAMERA CALIBRATION USING VANISHING POINT

A. *Using vanishing point*

Assume $P_{1\infty}$, $P_{2\infty}$ and $P_{3\infty}$ are three infinity point in direction of x, y and z axis of camera that created with a pair of orthogonal and parallel lines in the 3D space, and the corresponding vanishing points are p_1, p_2 and p_3 on the image plane. According to pinhole camera model, the relationship between the infinity points and their image projection is given by:

$$\begin{cases} \lambda_1 p_1 = K[R \quad T]P_{1\infty} \\ \lambda_2 p_2 = K[R \quad T]P_{2\infty} \\ \lambda_3 p_3 = K[R \quad T]P_{3\infty} \end{cases} \quad (9)$$

So from (1), (4) and (5) and under the assumption of known zero skew, the equation (9) can be rewritten as follows:

$$\begin{bmatrix} \lambda_1 u_1 & \lambda_2 u_2 & \lambda_3 u_3 \\ \lambda_1 v_2 & \lambda_2 v_2 & \lambda_3 v_3 \\ \lambda_1 & \lambda_2 & \lambda_3 \end{bmatrix} = \begin{bmatrix} f & 0 & u_0 \\ 0 & f & v_0 \\ 0 & 0 & 1 \end{bmatrix} R \quad (10)$$

Where, (u_1, v_1) is vanishing point of vertical line and (u_2, v_2) is vanishing point of horizontal lines, thus

$$R = \frac{1}{f} \begin{bmatrix} \lambda_1(u_1 - u_0) & \lambda_2(u_2 - u_0) & \lambda_3(u_3 - u_0) \\ \lambda_1(v_1 - v_0) & \lambda_2(v_2 - v_0) & \lambda_3(v_3 - v_0) \\ f\lambda_1 & f\lambda_2 & f\lambda_3 \end{bmatrix} \quad (11)$$

There are five unknown parameters and two vanishing points, so we must find some more equations in order to obtain the solution (we have focal length and principal point).

B. *Obtaining Third Vanishing Point*

According to relationship between vanishing vectors in 3D space, we can find third vanishing point from cross product of two other vanishing vectors [5].

The orthonormality of R(6) can be used to provide the following equation from (11):

$$(u_1 - u_0)(u_2 - u_0) + (v_1 - v_0)(v_2 - v_0) + 1 = 0 \quad (12)$$

$$(u_1 - u_0)(u_3 - u_0) + (v_1 - v_0)(v_3 - v_0) + 1 = 0 \quad (13)$$

$$(u_2 - u_0)(u_3 - u_0) + (v_2 - v_0)(v_3 - v_0) + 1 = 0 \quad (14)$$

Subtracting (14) from (12) and (13) gives:

$$\begin{cases} (u_1 - u_0)(u_2 - u_3) + (v_1 - v_0)(v_2 - v_3) = 0 \\ (u_2 - u_0)(u_1 - u_3) + (v_2 - v_0)(v_1 - v_3) = 0 \end{cases} \quad (15)$$

So, the third vanishing point is recovered.

C. *Obtaining* λ_i

In order to obtain a geometry interpretation of λ_i, row normality must be considered[8]. This gives:

$$\begin{cases} \left(\lambda_1^2(u_1 - u_0) + \lambda_2^2(u_2 - u_0) + \lambda_3^2(u_3 - u_0)\right)/f = 0 \\ \left(\lambda_1^2(v_1 - v_0) + \lambda_2^2(v_2 - v_0) + \lambda_3^2(v_3 - v_0)\right)/f = 0 \\ \lambda_1^2 + \lambda_2^2 + \lambda_3^2 = 1 \end{cases} \quad (16)$$

Subtracting third equation from two other one, gives:

$$\begin{cases} \lambda_1^2 = \dfrac{(v_0 - v_3)(u_2 - u_3) - (u_0 - u_3)(v_2 - v_3)}{(v_1 - v_3)(u_2 - u_3) - (u_1 - u_3)(v_2 - v_3)} \\ \lambda_2^2 = \dfrac{(v_1 - v_3)(u_0 - u_3) - (u_1 - u_3)(v_0 - v_3)}{(v_1 - v_3)(u_2 - u_3) - (u_1 - u_3)(v_2 - v_3)} \\ \lambda_3^2 = 1 - \lambda_1^2 + \lambda_2^2 \end{cases} \quad (17)$$

So, the λ_i is recovered.

D. Recovery of the Rotation Matrix

Now, in order to calculate camera rotation on world coordinate system, we placed lambdas and third vanishing point from (17) and (15) to equation (11). By decomposition of rotation matrix we can obtain rotation of camera, on camera coordinate system. Of course, this matrix actually describes a rotation of the world coordinate system (rather than the camera). But camera rotation matrix is equivalent to an inverse rotation of the world [9].

IV. EXPERIMENT AND RESULTS

A. simulations

The reliability and validity of our proposed approach has been tested by computer simulation data. The simulator camera parameter characterized by following properties: s=0, β=0, $(u_0, v_0) = (400,300)$ and the image resolution is 800×600. Our model parameters are l_1=10700cm and l_2=7400cm. In simulations, we fixed camera position in $T_c = [5350, 9620, -1440]^T$ and then changed camera pan and camera tilt (roll=zero).

As shown in Fig 4, we used three Images that are captured from computer simulator with various focal length and camera rotation angles. Then we found vanishing points and calculated rotation matrix and estimated pan and tilt of camera.

B. Finding vanishing points

The first step in camera calibration to recovery projection matrix is finding vanishing points.
For this purpose the Hough transform is used. Considering that the angle of horizontal lines in the main stadium camera always is between zero and 35 degree and the angle of vertical lines between 55 to ninety degrees, Hough transform selects two lines from among vertical lines and two lines among horizontal lines. Then by these two categories of parallel lines, vanishing points were calculated.

C. Rotation matrices

Finding the vanishing points, is the second step to recover the camera rotation matrix from (11), when (u_3, v_3) and λ_i are obtained by (15) and (17). To estimate the camera pan, tilt and roll, we use inverse decomposition of R_{zyx} instead of R_{xyz}.

D. Experiments

On the court model, 15% of points of each line are dropped. Gaussian noise with mean 0 and standard deviation ranging 0 to 4 pixels is added to each projected image point. For each noise level, we performed 100 runs and the results shown are average.

Fig 5 gives the standard deviations of camera rotation parameters. As shown in Fig 5, Noise effect on panning is greater than tilting. This is because of specific camera position in football stadium, and this results for that horizontal lines being smaller than vertical lines in projected image, so vanishing points which found by vertical lines have a higher sensitivity to noise rather than horizontal lines.

The results of external parameters are shown in Tab 1. Here the fisrt row describes the setup of camera rotation matrix and camera rotation vector in camera coordinate system. The averaged extrinsic parameters results of 100 runs at each noise level are shown from second to fifth row in table.

Fig 6 gives relationship between camera rotation error

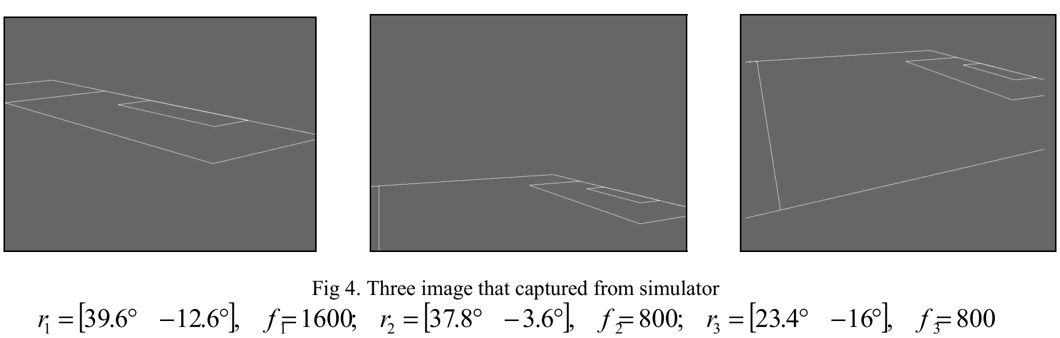

Fig 4. Three image that captured from simulator

$r_1 = [39.6° \quad -12.6°]$, f_1= 1600; $r_2 = [37.8° \quad -3.6°]$, f_2= 800; $r_3 = [23.4° \quad -16°]$, f_3= 800 and roll estimation. According to our experimental results, pan and tilt estimation error have direct relationship with roll estimation, as follow:

$$e_{pan} + e_{tilt} \leq \gamma \times roll \tag{18}$$

Where, γ is a threshold factor that set up to 4 (however it can be set at a lower number but we get best result with this value).

V. CONCLUSIONS

This paper presents a method to extract pan and tilt of camera from soccer video by vanishing points. The whole computational process is linear, and avoided from complex image matching. The simple but powerful constraints of parallelism and orthogonality in images can be used to recover very precise rotation matrix without any points and lines correspondence. Computer simulation has been used for test the proposed approach, and achieves accuracy and

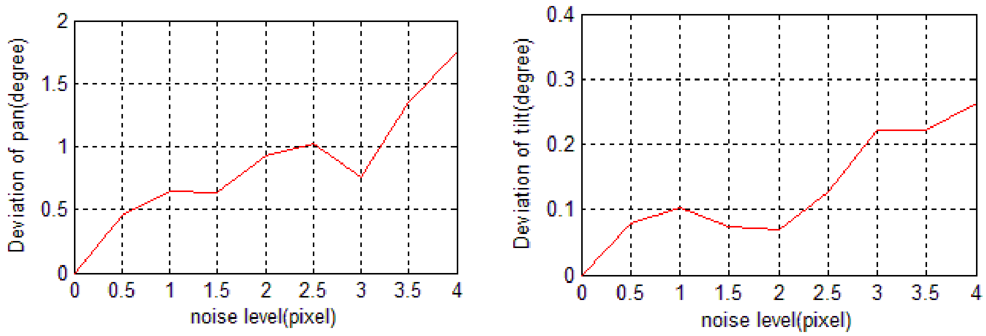

Fig 5. Standard deviations of the camera rotation at different noise levels

Tab 1.Result of rotation matrix, pan, tilt and roll at different noise level

Noise Level (Pixel)	The first Image	The second Image	The third Image
0	$R=\begin{bmatrix}0.9603 & -0.1108 & -0.2560\\ 0 & 0.9178 & -0.3971\\ 0.2790 & 0.3814 & 0.8813\end{bmatrix}$ $r=[23.4001°, -16.1999°, 0.0000°]$	$R=\begin{bmatrix}0.9980 & -0.0320 & -0.0547\\ 0 & 0.7626 & 0.6116\\ 0.0628 & 0.6248 & 0.7781\end{bmatrix}$ $r=[37.8002°, -3.6000°, 0.0000°]$	$R=\begin{bmatrix}0.9759 & -0.1391 & -0.1681\\ 0 & 0.7705 & -0.6374\\ 0.2181 & 0.6221 & 0.7520\end{bmatrix}$ $r=[39.5998°, -12.5998°, 0.0000°]$
1	$R=\begin{bmatrix}0.9484 & -0.1036 & -0.2567\\ -0.0089 & 0.9043 & -0.3979\\ 0.2801 & 0.3889 & 0.8777\end{bmatrix}$ $r=[23.9009°, -16.2650°, -0.5310°]$	$R=\begin{bmatrix}0.9713 & -0.0307 & -0.0508\\ -0.0075 & 0.7627 & -0.6042\\ 0.0605 & 0.6206 & 0.7821\end{bmatrix}$ $r=[38.4146°, -3.4676°, 0.4282°]$	$R=\begin{bmatrix}1.0956 & -0.1555 & -0.1922\\ -0.0062 & 0.8557 & -0.7274\\ 0.2201 & 0.6327 & 0.7425\end{bmatrix}$ $r=[40.4360°, -12.7120°, -0.3632°]$
2	$R=\begin{bmatrix}0.95 & -0.1036 & -0.2568\\ -0.0088 & 0.1059 & -0.3980\\ 0.2779 & 0.3885 & 0.8780\end{bmatrix}$ $r=[23.8662°, -16.2441° \ 0.5229°]$	$R=\begin{bmatrix}0.9759 & -0.0312 & -0.0538\\ -0.0093 & 0.7628 & -0.6119\\ 0.0629 & 0.4249 & 0.7781\end{bmatrix}$ $r=[38.7680°, -3.6043°, -0.5337°]$	$R=\begin{bmatrix}1.1072 & -0.1573 & -0.1953\\ -0.0076 & 0.8623 & -0.7379\\ 0.2208 & 0.6351 & 0.7402\end{bmatrix}$ $r=[40.6308°, -12.7560°, -0.4458°]$
3	$R=\begin{bmatrix}0.9371 & -0.1024 & -0.2604\\ 0.0109 & 0.8961 & -0.3915\\ 0.2859 & 0.3866 & 0.8768\end{bmatrix}$ $r=[23.7928°, -16.6133°, -0.6524°]$	$R=\begin{bmatrix}0.9955 & -0.0320 & -0.0537\\ -0.0093 & 0.7626 & -0.6116\\ 0.0641 & 0.6248 & 0.7781\end{bmatrix}$ $r=[38.7651°, -3.6770°, -0.5320°]$	$R=\begin{bmatrix}1.1021 & -0.1573 & -0.1943\\ -0.0064 & 0.8602 & -0.7328\\ 0.2211 & 0.6334 & 0.7416\end{bmatrix}$ $r=[40.5006°, -12.7748°, 0.3770°]$
4	$R=\begin{bmatrix}0.9969 & -0.1211 & -0.2593\\ 0.0117 & 0.9564 & -0.4012\\ 0.2757 & 0.3690 & 0.8876\end{bmatrix}$ $r=[23.5735°, -16.0043°, 0.7003°]$	$R=\begin{bmatrix}0.9759 & -0.0312 & -0.0538\\ -0.0093 & 0.7628 & -0.6119\\ 0.0629 & 0.4249 & 0.7781\end{bmatrix}$ $r=[38.7537°, -4.1274°, -0.4253°]$	$R=\begin{bmatrix}1.0126 & -0.1330 & -0.1871\\ -0.0299 & 0.7625 & -0.7040\\ 0.2192 & 0.6665 & 0.7126\end{bmatrix}$ $r=[43.0867°, -12.6626°, -1.7584°]$

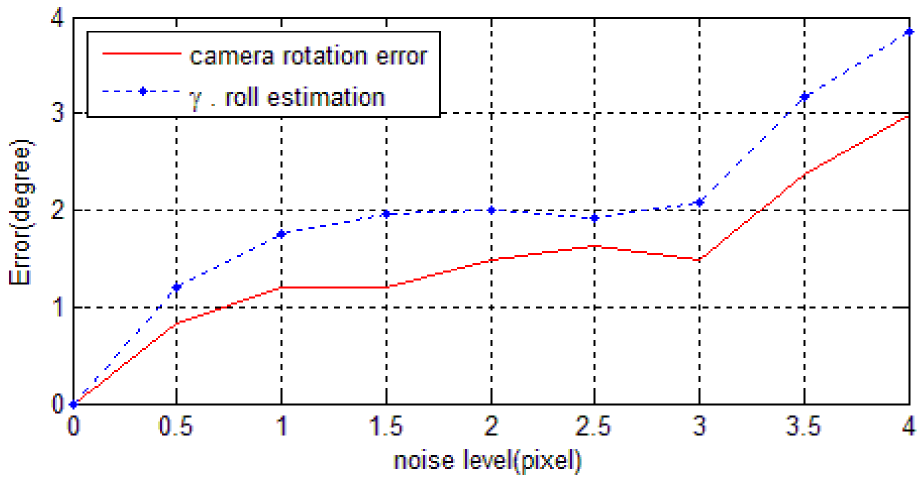

Fig 6. Relation between rotation error and roll estimation (we know roll must be zero) at different noise levels.

reliable results. It can also be applied for other sports, such as tennis and volley ball.

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