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Using Lego pieces for camera calibration: a preliminary study

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Abstract

Camera calibration is an important operation for a number of applications in the field of Computer Graphics and Computer Vision. In particular, if the intrinsic parameters of the camera are known in advance, the accuracy of results is extremely improved. For this reason, several easy procedures to calibrate a camera have been proposed. The accuracy and ease-of-use of these procedures is strongly related to the needed calibration target, which is usually a single 2D printed pattern (i.e. a checkerboard). In this paper we propose the use of an alternative: a Lego structure. Lego pieces exhibit several strong-points, like the off-the-shelf availability and the geometric accuracy. Additionally, it's easy to prepare a structure and obtain the corresponding 3D model using freeware tools.

Hence, we present the preliminary tests on the use of Lego structures for camera calibration. The tests have been performed on a user-friendly ad-hoc tool, which takes advantage of the peculiar features of Lego to automatically correct the positions of the 2D and 3D correspondences used for calibration. Results show that it's possible to obtain accurate results starting from a few photos, and that the entire procedure can be completed in a very short time.

Categories and Subject Descriptors (according to ACM CCS): Digitization and Image Capture [I.4.1]: Camera calibration—

1. Introduction

The calibration of cameras has been an extremely important issue in the field of Computer Graphics and Computer Vision. The camera parameters that need to be estimated can be divided in two groups: the extrinsic and the intrinsic parameters. The values of the first group, which is related to the camera position in space, usually change from one shot to the other. On the contrary, it is possible to calibrate the intrinsics once for all, and to use the estimated values in a number of useful applications.

Several tools have been proposed to obtain a calibrated camera in an easy and fast way. Essentially, the parameters estimation is obtained by indicating some points on one or more images of a pre-defined calibration object. The main issues in order to produce a user-friendly tool are related to the shape and nature of the calibration object, and on the setting of accurate correspondences.

In this paper we present a prototypal tool which makes use of an off-the-shelf calibration object, which is composed by Lego blocks. The idea is to use the peculiar features of Lego (extreme accuracy, easiness of use, freeware 3D modeling solutions) to give the user to possibility to build his own calibration object. Moreover, a simple automatic procedure to correct the points provided by the user enhances the quality of results.

The paper presents a very short overview of calibration tools, a brief discussion about the advantages of using Lego, and some preliminary calibration tests performed on a specifically designed tool.

2. Related work

The amount of research in the field of camera calibration is huge. Several algorithms [Tsa87, FT86, HS97] have been proposed, and the issue of aligning an image has been faced using different approaches, like image processing [LHS00, NK97], data provided by the user [FDG*05], statistical approaches [VWMW97, CDPS09]. Several commercial products integrate semi-automatic procedure to cal-

ibrate a camera.
Every time a camera calibration is performed, all the parameters (extrinsic and intrinsic) are estimated. Nevertheless, a subgroup of works focused mainly on the extrinsic parameters [KH94], facing the so-called pose estimation problem. These approaches are usually based on the assumption of using a calibrated camera, where all the intrinsics are known in advance. The use of a calibrated camera can be critic for the accuracy of a number of applications (i.e. 3D reconstruction and color projection). For this reason, a lot of simple approaches to estimate the intrinsics of a camera have been presented. Essentially, the goal is to model and correct the distortion introduced by lenses. The needed accuracy for the estimation of these parameters is very high.
Self-calibration approaches (see the tutorial by Heyden [HP00] for an overview) don't need a calibration object, but the number of parameters to estimate is very big and the optimization problem becomes very complex.
An alternative solution is to use a calibration object. The differences between the proposed approaches in this field are essentially based on: the planar [Zha00], non-planar [Tri98, SM99] or even one-dimensional [Zha04] nature of the calibration object, which usually requires the use of different solving algorithms, and the setting of correspondences (or indication of important points) which can be automatic [Bou] or semi-automatic [Zha00].
Nowadays, most of the 3D acquisition devices based on cameras use simple procedures to make the calibration in a short time: nevertheless, the calibration object is very accurate and it is provided by the manufacturer. The aim of this work is to give the user the possibility to create the calibration object with off-the-shelf material.

3. The advantages of Lego blocks as calibration objects

The tools which provide a way to easily calibrate a camera make use of easy patterns: Zhang [Zha00] proposed a 2D pattern made of a grid o black squares, while the Camcheck tool [Bou] uses a simple checkerboard. In both cases, the points which are used for calibration are found on the corners of the squares. In order to obtain an accurate calibration, at least two images from different positions are needed, but a number of five or more is suggested for better performance. Also the 3D calibration objects are composed by two or more perpendicular 2D patterns. In this case, a smaller number of images is needed to obtain good results.
Both the solutions present drawbacks: in the case of 2D patterns, it is usually necessary to print them using a laser printer. Then, they must be glued on a perfectly flat surface: small inaccuracies could result in errors, since the provided points are not exactly coplanar. In the case of three-dimensional objects, the main problem stands in putting the planes in a perfectly perpendicular position.
In this paper we propose the use of Lego blocks as calibration objects. This is because they present several advantages:

- Lego is an extremely popular and cheap toy. Most of the people have Lego bricks at home, and it's very easy to get some.
- In order to provide a perfect joint, Lego pieces are produced by machines with a precision tolerance of 0.002 mm [Leg]. Hence, structures made with Lego pieces provide extremely flat surfaces and accurate orthogonality between planes.
- There are several freeware tools (like Leocad [Leo]) with which a 3D model of a real structure can be created in a few minutes. See Figure 1 for a snapshot of a 3D model of a real Lego structure, used for camera calibration.
- The different colors of Lego pieces and their sharp edges help to automatically find correspondences points. Alternatively, it's easy to correct the points provided by the user both in the image and in the 3D model. See next Section for a possible exploitation of this feature.

Figure 1: *Left: a Lego structure. Right: a snapshot of the corresponding 3D model, obtained using Leocad.*

Hence, as suggested in other research projects [Sta], it's very easy for the user to produce its own real and "virtual" calibration rig, by using the pieces at disposal. Instead other known approaches [Gar99], no pre-defined pattern has to be printed and created, only a few simple guidelines (like for example trying to create perpendicular planes, or using pieces with different colors) must be followed to obtain an effective calibration object.

4. The calibration tool and its features

In order to test if the advantages of Lego could lead to an accurate camera calibration, a simple tool was created. A snapshot of the interface is shown in Figure 2: in addition to the windows showing an image and the 3D model, the left side provides a zoom window and the information about the images and the correspondence points. The bottom log windows provides information about the results of calibration.
The calibration is calculated using the Tsai method, hence it's necessary to set at least eleven correspondences between each image and the 3D model. The correspondences are set by the user. During the calibration phase, the camera parameters are calculated for each image of the set, and the statistics of their values (average and standard deviation) is shown in the log window.
As already stated in the previous Section, the peculiarities of Lego structure may help in obtaining a very precise correspondences set. The points indicated by the user are usually

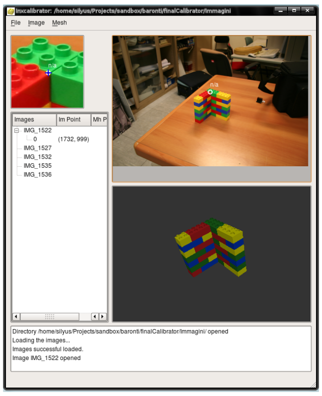

Figure 2: *A snapshot of the interface of the calibration tool*

set in parts of the object which are easily found both on the 3D model and on the image. This can lead to the automatic correction of inaccuracies in the picked points.
Since the points are usually set in the borders between pieces of different colors, or on the corner of a single piece, it's easy to define simple procedures to apply the correction. The points in 3D are replaced with nearest (under a threshold of a few mm) vertices of the 3D model (see Figure 3). In the case of 2D points, a simple Hough transform is able to detect the corner points on the image: the 2D point is replaced by the nearest corner point in an area of a few pixel around it. Figure 4 shows that the correction is applied even when the Lego pieces are a bit damaged.
With the help of this feature, the user doesn't need an extreme accuracy in points setting, so that this operation can be completed in a few minutes.

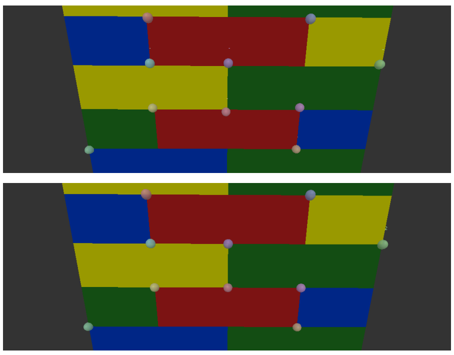

Figure 3: *The position of some points in 3D before and after automatic correction.*

5. Preliminary test and discussion

The validation and comparison of calibration methods is a quite complex task, due to the differences in the methods and to the difficult definition of a ground truth [WM94, RF06].
In our preliminary test, we checked for the stability of the system, by analyzing groups of images taken under the same intrinsic conditions. The preliminary test showed that the tool is able to provide stable results with at least 3 images: the total time needed for calibration (including photo shooting, points picking and parameters estimation) takes nearly 40 minutes for a set of 5 images.
As an example, we show the results for a small set of five images, taken using a Nikon D80 camera, with a focal indicated as 37 in the EXIF metadata. The image set is shown in Figure 5. The number of correspondences for each image was between 13 and 19. We analyzed the results of the Tsai calibration (which calculates the focal lenght, the center and the first coefficient of radial distortion) on all the images and on several subgroups of three images.
Results are shown in Table 1: the obtained values show a low variance. The very low distortion introduced by lenses prevents from an in-depth assessment.
The analysis of the preliminary tests show that the use of a Lego calibration object provides stable data even with a low (three to five) number of images. Moreover, the simple tool proved to be very flexible, since the user can create his own calibration object, and the entire calibration process takes usually nearly half an hour of total work.

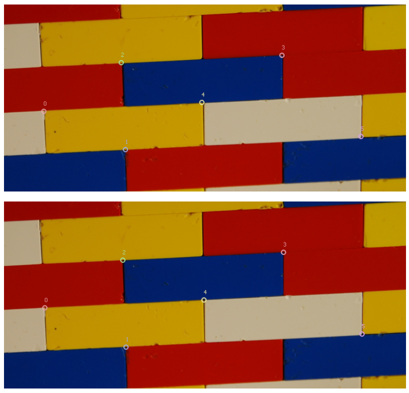

Figure 4: *The position of some points in 2D before and after automatic correction.*

6. Conclusions and future work

In this paper we discussed the use of Lego structures as objects for camera calibration. Lego pieces have several strong-points, like the low cost, the accuracy and the possibility to obtain the corresponding 3D model with freeware tools.
In order to test the real accuracy of the structures, a simple tools was created: automatic correction methods for the correspondences help the user in completing the calibration procedure in a short time. While the results

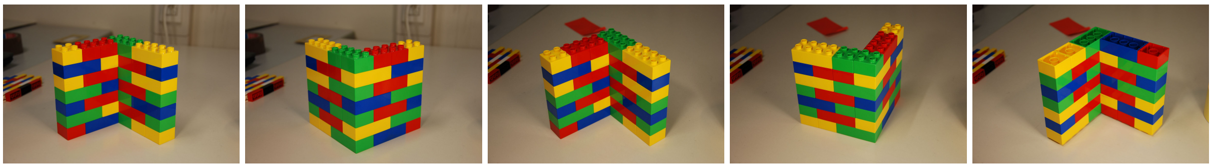

Figure 5: *The five images used for the test.*

Image Subset	Focal Length (Variance)	Dist. Center (Variance)		Dist. Coeff. (Variance)
All	36.76 (0.10)	1935.69 (1.51)	1295.68 (0.09)	3.87e-05 (2.28e-09)
1,3,5	36.99 (0.00)	1935.06 (0.82)	1295.76 (0.09)	4.38e-05 (2.02e-10)
1,3,4	36.84 (0.03)	1935.50 (1.84)	1295.65 (0.03)	1.84e-04 (2.44e-09)
2,4,5	36.62 (0.12)	1936.54 (0.70)	1295.77 (0.12)	2.57e-05 (1.28e-09)
2,3,4	36.57 (0.08)	1935.84 (1.86)	1295.61 (0.05)	1.82e-05 (2.15e-09)

Table 1: *Results of the calibration for the image set and some of the subgroups*

of the preliminary tests are encouraging, further testing is needed: in particular, the calibration of wide-angle lenses and the comparison with other available tools will show the robustness and usability of the method.
In conclusion, a promising and easy way of using off-the-shelf objects for an important preliminary step for several CG and CV applications have been shown: in this way, the calibration of a digital camera could become something that can be easily and accurately done at home.

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