Parallel Lines for Calibration of Non-Central Conical Catadioptric Cameras

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Abstract

In this paper we propose a new calibration method for non-central catadioptric cameras that use a conical mirror. This method consists of using parallel lines, extracted from a single omnidirectional image, instead of using the typical checkerboard to obtain the calibration parameters of the system.

Introduction

Our goal is to propose a new calibration method for Non-Central Catadioptric Systems, specifically those that use a conical mirror. And our main contribution is to be able to make this calibration from man made environments and not depend on the traditional calibration pattern (chessboard type) that is currently used. Environments like corridors and sidewalks, for example, where we can find long and parallel lines (see Figure 1).

Image projection in Non-Central Catadioptric Systems [1], [2] differs a lot from Central Catadioptric Systems [3]. In our case, we work with those Non-Central who make use of a conical mirror, whose projective geometry has been previously studied in [4] (with the Unitary Torus Model), whose position is conditioned by the aperture angle of the mirror, explained in [5].

Our principal contribution is that from a single omnidirectional image (2D), which contains the projection of two parallel lines, we can obtain the calibration parameters of the entire non-central catadioptric system. The main advantage of using lines is that they are present in many environments and we do not need a special pattern to perform the calibration.

The Plücker coordinates of a 3D line is a homogeneous representation of a line $L \in \mathbb{P}^5$. This representation can be organized in such a way that they form two vectors, $L = (l, \bar{l})^T = (l_1, l_2, l_3, \bar{l}_1, \bar{l}_2, \bar{l}_3)^T$. One, the director vector (l), which represents the direction of the line; the other, the moment vector ($\bar{l}$), which represents the normal to the plane formed by the line and the origin of the reference system.

In conical catadioptric systems with the camera aligned to the axis of revolution of the mirror, the locus of the viewpoint is a circle of radius R_c, centered on the axis of revolution and at a distance Z_c of the optical center of the camera [4] (see Figure 2, where the circle is on the mirror surface).

Calibration Method

The first step is to identify two parallel lines within the omnidirectional 2D image, then we take at least five points from each one of them (see Figure 3) to start with their respective adjustment.

We know from [6] that with five points we can linearly calculate the line-image (ρ_j).

$$\rho_j = -\hat{r}_{i,j} pinv\left(\hat{r}_{i,j}\hat{x}_{n(i,j)}, \hat{r}_{i,j}\hat{y}_{n(i,j)}, \hat{r}_{i,j}^2, \hat{x}_{n(i,j)}, \hat{y}_{n(i,j)}\right),$$
for $i = 1..5$, and $j = 1..2$

Introducing f in this last equation, our new line-image (ρ_j) is represented by $\left(\frac{\omega_1}{f^2}, \frac{\omega_2}{f^2}, \frac{\omega_3}{f^2}, \frac{\omega_4}{f}, \frac{\omega_5}{f}, \frac{\omega_6}{f}\right)^T$ and expressing it in plücker coordinates we have the following:

$$\rho_j = \begin{pmatrix} \rho_{j,1} \\ \rho_{j,2} \\ \rho_{j,3} \\ \rho_{j,4} \\ \rho_{j,5} \\ \rho_{j,6} \end{pmatrix} = \begin{pmatrix} \frac{1}{f^2}\left(\frac{(1-cos2\tau)}{cos2\tau} Z_v l_{j,2} - \bar{l}_{j,1}\right) \\ -\frac{1}{f^2}\left(\frac{(1-cos2\tau)}{cos2\tau} Z_v l_{j,1} + \bar{l}_{j,2}\right) \\ \bar{l}_3 tan2\tau \\ tan2\tau\left(\bar{l}_1 + Z_v l_2\right) \\ tan2\tau\left(\bar{l}_2 - Z_v l_1\right) \\ \bar{l}_3 \end{pmatrix}$$

Then solving our system of equations, we get L_j (in function of ρ_j) in Plücker coordinates.

$$L_j=\begin{pmatrix} l_{j,1}\\ l_{j,2}\\ l_{j,3}\\ \bar{l}_{j,1}\\ \bar{l}_{j,2}\\ \bar{l}_{j,3}\end{pmatrix}=\begin{pmatrix} -\frac{f^2 sin2\tau\rho_{j,2}+fcos2\tau\rho_{j,5}}{Z_v tan2\tau}\\ \frac{f^2 sin2\tau\rho_{j,1}+fcos2\tau\rho_{j,4}}{Z_v tan2\tau}\\ \frac{f^2 cos2\tau(\rho_{j,2}\rho_{j,4}-\rho_{j,1}\rho_{j,5})}{Z_v tan2\tau\rho_{j,6}}\\ \frac{f(1-cos2\tau)\rho_{j,4}-f^2 sin2\tau\rho_{j,1}}{tan2\tau}\\ \frac{f(1-cos2\tau)\rho_{j,5}-f^2 sin2\tau\rho_{j,2}}{tan2\tau}\\ f\rho_{j,6}\end{pmatrix}$$

We know that two lines are parallel if and only if their direction vectors are linearly dependent:

$$\frac{l_{1,1}}{l_{2,1}}=\frac{l_{1,2}}{l_{2,2}}=\frac{l_{1,3}}{l_{2,3}}$$

Taking the following equalities, $\left(\frac{l_{1,1}}{l_{2,1}}=\frac{l_{1,3}}{l_{2,3}}\right)$ and $\left(\frac{l_{1,2}}{l_{2,2}}=\frac{l_{1,3}}{l_{2,3}}\right)$, and replacing with their respective values, we get two equations respectively for the calibration parameters sought:

$$ftan2\tau=-\frac{\rho_{1,5}\rho_{1,6}(u)-\rho_{2,5}\rho_{2,6}(v)}{\rho_{1,2}\rho_{1,6}(u)-\rho_{2,2}\rho_{2,6}(v)}$$

$$ftan2\tau=-\frac{\rho_{1,4}\rho_{1,6}(u)-\rho_{2,4}\rho_{2,6}(v)}{\rho_{1,1}\rho_{1,6}(u)-\rho_{2,1}\rho_{2,6}(v)}$$

where: $u=\rho_{2,1}\rho_{2,5}-\rho_{2,2}\rho_{2,4}$; $v=\rho_{1,1}\rho_{1,5}-\rho_{1,2}\rho_{1,4}$

Also, from ρ_1 and ρ_2 we can deduce: $\frac{\rho_{j,3}}{\rho_{j,6}}=\frac{tan2\tau}{f}$

As an example of our experimental results, we can show the error in the calculation of the aperture angle of the mirror (τ) measured in radians and compared with the ground (see the boxplot of the Figure 4).

Conclusion

In this paper we propose a new method for calibrating conical catadioptric images from the projection of two parallel lines. We have shown that working in a selected projection it is possible to decouple the focal length of the camera f and the aperture angle of the mirror τ in an analytical procedure.

Acknowledgments

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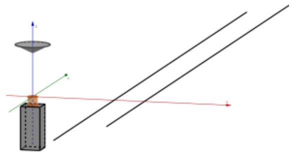

Figure 1: Parallel lines in front of a Conical Catadioptric System.

Figure 3: Synthetic Images with Parallel lines.

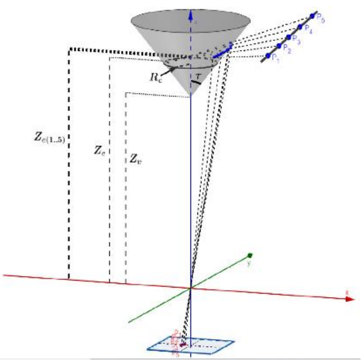

Figure 2: Projection of a line in Conical Catadioptric System.

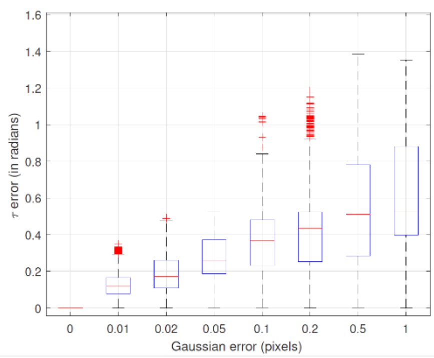

Figure 4: Aperture angle (τ) error (in pixels) in function of the applied Gaussian Noise.