Automatic Camera Calibration Applied to Medical Endoscopy

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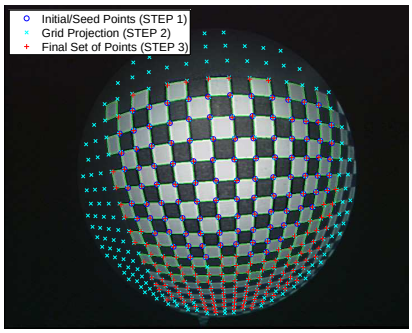

Figure 1: Corner detection in the periphery region of the calibration image is problematic because of radial distortion. These corners are roundish and too close, making unsupervised detection and localization hard to accomplish. We perform automatic corner detection in the center region, where the effect of radial distortion is less pronounced. These 'seed' correspondences are used for an initial estimation of a 6×6 lifted homography that takes into account lens distortion. The homography is used to project the entire grid into the image. The corners position are refined using an Harris detector with a small search window.

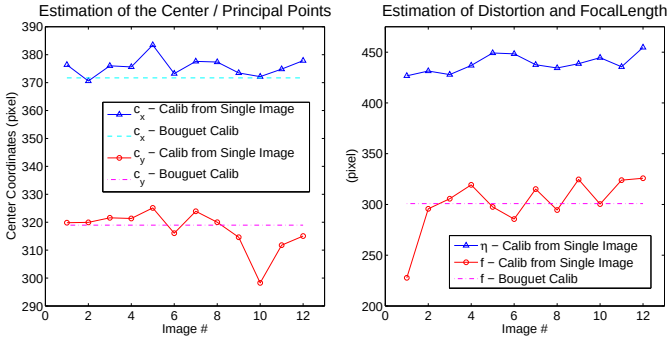

Figure 2: Single Image Calibration (SIC) applied to 12 calibration images. The figure compares the results of 12 independent calibrations using SIC (each image enables a full calibration), against the result obtained with Bouguet toolbox. Bouguet uses simultaneously the 12 images and performs final global refinement with iterative optimization.The left side concerns the results in estimating the principal point (c_x, c_y), while the right side shows the focal length and distortion.

Abstract: *We present a calibration algorithm for cameras with lens distortion, that uses a single image of a planar chessboard pattern acquired in general position. The radial distortion is modeled using the first order division model, and the method provides a closed form estimation of the intrinsic parameters and distortion coefficient. The experimental evaluation shows that the calibration accuracy is comparable to state-of-the-art algorithms requiring multiple input images. We believe that our approach is particularly well suited for the the calibration of medical endoscopes in computer aided surgery. Since the lens is mounted on the camera before each usage in the OR, the calibration procedure must be performed by the clinical practitioner with minimum effort. We solve this problem by proposing a fully automatic procedure that requires no human intervention other than acquiring the calibration image*[1].

Camera calibration can hardly be avoided in the context of image-based computer aided surgery. However, developing an effective method for geometric calibration of a medical endoscope is a very challenging task [4]. The reasons are the following: (i) the calibration must be very accurate; (ii) the endoscope optics introduces strong radial distortion that must be considered in the projection model; (iii) the calibration procedure has to be performed by a non-expert in the Operation Room (OR), which requires the method to be robust and fully automatic.

Geometric camera calibration is a well studied topic, for which there are several methods and software currently available. Bouguet's implementation of Zhang's method for calibrating a camera from a minimum of three grid images is particularly popular [2, 5]. Unfortunately the calibration procedure does not meet the usability specifications stated above. The approach requires the acquisition of several grid images and the manual selection of corner points. This selection, although easily automatized for standard perspective images, it is very problematic in the presence of strong lens distortion. We can hardly imagine a medical doctor being eager to acquire 10 to 20 grid images during his regular clinical practice, and then struggle to manually select points over all this imagery. Wengert et al. address the problem by proposing an add-on to the Bouguet toolbox, where a dot grid is used to avoid manual point selection [4]. Unfortunately, and since it is impossible to determine the centers of the dots in an image with radial distortion, replacing the chessboard by dot grid implies a decrease in the calibration accuracy.

This article proposes a method for endoscope calibration that overcomes the usability issues without compromising the accuracy. The approach is fully automatic (see Fig 1) and, to the best of our knowledge, it is the first algorithm in the literature able to calibrate a camera with radial distortion from a single image of a planar grid. We build on recent developments in using *lifted coordinates* to model the projection in central catadioptric systems [3]. This theory is extended to the case of medical endoscopes by exploring the similarities between the division model for radial distortion and the para-catadioptric projection [1]. The experimental results show that our linear calibration method from a single image presents an accuracy comparable with Bouguet, that uses multiple images and iterative non-linear optimization (see Fig. 2).

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[1] Patent Pending (number 20091000069650)