Chapter 5
Camera Calibration with 1D Objects

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ABSTRACT

Camera calibration is a process that allows to fully understand how the camera forms the image. It is necessary especially when 3D information of the scene must be known. Calibration can be performed using a 1D pattern (points on a straight line). This kind of pattern has the advantage of being "visible" simultaneously even by cameras in opposite positions from each other. This makes the technique suitable for calibration of multiple cameras. Unfortunately, the calibration with 1D patterns often leads to poorly accurate results. In this work, the methods of single and multi-camera calibration are analyzed. It is shown that, in some cases, the accuracy of this type of algorithm can be significantly improved by simply performing a normalization of coordinates of the input points. Experiments on synthetic and real images are used to analyze the accuracy of the discussed methods.

1. INTRODUCTION

Mathematically, in the process of image creation, the camera accomplishes a mapping between a 3D space (the world environment) and a plane (the image plane). During this process, some informations are lost (e.g., angles, distances and volume). If these informations are needed, it becomes necessary to estimate the intrinsic and extrinsic camera parameters, i.e., matrices with special properties that represent the camera mapping, through a procedure known as calibration. Usually, during this procedure, the camera captures images from an object with well known dimensions and form

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(known as the calibration apparatus or calibration pattern). Afterwards, the relation between some points of the calibration pattern and their respective projections in the image plane is used to determine the camera parameters.

The first calibration algorithms to become widely used were based on 3D patterns (Lenz and Tsai, 1988; Tsai, 1987). Typically, such calibration objects are composed of two or more orthogonal planes with a well-known pattern on their faces. These methods have the advantage of performing the calibration with few images and have excellent accuracy. Over the years, new calibration methods have been proposed using 2D patterns (Sturm and Maybank, 1999; Zhang, 2000). In this case, the main advantages are the simplicity of the calibration apparatus (even a sheet of paper with a known pattern can be used) and the abundance of planes in man-made environments (which enables the use of some pre-existing pattern in the camera environment as a calibration apparatus). In fact, the abundance and ease of detection of planes in the environment led to the proposition of self-calibration algorithms based on planes (Triggs, 1998). In self-calibration, there is no need for a calibration apparatus. Instead, the camera performs some displacements while capturing images. Then, typically, it is enough to trace down a few points over these images to be able to perform the calibration. However, despite the convenience and abundance of already proposed self-calibration algorithms (Dornaika and Chung, 2001; Hartley, 1997b; Maybank and Faugeras, 1992; Mendonça and Cipolla, 1999), the self-calibration is still rarely used in practice. This is mainly due to the large number of variables that need to be estimated, which leads to inaccurate algorithms and high computational complexity.

More recently, Zhang (2004) proposed a calibration procedure using patterns of only one dimension (points in a straight line). Here, the 1D pattern has to execute unknown displacements while the camera captures images from it. The only restriction of this method is that one of the pattern's points must remain stationary during the image acquisition. This method has been investigated and extended by several other authors (Hammarstedt et al., 2005; Qi et al., 2007a,b; Wu et al., 2005). Wu et al. (2005) equated the problem in a different form, showing that the 1D calibration object with a segment rotating around a stationary point in Zhang's setup is in essence equivalent to a 2D rectangular calibration object with unknown sides. Still, such change does not bring any gain in accuracy. In fact, the results from Wu et al. (2005) are comparable to the ones obtained by Zhang (2004). More recently, Qi et al. (2007a) extended the work from Wu, removing the need for one of the pattern points to be stationary. Instead, it is necessary that the trajectory of the calibration pattern's center of mass is a parable. Furthermore, Qi et al. (2007a) demonstrated that a significant part of the instability in the method of Wu et al. (2005) is due to movements that cause singularities, which can be detected and avoided. With this care, the accuracy of the method of Wu et al. (2005) is significantly improved. However, the movement that the calibration pattern has to execute in the method of Wu et al. (2005) is very difficult to accomplish in practice. Therefore, only with the work of de França, J. A. and Stemmer, M. R. and de M. França, M. B. and Alves, E. G. (2010) the calibration with 1D patterns became usable in practice and with an accuracy comparable to other traditional methods. This work has shown that the accuracy of the original method of Zhang (2004) can be significantly improved simply by analyzing the mathematical equating of the problem and that it is possible to improve the numerical conditioning by performing a simple data normalization.

If, instead of one camera, a set of two or more cameras is considered, the epipolar restriction increases the degree of freedom of the problem and allows the calibration pattern to perform unrestricted displacements. The main advantage of this approach is the possibility of calibrating more than one camera at the same time. This hap-

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