CALIBRATION OF 3D KINEMATIC SYSTEMS USING 2D CALIBRATION PLATE

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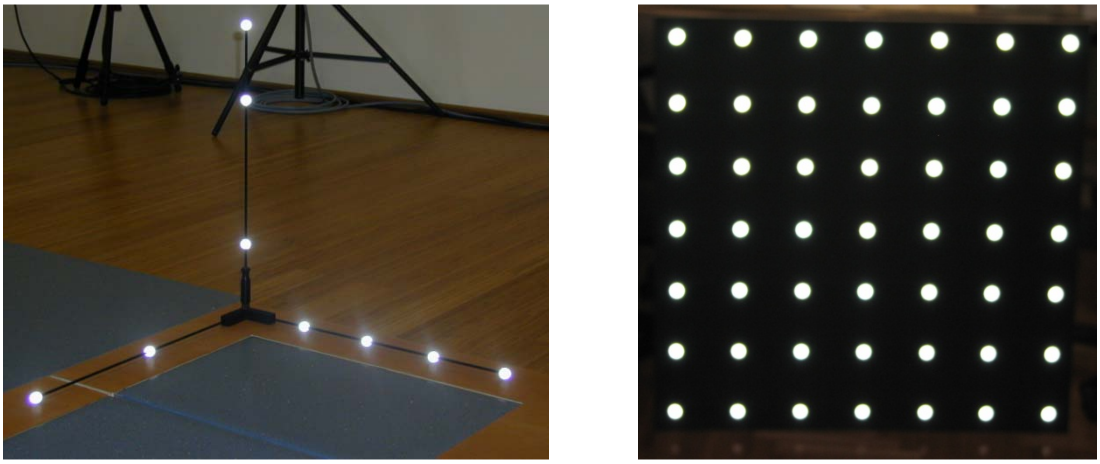
3D kinematic systems based on the images acquired by cameras are one of the most popular tools for a human motion analyses. Prior to the actual reconstruction a camera calibration procedure is needed. Originally 3D calibration cages were utilized for that purpose, but nowadays a vast majority of commercial systems rely on the wand calibration. When the highest degree of accuracy is requested, than using 3D calibration cage is often recommended over the wand calibration. On the other hand, from a user point of view a wand calibration is generally regarded as the most user friendly. A substantial 'intermediate' solution would be using 2D calibration plate. Interestingly, there could be hardly found any trace that commercial 3D kinematic systems ever relied on 2D calibration plate. The purpose of this study was to investigate quantitative and qualitative aspects of calibrating the 3D kinematic system using 2D calibration plate.

KEY WORDS: 3D kinematic system, camera calibration, 2D calibration plate, wand calibration

INTRODUCTION:

A system based on the photogrammetric principles is certainly one convenient approach for motion analysis (Allard et al. 1995), since generally it does not constraint subject movement. It is based on processing images acquired by cameras. Typically, the very first parameters available from such 3D reconstruction system are kinematic parameters, e.g. position, velocity, acceleration. Hence, one often refers to it as 3D kinematic systems. A necessary step before the actual 3D reconstruction is a camera calibration (Salvi et al. 2002). Process of a camera calibration came across many stages of improvements during the last few decades. One aspect of the improvement is witnessed by particular calibration tool that user normally uses to calibrate camera of 3D kinematic system. It went from, traditionally, manipulation of cumbersome 3D cages to nowadays sweeping the volume with only a single wand of the known length, i.e. so called wand dance (Cerveri et al. 1998, Pribanić et al. 2007). Indeed, a number of popular and commercially available systems offer wand calibration (e.g. BTS/Elite, MotionAnalysis, Vicon Motion Systems 2008). In principle, precisely and accurately fabricated 3D calibration cage is regarded as the most reliable calibration tool. On the other hand, most practical difficulties concerned with traditional 3D calibration cage can be nicely overcome with a calibration wand: there is no problem of storage of a fairly large 3D object, fabrication is relatively simple and cheap, spatial maneuvering is straightforward and allows for a convenient determination of calibration volume size. However, a wand calibration is typically two step procedure (Figure 1 a)). In the first step an initialization of camera parameters is required through imaging of a orthogonal triad of wands with relatively small number of calibration points on it (e.g. 9 points, just about enough to compute only a rough estimates for cameras' parameters). In the second (refinement) step a so-called wand dance is preformed where the users walks throughout the space and tries to image the wand of known length on as many locations/orientations in the space possible and simultaneously by as many cameras as possible. Clearly, now a sequence of images is required and the actual physical constraint enforced during this type of calibration is known wand length(s). Note that when using 3D cage then a single image is, as rule, sufficient.

An interesting alternative that combines certain strengths of 3D calibration cage and wand calibration is a calibration using 2D calibration plate (Figure 1 b)). It has a certain number of coplanar calibration points which positions are also accurately known within a plane. Such approach is presently very popular among many researches, particularly within computer vision community, and even variety of freely available software can be found (OpenCV, 2008). Nevertheless, it appears that 2D calibration plate never become part of commercially available 3D kinematic system, aimed at human motion analysis. In this work we have preformed certain experiments calibrating commercially available 3D kinematic system using 2D calibration plate. Moreover, in the next sections we show and discuss both calibration and reconstruction results after wand calibration and 2D plate calibration.



a) b)

Figure 1: a) Wand calibration: orthogonal triad of wands used for initialization of camera parameters and definition of spatial coordinate system; vertical wand (3 markers on) can be detached and used for a wand dance. b) 2D plate calibration: 7×7 coplanar calibration points.

METHOD:

In our experimenting we have used the popular commercial 3D kinematic system Smart (version 1.10, Build 2.39; BTS 2008). The experimental setup consisted of 9 cameras (50 Hz). The first experiment assumed a typical wand calibration as proposed by Smart: an initialization step assumes imaging of rather small number of calibration points, but it is meant only for a computation of rough estimates for camera parameters and for the definition of spatial coordinate system according to user requests. This initial phase is followed by a wand dance (refinement phase) with a single wand for approximately 60 seconds. The second experiment used an approach where we have calibrated cameras using our own calibration routines (coded in Matlab) and accurately fabricated 2D calibration plate. Our calibration plate has had 7×7 markers on, i.e. circular stickers which were made of the same retroreflective material as ‘regular’ Smart markers. The markers diameter was 20mm and they were 150mm apart. The implemented algorithm for 2D calibration followed the idea presented by Zhang (2000). The ‘2D plate dance’ lasted also roughly 60 seconds, during which we have tried (similarly as with calibration wand) to image 2D calibration plate on as many locations/orientations in space with respect to cameras. Laying down the 2D calibration plate at the end of plate dance allowed the definition of a spatial coordinate system and computation of cameras’ external parameters, all with respect to the common spatial coordinate system. The experimental volume was approximately 4.0m × 2.0m × 2.0m. Besides 3D reconstructed data, we were also able to export from the Smart system 2D image data of calibration wands and plate markers. We have used those data for the subsequent experimental evaluation. To evaluate the quality of a calibration result we use the common static test where some form of ground truth information is available (Chen et al., 1994). In more detail, a wand of known length is imaged and reconstructed for a large number of positions/orientations in space. Essentially, we processed a separate data set, not used for calibration. That wand dance also covered the entire calibration volume and lasted as well approximately 60 seconds. The standard deviation and absolute mean error between the true wand length (450mm) and the reconstructed ones were used as one of the accuracy measures. Besides, we show one of the quantitative descriptors of the camera calibration itself: the standard deviation and absolute mean error between the detected image coordinates of markers and image coordinates as determined by the camera function model. In fact those 2D residuals are available on the screen in case of Smart wand calibration, after the user finishes calibration procedure.

RESULTS:

Table 1 Absolute mean error and standard deviation between detected image coordinates of calibration markers and image coordinates computed by camera function model.

Camera	Wand Calibration		2D plate calibration	
	Mean[pix.]	Std[pix.]	Mean[pix.]	Std[pix.]
1	0.232	0.155	0.142	0.101
2	0.125	0.081	0.168	0.127
3	0.140	0.090	0.144	0.110
4	0.127	0.075	0.109	0.079
5	0.110	0.074	0.135	0.093
6	0.131	0.079	0.139	0.090
7	0.111	0.071	0.157	0.078
8	0.116	0.077	0.124	0.073

Table 2 Mean error and standard deviation between wand's known lengths (450mm) and reconstructed lengths obtained from five different experimental trials.

Trial	Wand Calibration		2D plate calibration	
	Mean[mm]	Std[mm]	Mean[mm]	Std[mm]
1	0.659	0.793	0.725	0.817
2	0.712	0.811	0.840	0.848
3	0.707	0.823	0.690	0.780
4	0.722	0.830	0.772	0.839
5	0.749	0.838	0.715	0.801

DISCUSSION:

Representative typical results from an extensive experimenting (Table 1 and Table 2) indicate that from the point of accuracy wand calibration and 2D plate calibration perform about equally well. It is beyond the scope of this paper to undertake deeper statistical analyses revealing ultimately if such small differences are statistically significant or not. Moreover, we believe there is large body of applications were such small differences would not come into effect, even if statistically significant difference were existing, due to 'masking' of other potential sources of errors in practical measurements on the human subjects. For example, artefacts caused by skin movement or problems with attaching the markers exactly on the certain anatomical points are typical far greater than few tenths of millimetres. In addition, system provided kinematic data are frequently further used to compute kinetic parameters by the means of inverse dynamic approach. In that procedure, computation of so called body segment parameters (e.g. mass, volume, segment's centre of mass, principal moments of inertia) are regarded as more serious sources of error than kinematic data itself. Finally even when evaluating only one method, we can obtain evaluation results differing easily by few tenths of millimetres. For a given volume this is quite expected. For instance, during certain experimental trial it is quite possible that we obtain image sequence where either test object has been seen, most of the time, by fewer cameras and/or very close to the boarders of the calibration volume.

Therefore, it would appear initially that wand calibration is a method of choice since it is, in principle, more convenient. Nevertheless we would like to point out several advantages of calibrating with 2D calibration plate that we feel they are worth of considering. Tracking of the wand markers throughout the camera frames, just like any kind of markers, could be quite challenging if one is not typically using infrared cameras particularly sensitive on (infrared) markers coated with a special material. On the other hand, tracking the 2D calibration plate is, as rule, considerably easier compared to just a wand, when using regular (cheaper) video cameras. Moreover, the calibration plate in the single image provides a lot more (redundant) calibration data. Consequently, 2D plate calibration could potentially last shorter. In addition, to calibrate a specific camera it is not necessary for the 2D plate to be visible by at least one more camera (as with wand dance). In principle, it is necessary only one common view of 2D plate for all cameras in order to compute cameras (external) parameters with respect to common spatial coordinate system. This bring us actually to an important conclusion that typical two step wand calibration procedure could be boiled down into single one, as it has been in our experimenting. Namely, the first typical calibration step when using a wand, in the case of 2D plate calibration is necessary neither for the camera parameters initialization nor for the definition of a spatial coordinate system. The later request is neatly fulfilled simply by laying down a calibration plate at the end of 'plate' dance, making it therefore visible to all cameras in at least one frame. Finally one may argue that spatial wand manoeuvring is considerably easier than with two-dimensional object. However, 2D plate could be also made from extra light material and attaching, for instance, the single bar at the back of it as type of handle, would make it possible to move it around almost as easily as a single wand. It is true that fabrication of such 2D plate would increase the cost, but we believe this extra cost would not become an issue considering the total price for some commercial 3D system.

CONCLUSION:

It would be unreasonable to unconditionally favour any type of calibration over all others. Nevertheless, this study identified the most important advantages when calibrating 3D kinematic system using 2D calibration plate. Additionally, an extensive experimenting based on which a couple of tables with qualitative results are provided, revealed that when in comes down to the ultimate 3D reconstruction accuracy then 2D calibration is in the line with a popular wand calibration. Therefore, we feel that 2D calibration plate offers still unused potential when it comes down to a calibration of 3D kinematic systems, and our future work may strive in that direction.

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