

A Unified Procedure for Calibrating Intrinsic Parameters of Spherical Lenses

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Abstract

Spherical cameras are variable-resolution imaging systems that have been recognized as promising devices for autonomous navigation purposes, mainly because of their wide viewing angle which increases the capabilities of vision-based obstacle avoidance schemes. In addition, spherical lenses resemble the primate eye in their projective models and are biologically relevant. We present a novel method for spherical-lens camera calibration which models the lens radial and tangential distortions and determines the optical center and the angular deviations of the CCD sensor array within a unified numerical procedure. Contrary to other methods, there is no need for special equipment such as low-power laser beams or non-standard numerical procedures for finding the optical center. Numerical experiments and analyses are presented.

1 Introduction

Spherical cameras are variable-resolution imaging systems that are recognized as promising devices for autonomous navigation purposes, mainly because of their wide viewing angle which increases the capabilities of vision-based obstacle avoidance schemes [11]. In addition, spherical lenses resemble the primate eye in their projective models and are biologically relevant [4]. In spite of this, the calibration of spherical lenses is not well understood [10] and contributions to this topic have only recently begun to appear in the literature.

Current standard procedures for pinhole camera calibration are inadequate for spherical lenses as such devices introduce significant amounts of image distortion. Calibration methods such as Tsai's [13] only consider the first term of radial distortion which is insufficient to account for the distortion typically induced by spherical lenses. Other calibration procedures for high distortion and spherical lenses such as Shah and Aggarwal's [9]

and Basu and Licradie's [3] have been defined. However, these methods use special equipment such as low-power laser beams or ad-hoc numerical procedures for determining the optical center of spherical lenses. We propose a novel method which only requires an adequate calibration plane and a unified numerical procedure for determining the optical center, among other intrinsic parameters.

1.1 Types of Distortion

The calibration of optical sensors in computer vision is an important issue in autonomous navigation, stereo vision and numerous other applications where accurate positional observations are required. Various techniques have been developed for the calibration of sensors based on the traditional pinhole camera model. Typically, the following types of geometrical distortion have been recognized and dealt with [14]:

- **Radial Distortion:** This type of distortion is point-symmetric at the optical center of the lens and causes an inward or outward shift of image points from their initial perspective projection. About the optical center, radial distortion is expressed as

$$\hat{r} = r + \kappa_1 r^3 + \kappa_2 r^5 + \kappa_3 r^7 + \dots, \quad (1.1)$$

where κ_i are radial distortion coefficients, r is the observed radial component of a projected point and \hat{r} , its predicted perspective projection [7].

- **Decentering Distortion:** The misalignment of the optical centers of various lens elements in the sensor induces a decentering distortion which has both a radial and a tangential component. They are expressed as

$$\begin{aligned} \hat{r} &= r + 3(\eta_1 r^2 + \eta_2 r^4 + \eta_3 r^6 + \dots) \sin(\theta - \theta_0) \\ \hat{\theta} &= \theta + (\eta_1 r^2 + \eta_2 r^4 + \eta_3 r^6 + \dots) \cos(\theta - \theta_0), \end{aligned}$$

