Preface

In this book, we focus on central catadioptric systems. We go from the very early step of calibration to the high-level task of 3D information retrieval. In between we also consider the intermediate step of developing properly adapted features for central catadioptric systems and the analysis of two-view relations between central catadioptric systems and conventional cameras. In the following paragraphs, we describe in more detail the chapters contained in this book.

The model selected to deal with the central catadioptric systems is the sphere camera model, since it gives more information about the elements of the system than other models. In particular it gives important information about the mirror shape used in the catadioptric system. We introduce this model in detail in Chap. 1 along with an analysis of the relation between this model and actual central catadioptric systems. We also introduce the so-called *lifted coordinates* that are used to understand the two-view relations between central catadioptric systems. In Chap. 2 we use the complete general theoretic projection matrix that considers all central catadioptric systems, presented by (Sturm and Barreto 2008), to construct a new approach to calibrate any single-viewpoint catadioptric camera. This approach requires twenty 3D-2D correspondences to compute the projection matrix and the 3D points must lie on at least three different planes. The projection of 3D points on a catadioptric image is performed *linearly* using a 6×10 projection matrix, which uses *lifted coordinates* for image and 3D points. From this matrix, an initial estimation of the intrinsic and extrinsic parameters of the catadioptric system is obtained. We use these parameters to initialize a nonlinear optimization process. This approach is also able to calibrate slightly non-central cameras, in particular, fish-eye cameras. Since reprojection error is not sufficient to determine the accuracy of the approach, we decide to perform a 3D reconstruction from two omnidirectional images.

During the development of our calibration algorithm we realize that there was a lack of deep analysis and comparison of the existing calibration methods for central catadioptric systems. Moreover, for the robotics community where most tasks require to recover information from the environment, calibration of cameras is a basic step. At the same time this step should be easy to perform and reliable. In this order we perform a classification of the existing approaches. On the other hand, we select those approaches which are already available as OpenSource and which do not require a complex pattern or scene to perform a comparison using synthetic and real images, so the user could select the more convenient for its particular case. In Chap. 3 we present these methods and an analysis of their advantages and drawbacks.

In Chap. 4 we present a deep analysis of the two-view relations of uncalibrated central catadioptric systems. We particularly pay attention to the mixture of central catadioptric systems and perspective cameras, which we call *hybrid*. The two-view geometric relations we consider are the hybrid fundamental matrix and the hybrid planar homography. These matrices contain useful geometric information. We study three different types of matrices, varying in complexity depending on their capacity to deal with a single or multiple types of central catadioptric systems. The first and simplest one is designed to deal with paracatadioptric systems, the second one and more complex, considers the combination of a perspective camera and any central catadioptric system. The last one is the complete and generic model which is able to deal with any combination of central catadioptric systems. We show that the generic and most complex model sometimes is not the best option when we deal with real images. Simpler models are not as accurate as the complete model in the ideal case, but they provide a better and more accurate behavior in presence of noise, being simpler and requiring less correspondences to be computed. Finally, using the best models we present the successful matching between perspective images and hypercatadioptric images introducing geometrical constraints into a robust estimation technique.

Another basic step in vision and robotics applications is feature detection/extraction. Through the years several techniques have been developed for conventional (perspective) cameras. The SIFT proposed by (Lowe 2004) has become the most used feature extraction approach. This scale-invariant approach is based on the approximation to the Laplacian of Gaussians (LoG) through the difference of Gaussians (DoG). The Gaussian filtering in Euclidean computer vision, which is required to construct the scale space of the images can be computed in two ways: either using convolution with a Gaussian kernel or by implementing the linear heat flow. In Chap. 5 we develop a new approach to compute the scale space of any omnidirectional image acquired with a central catadioptric system. We combine the sphere camera model and the partial differential equations framework on manifolds, to compute the Laplace–Beltrami (LB) operator which is a second-order differential operator required to perform the Gaussian smoothing on catadioptric images. Finally in Chap. 6 we present an approach to compute the orientation of a hand-held omnidirectional catadioptric camera. We use the vanishing points which contain geometric information related to the orientation of the catadioptric system with respect to the dominant directions in man-made environments. The vanishing points are computed from the intersection of parallel lines. The 3D lines are projected in catadioptric images as conics. We extract analytically the projected lines corresponding to straight lines in the scene by using the internal calibration and two image points that lie on the corresponding line projection.