ANNALS of the ORADEA UNIVERSITY.

Fascicle of Management and Technological Engineering, Volume VII (XVII), 2008

THE CAMERA CALIBRATION FOR A TELEROBOT SYSTEM

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Key words: camera calibration, lens distortion, undistorted image,

Abstract: Camera calibration has always been an essential component of the robot vision systems, with self-calibration nowadays being an integral and routinely applied operation within photogrammetric triangulation, especially in high-accuracy close-range measurement. With the very rapid growth in adoption of off-the-shelf digital cameras for a host of new 3D measurement applications, however, there are many situations where the geometry of the image network will not support robust recovery of camera parameters via on-the-job calibration. For this reason, stand-alone camera calibration has again emerged as an important issue, and it also remains a topic of research interest in computer vision. This paper overview the current approaches adopted for camera calibration in computer vision. Also, the author's results of camera calibrations are summarized.

1. INTRODUCTION

Accurate camera calibration and orientation procedures are a necessary prerequisite for the extraction of precise and reliable 3D metric information from images. A camera is considered calibrated if the principal distance, principal point offset and lens distortion parameters are known. In many applications, especially in computer vision (CV), only the focal length is recovered while for precise measurements all the calibration parameters are generally employed. Various algorithms for camera calibration have been reported over the years in the literature. The algorithms are generally based on perspective or projective camera models, with the most popular approach being the well-known selfcalibrating bundle adjustment.

2. CALIBRATION METHODS AND MODELS

In the literature it can be found different criteria to classify the camera calibration.

One of them is the nature of the application and starting from this, the required accuracy can dictate which of two basic underlying functional models should be adopted:

- A camera model based on perspective projection, where the implication is that the IO is stable (at least for a given focal length setting) and that all departures from collinearity, linear and non-linear, can be accommodated. This collinearity equation-based model generally requires five or more point correspondences within a multi-image network and due to its non-linear nature requires approximations for parameter values for the least-squares bundle adjustment in which the calibration parameters are recovered.
- A projective camera model supporting projective rather than Euclidean scene reconstruction. Such a model can accommodate variable and unknown focal lengths, but needs a minimum of 6 - 8 point correspondences to facilitate a linear solution, which is invariably quite unstable. Nonlinear image coordinate perturbations such as lens distortion are not easily dealt with in such models.

Further criteria can also be used to classify camera calibration methods:

- Implicit versus explicit models. The photogrammetric approach, with its explicit physically interpretable calibration model, is contrasted against implicit models used in structure from motion algorithms which correct image point positions in accordance with alignment requirements of a real projective mapping (Hall et al., 1982; Wei & De Ma, 1994).
- Methods using 3D rather than planar point arrays (Triggs, 1998; Zhang, 2000). Whereas some CV methods and photogrammetric self-calibration can handle both cases – with appropriate network geometry – models such as the Essential matrix cannot accommodate planar point arrays.
- Point-based versus line-based methods (Fryer and Brown, 1986). Point-based methods are more popular in photogrammetry, with the only line-based approach of note, namely plumbline calibration, yielding parameters of lens distortion, but not of IO.

A more specific classification can be made according to the parameter estimation and optimization technique employed:

- Linear techniques are quite simple and fast, but generally cannot handle lens distortion and need a control point array of known coordinates. They can include closed-form solutions, but usually simplify the camera model, leading to low accuracy results. The well-known DLT (Abdel-Aziz & Karara, 1971), which is essentially equivalent to an Essential matrix approach, exemplifies such a technique.
- Non-linear techniques such as the extended collinearity equation model, which forms the basis of the selfcalibrating bundle adjustment, are most familiar to photogrammetrists. A rigorous and accurate modelling of the camera IO and lens distortion parameters is provided (Brown, 1971) through an iterative least-squares estimation process.
- A combination of linear and non-linear techniques where a linear method is employed to recover initial approximations for the parameters, after which the orientation and calibration are iteratively refined (Faugeras & Toscani, 1986; Tsai, 1987). This two-stage approach has in most respects been superceded for accurate camera calibration by the bundle adjustment formulation above, which is also implicitly a two-stage process.

3. CAMERA CALIBRATION IN COMPUTER VISION

The calibration models for machine and computer vision have traditionally employed reference grids, the calibration matrix **K** being determined using images of a known object point array (e.g. a checkerboard pattern). Commonly adopted methods are those of Tsai, (1987), and Zhang (2000). These are all based on the pinhole camera model and include terms for modelling radial distortion.

Tsai's calibration model assumes that some parameters of the camera are provided by the manufacturer, to reduce the initial guess of the estimation. It requires n features points ($n > 8$) per image and solves the calibration problem with a set of n linear equations based on the radial alignment constraint. A second order radial distortion model is used while no decentering distortion terms are considered. The two-step method can cope with either a single image or multiple images of a 3D or planar calibration grid, but grid point coordinates must be known.

The technique developed by Heikkila & Silven (1997) first extracts initial estimates of the camera parameters using a closed-form solution (DLT) and then a nonlinear least-squares estimation employing a the Levenberg-Marquardt algorithm is applied to refine the IO and compute the distortion parameters. The model uses two coefficients for both radial and centering distortion, and the method works with single or multiple images and with 2D or 3D calibration grids.

Zhang's calibration method requires a planar checkerboard grid to be placed at different orientations (more than 2) in front of the camera. The developed algorithm uses the extracted corner points of the checkerboard pattern to compute a projective transformation between the image points of the *n* different images, up to a scale factor. Afterwards, the camera interior and exterior parameters are recovered using a closed-form solution, while the third- and fifth-order radial distortion terms are recovered within a linear least-squares solution. A final nonlinear minimization of the reprojection error, solved using a Levenberg-Marquardt method, refines all the recovered parameters. Zhang's approach is quite similar to that of Triggs (1998), which requires at least 5 views of a planar scene.

The term self-calibration (or auto-calibration) in CV is used when no calibration object is employed and the metric properties of the camera and of the imaged scene are recovered from a set of 'uncalibrated' images, using constraints on the camera parameters or on the imaged scene. Self-calibration is generally adopted in 3D modeling to upgrade a projective reconstruction to one that is metric (i.e. determined up to an arbitrary Euclidean transformation and a scale factor). In general, three types of constraints are applied (separately or in conjunction) to perform self-calibration: scene constraints, camera motion constraints, or constraints on the camera intrinsic parameters. All of these have been tried, but in the case of an unknown camera motion and unknown scene, only constraints on the IO can be used.

The majority of the so-called self-calibration algorithms described in the computer vision literature treat intrinsic camera parameters as constant but unknown (Faugeras et al., 1992; Heyden & Åström, 1996; Triggs, 1997). The problem of variable IO parameters has also been studied by Heyden & Åström (1997). Self-calibration can be problematic with certain critical motion sequence networks, where the motion of the camera is not generally sufficient to allow for the recovery of calibration parameters and an ambiguity remains in the 3D reconstruction. Moreover only the focal length is usually determined while lens distortion and other internal parameters are neglected, assumed known, or considered as unknown and are recovered without any statistical testing for significance.

4. THE EXPERIMENT

The camera calibration was made for a telerobot system developed by our research team (figure 1). The telerobot system structure consist in two servers, the first one the local computer (HIC) and the second one the remote computer (TIC). As a robot we have used a Mitshubishi Movemaster RV-M1 robot with 5 axes.

Different kinds of objects are placed on a table, in its workspace. The task of the telerobot system is to acquire the scene image with the objects, to transfer this image to the HIC, than to calibrate the image, and than the human operator to realise the 3D model of any piece from the visual field, to overlay this model on the real object, and in this way to obtain the mass centre position and the orientation of the object. With this information the robot will be driven via Internet to pick the object and place it anywhere in the robot workspace.

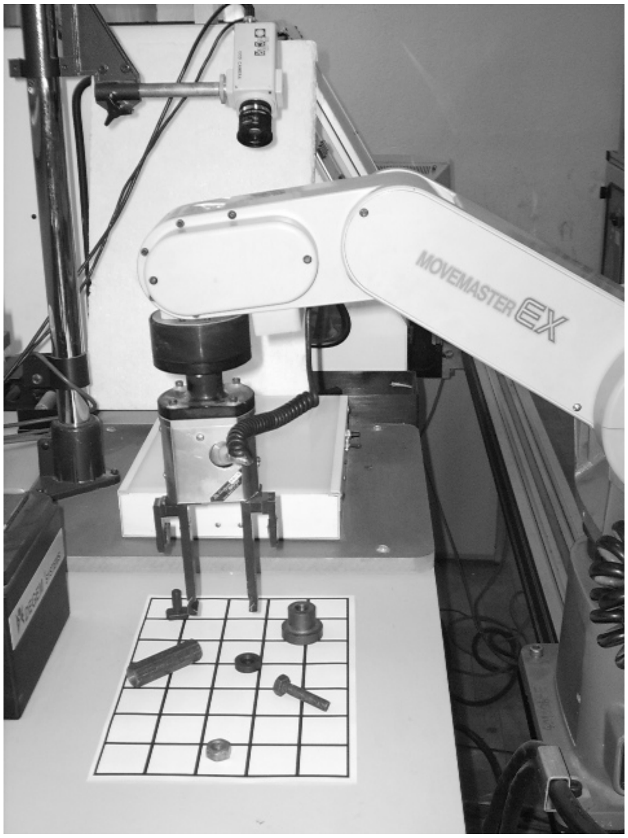

Fig. 1. The telerobot system

The scene is observed by a CCD camera. For this CCD camera we have to make the calibration. The system calibration consists in two stages. The first one was the camera calibration. To solve this problem we use the Devernay and Faugeras' technique for lens distortion removal from structured scenes. The acquired image of the grid is presented in figure 2.

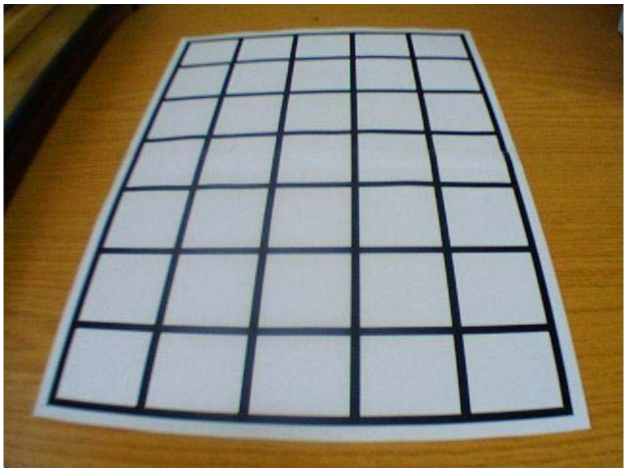

Fig. 2. The acquired image of the grid

The algorithm consists in the following steps:

- edge extraction on the acquired image as is presented in figure 3;

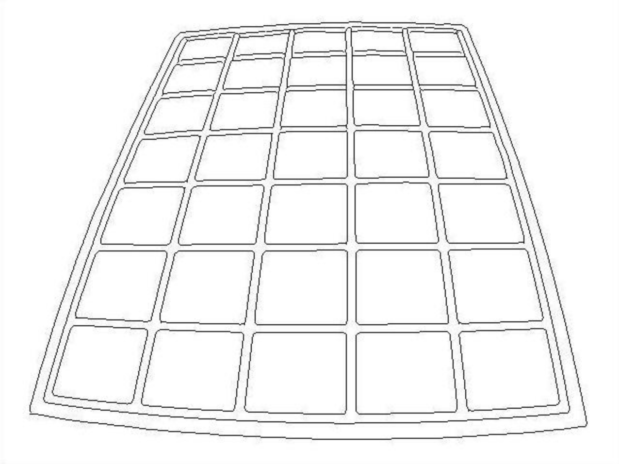

Fig. 3. The edge extraction on the acquired image

- the polygonal approximation with a large tolerance on these edges to extract possible lines from the sequence;
- finding the parameters of the distortion model that best transform these edges to segments;
- generating the “undistorted image” using the parameters computed using this algorithm (k - radial distortion term. c_x, c_y - x and y coordinates of lens centre expressed as fraction of the image size relative to the top left corner; s - apparent aspect ratio.)

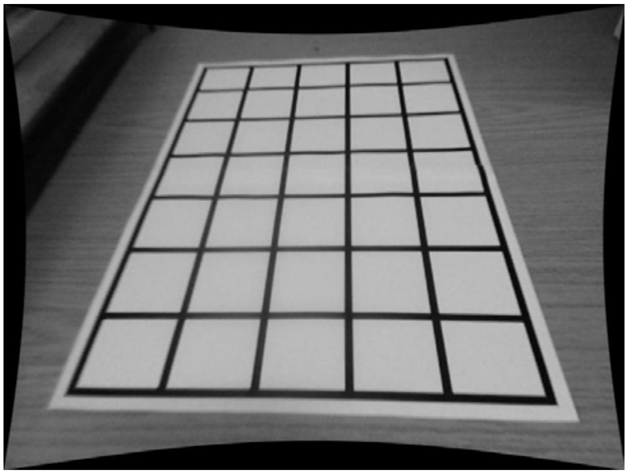

Fig. 4. The “undistorted image”

5. CONCLUSION

Camera calibration continues to be an area of active research within the computer vision community. Our camera calibration software is working in real-time and it is integrated in the Augmented Reality Interface software.

The project was successful in the development of the AR interface for the Mitshubishi Telerobot.

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