Localization of Robots in F180 League Using Projective Geometry

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Abstract. The F180 RoboCup league relies on a single camera mounted on top of the field. It is of great importance to use an adapted calibration method to locate robots. Most of the methods used are developped for specific application where 3D is required. This paper presents a new calibration method specially developped for the F180 league geometry, allowing the determination of the camera pose parameters and the correction of the parallax in the image due to different heights of observed robots. This method needs one calibration plane that also could be used for correcting optical distortions introduced by the lens.

1 Introduction

The determination of the robot location on the field is of great importance in the RoboCup contest. The camera calibration determines the intrinsics parameters of the camera and its position according to the field. A high number of calibration methods can be found in the litterature. Camera calibration has seen great improvement since the beginning of the 90's. The main drawbacks of these methods is that in most cases they were developped for special applications, sometimes using complicated formulations that are not necessary in the case of the F180 calibration problem. Projective geometry is most of the times unavoidable each time camera calibration is needed. Giving a closer look to the main task to be solved, we find out that most of the features of the calibration are points lying on planes. In this case the use of homographies is by far the most approriate tool to solve the problem. The method proposed here relies on the computation of a single homography determined between the image plane and the field plane. This homography can be used to switch from one plane to the other. Compared to [1] the developped method needs one plane of calibration at a single height, then by introducing the intrinsics parameters one can retreive any homography

G.A. Kaminka, P.U. Lima, and R. Rojas (Eds.): RoboCup 2002, LNAI 2752, pp. 312–318, 2003.

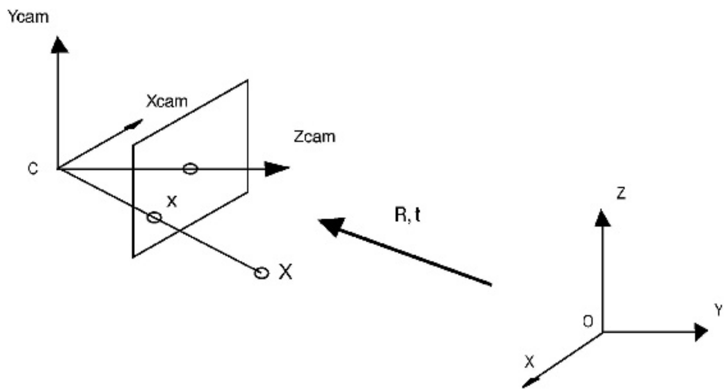

Fig. 1. Rotation and translation between world and camera coordinate frames

for a specific height. The method can be applied to any world plane but, in F180 context, we only need it for planes at different heights. The determination of the intrinsics parameters can be computed by different approaches, for a better overview the reader should refer to [3][2] where several methods are exposed.

2 The Projective Camera

A general camera can be modelized according to the pinhole model by a 3×4 projection matrix P. It represents the transformation between a world point expressed by a homogeneous 4-vector $\mathbf{X} = [\,X\ Y\ Z\ 1\,]^T$, and an image point expressed by a homogeneous 3-vector $\mathbf{x} = [\,x\ y\ 1\,]^T$:

$$\mathbf{x} = P\mathbf{X}\ . \tag{1}$$

The matrix P can be decomposed in blocks in the following way:

$$P = K[\,R\ \mathbf{t}\,]\ , \tag{2}$$

where, K is a upper-triangular 3×3 matrix and represents the intrinsic camera parameters, R is a 3×3 rotation matrix and $\mathbf{t}$ is a translation vector. $\{R, \mathbf{t}\}$ relates the camera orientation and position with the world coordinate system (fig. 1).

More information on the projection matrix P can be found in [3], [4].

3 Projection Matrix and World Plane at $Z = 0$

The relation (2) can be expressed as:

$$\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = K[\,\mathbf{r_1}\ \mathbf{r_2}\ \mathbf{r_3}\ \mathbf{t}\,] \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}\ , \tag{3}$$

with $\mathbf{r_1}$, $\mathbf{r_2}$, $\mathbf{r_3}$, the three column vectors of the rotation matrix R.

Z. Zhang has shown in [5] that (3) can be written without lost of generality in the case $Z = 0$:

$$\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = K[\,\mathbf{r_1}\;\mathbf{r_2}\;\mathbf{t}\,] \begin{pmatrix} X \\ Y \\ 1 \end{pmatrix} . \tag{4}$$

This represents the relation between points of the world plane $Z = 0$ and the image plane. Such a relation is a projective transformation H and is called a homography:

$$\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = \lambda H \begin{pmatrix} X \\ Y \\ 1 \end{pmatrix} . \tag{5}$$

The homography H is defined up to a scale factor λ.

From (4) and (5), we deduce that:

$$\lambda H = K[\,\mathbf{r_1}\;\mathbf{r_2}\;\mathbf{t}\,] \tag{6}$$

$$\lambda[\,\mathbf{h_1}\;\mathbf{h_2}\;\mathbf{h_3}\,] = K[\,\mathbf{r_1}\;\mathbf{r_2}\;\mathbf{t}\,] \tag{7}$$

4 Pose Determination from a World Plane at $Z = 0$

We start with the hypothesis that the homography H has been computed from world points ($Z = 0$) and image points correspondances [3], [1]. Then, the pose $\{R, \mathbf{t}\}$ of the camera can be determined from (6) [5]:

$$[\,\mathbf{r_1}\;\mathbf{r_2}\;\mathbf{t}\,] = \frac{1}{\|K^{-1}\mathbf{h_1}\|} K^{-1} H . \tag{8}$$

As R is a rotation matrix we easily deduce $\mathbf{r_3}$ from:

$$\mathbf{r_3} = \mathbf{r_1} \times \mathbf{r_2} . \tag{9}$$

5 Homography of a World Plane in General Position

In this section we will explain the method to determine the homography H_π corresponding to a world plane π wich as been translated from a distance d on the Z axis above the the plane $Z = 0$ (cf. fig. 2). The reader should be aware that once $H_{Z=0}$ has been determined, it is possible to retrieve H_π for any plane of the 3D-space.

A plane in 3-space can be written in homogeneous representation as:

$$\pi = \begin{pmatrix} \mathbf{n} \\ d \end{pmatrix} , \tag{10}$$

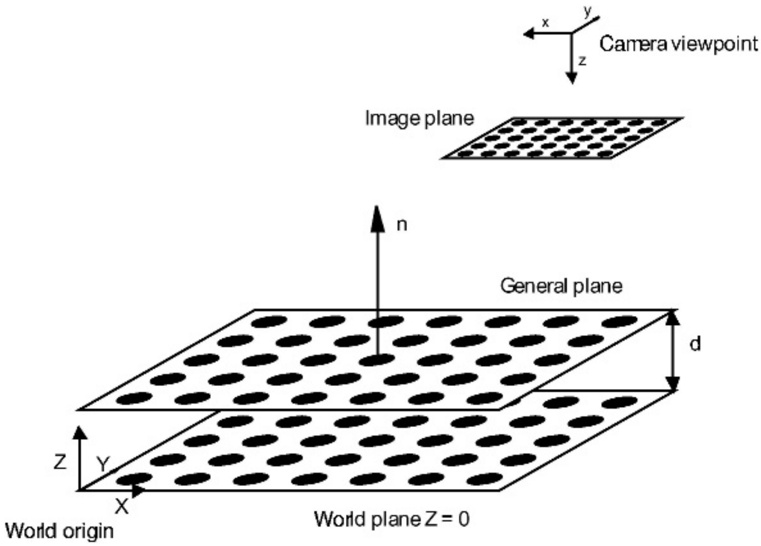

Fig. 2. Camera pose determination and homography of a general plane

with $\mathbf{n}$ a 3-vector representing the plane normal, and d a scalar representing the plane distance from the world origin.

Points $\mathbf{X}_\pi$ on a plane π verify the dot product:

$$\pi^T \mathbf{X}_\pi = \mathbf{0} \; . \tag{11}$$

X_π can be decomposed in two blocks:

$$\mathbf{X}_\pi = \begin{pmatrix} \tilde{\mathbf{X}_\pi} \\ T \end{pmatrix} \; , \tag{12}$$

where $\tilde{\mathbf{X}_\pi}$ is the euclidean coordinates and T is the homogeneous term.

From (10), (11) and (12) we have:

$$\mathbf{n}^T \tilde{\mathbf{X}_\pi} + dT = 0 \; , \tag{13}$$

$$T = -\frac{\mathbf{n}^T \tilde{\mathbf{X}_\pi}}{d} \; . \tag{14}$$

Then, from (1) with $\mathbf{X} = \mathbf{X}_\pi$ and (12):

$$\mathbf{x} = K[\,R\;\mathbf{t}\,] \begin{pmatrix} \tilde{\mathbf{X}_\pi} \\ -\frac{\mathbf{n}^T \tilde{\mathbf{X}_\pi}}{d} \end{pmatrix} \; , \tag{15}$$

thus

$$\mathbf{x} = K \left(R - \frac{\mathbf{t}\mathbf{n}^T}{d} \right) \tilde{\mathbf{X}_\pi} \; , \tag{16}$$

we then have

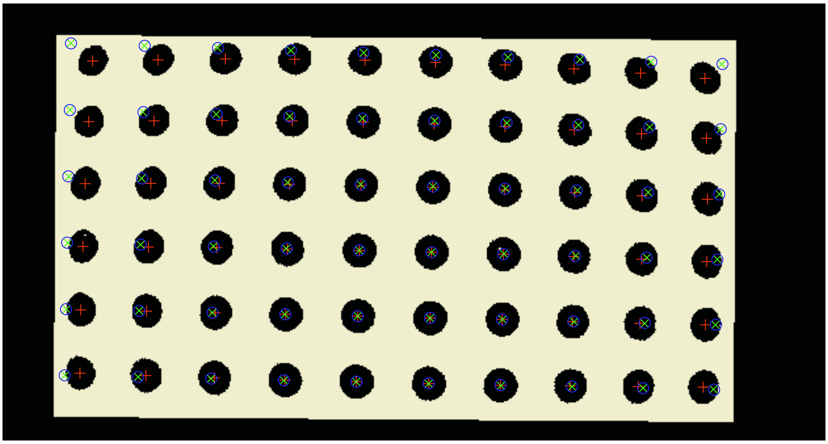

Fig. 3. Binary image of the calibration object in $Z = 0$. Red plus are the gravity centers. Green croses are the gravity centers corrected in optical distortion. Blue circles are the reprojection by the ground plane homographie ($Z = 0$)

$$\mathbf{x} = H_\pi \tilde{\mathbf{X}}_\pi \ , \tag{17}$$

where

$$H_\pi = K \left(R - \frac{\mathbf{t}\mathbf{n}^T}{d} \right) \tag{18}$$

We have seen that all our development supposes that we know the matrix K of the intrinsic parameters. Different techniques can be found in the literature such as in [3], [5] or [2].

6 Experiments

The matrix K and the distortion parameters have been previously computed using an iterative Faugeras-Tauscani method [2][4]. The calibrated camera is placed above the plane $Z = 0$. Not necessarily in front. A known grid has been placed on this plane. After extraction of the circles gravity centers and correction of the optical distortion, we can compute the homography $H_{Z=0}$ that relates the world points of the grids with the corresponding image points (cf. fig. 3):

$$H_{Z=0} = \begin{pmatrix} 2.1606 & -0.0394 & 28.0646 \\ 0.0710 & 2.1464 & 8.8549 \\ 0.0001 & -0.0000 & 1.0000 \end{pmatrix} . \tag{19}$$

The pose of the camera is evaluated as explained in Section 4. Then we can compute the homography for a plane. We have chose a plane placed at 20 cm above the ground ($Z = -20cm$). It is supposed to be the hight of a robot. More

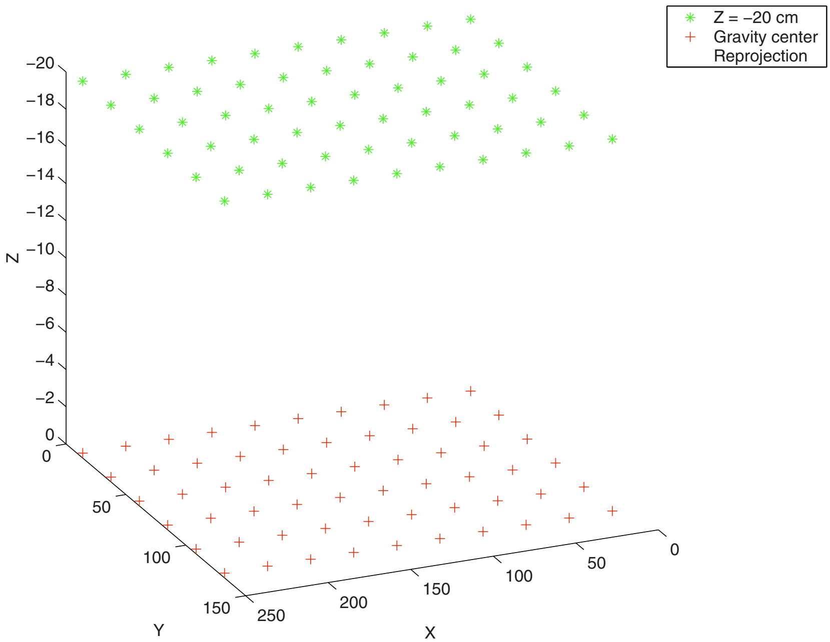

Fig. 4. 3D representation of the extracted gravity center (red plus) on the plane $Z = 0$ and the estimated position on a plane at $Z = -20cm$ (green asterisks)

Table 1. Residual errors for $H_{Z=0}$ and $H_{Z=-20cm}$. The images points have been corrected in opical distortion before the homography estimation. We can see the hight precision of the localization

Homography	Ground error	Image error
$H_{(Z=0)}$	0.12646 cm	0.26687 pixel
$H_{(Z=-20cm)}$	0.29487 cm	0.38189 pixel

precisely the hight of the color code identifying it. The position is determined by the gravity center of the color code (cf. fig. 4 and 5):

$$H_{(Z=-20cm)} = \begin{pmatrix} 618.8987 & -12.1651 & -101.5083 \\ 19.5795 & 621.2943 & 108.5343 \\ 0.0238 & 0.0075 & -13.3978 \end{pmatrix} . \tag{20}$$

For error evaluation, the calibration object has been translated by 20 cm up. Gravity centers are extracted and optical distorsion is removed. Then points positions are compared with those obteined by the method explained above. Results are presented in table 1.

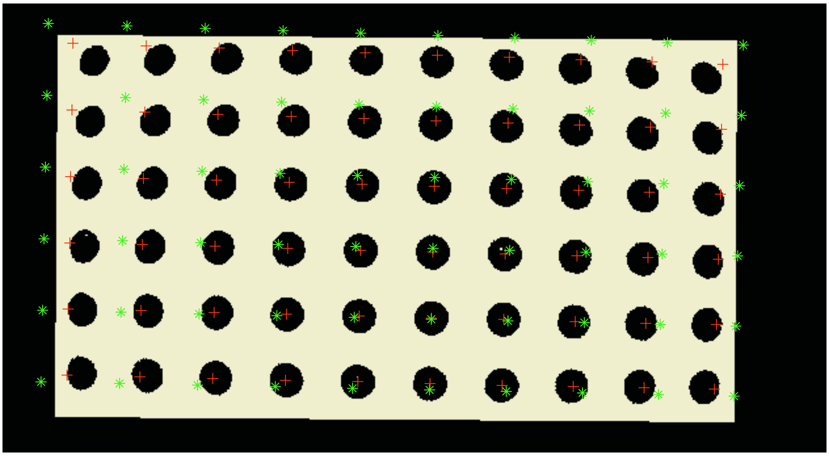

Fig. 5. Extracted grid, corrected in distortion, (red plus) and estimated positions of a virtual grid placed at 20 cm above the ground (green asterisks)

7 Conclusion

We have there proposed a simple and efficient method that deals with parallax for the F180 robots localization. It requires only a single calibration pattern on the ground flour and the camera can be posed in general position. From this one it is now possible to determine robots locations with quite a good precision. The user only needs to compute one homography per robot's hight. The experimental results have shown that the object can be localized with good accuracy at any level from the ground floor.

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