Flexible and User-Centric Camera Calibration using Planar Fiducial Markers

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Recently, 3D vision methods have demonstrated increased robustness and resulted in high quality models. Hence multi-view modeling appears more often in industrial projects targeted at large-scale scenes such as Google Earth and Microsoft Bing. Combined with the emergence and availability of affordable high resolution cameras, this development has made 3D vision methods and tools popular not only among researchers, but also lead to the participation of an ever increasing population of end-users, who are not experts in computer vision. Though the advent of sophisticated multi-view stereo systems used in these tools have enabled the creation of visually appealing models, the geometric fidelity mainly depends on the accuracy of the camera parameters as shown in Fig. 1. Consequently, there is a need to increase the flexibility of existing calibration procedures used to estimate the camera intrinsics in image-based modeling, especially when inexperienced end users are involved.

Given its crucial role with respect to overall precision, camera calibration has been a well studied topic over the last two decades. However, in most of the calibration literature, a strict requirement on the target geometry and a constraint to acquire the entire calibration pattern has been enforced. This has recently become a matter of question [3]. Other issues like robust detection of correspondences has also received little attention as most of the standard routines assume that the correspondences have already been found. The poor quality of gathered data, owing to the user's inexperience in calibration procedures (e.g. failure to cover the pattern along the corners of the image) and bad illumination are often sources of inaccuracy as shown in Fig. 2. It is these considerations that motivate our contribution.

The goal of this paper is to present and advocate the use of planar paper based fiducial markers as a target pattern to put together a flexible and reliable calibration pipeline, thereby easing the efforts for the end user. Our contribution is three-fold: First, to improve the accuracy of feature localization and correspondence with the use of simple printed markers having unique extractable ID's and sub-pixel accuracy. Second, to provide sensitivity to partial occlusions of the calibration object, resulting due to bad or uneven illuminations or partially clipped patterns, by releasing the critical requirement to process the entire pattern. Finally, we extend the fidelity of calibration consistency to even wide angle applications and highly distorted lenses by enabling a well distributed set of control points, especially along the fringes of the image and thereby eliminating the need for an elaborate procedure for accurate parametrization.

Our calibration routine follows the basic principles of planar target based calibration [4] and thus requires corresponding points to be imaged in several views. However, we use marker patterns printed on several sheets of paper and laid on the floor in an approximate grid pattern (see Fig. 3) to obtain those correspondences. There is no strict requirement for all markers to be visible in the captured images. To ensure that each marker is classified with a high degree of confidence and to eliminate

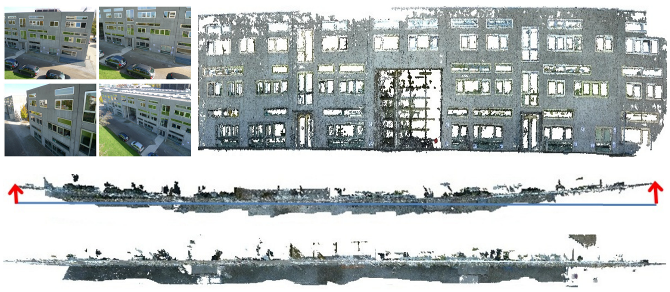
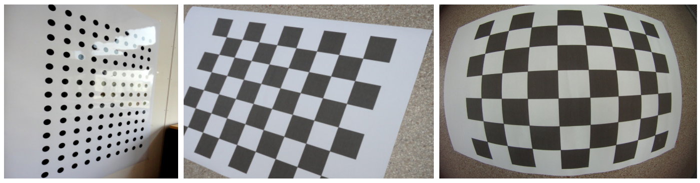


Figure 1: Reconstruction of a facade shows that though visually correct in appearance, geometric inconsistencies (significant bends along the fringes) are prevalent when using calibration and undistortion results from OpenCV (middle). In comparison, using accurate camera parameters delivered by the proposed method results in a straight wall (bottom).



(a) (b) (c)

Figure 2: Images provided by users which *(a)* have uneven illumination or *(b)* are partially clipped serve as common failure points for calibration methods having a critical requirement on pattern geometry. *(c)* On the other hand, if images are taken correctly the critical corners of the image (highest distortion) are never covered.

(a) (b) (c)

Figure 3: (a) Fiducial markers: Each marker encodes a unique ID. (b) A typical calibration image (partially corrupted due to uneven illumination) arbitrarily arranged in a 4x4 grid on the floor. (c) Reliably extracted markers with positions and IDs.

any false positives in case of blurred or otherwise low-quality images, a robust marker detection method is employed. An initial estimate of lens distortion parameters attempts to minimize the reprojection error of extracted feature points based on homographies between the individual views. We follow the approach of Irschara et al. [2], thereby searching for a constant, but unknown focal length f determining the calibration matrix K. Subsequently, bundle adjustment is applied to perform a non-linear optimization of the intrinsics (f, u_0, v_0) and radial distortion (θ).

We comprehensively validate the consistency in estimation of camera calibration parameters, and the robustness to images corrupted by noise or human error with our proposed method using a set of off-the-shelf cameras. The experiments are performed in an uncontrolled environment to simulate conditions similar to that experienced by a common user. The OpenCV Camera Calibration toolbox [1] is used as our primary reference as it represents the most popular method for calibration outside of computer vision and photogrammetry. Pixel reprojection errors and ground truth errors are significantly lowered by our method, even though paper-printable and easy-to-use targets are employed. In addition, we show both qualitative and quantitative benefits of increased flexibility in camera calibration towards multi-view reconstruction of large scale scenes. Empowered with an easy to use GUI with user-feedback facility, the proposed calibration method has been made publicly available at `http://aerial.icg.tugraz.at` so that a wide audience can benefit from our findings.

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