

A PLANE-BASED CALIBRATION PROCEDURE FOR THE 3D ANALYSIS OF VIDEO RECORDINGS IN DISCUS THROWING DURING COMPETITION

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Standard procedures for the calibration for 3D video measurements in sports biomechanics are the recording of a spatial calibration frame or the wand calibration. Both methods require access to the competition site, which often is not allowed in international championships. Therefore, alternative calibration routines are needed that utilize the geometric conditions of the competition site. For the calibration of 3D video recordings in discus throwing a new method is introduced. It is based solely on given coordinates of spatial control points in the background and the known interior camera parameters. After introducing the solution steps, the method is validated by comparing it to established standard methods using model data. The applicability of this method is demonstrated by analysing discus competition recordings.

KEY WORDS: videogrammetry, calibration, 3D, discus throwing.

INTRODUCTION:

The atmosphere of international championships often motivates athletes to achieve their top-performances. Obviously, detailed knowledge of these performances is of particular interest. A common method to gather such information is the analysis of video recordings. A typical problem for the calibration of the cameras results from the regulations for international championships: it is usually not allowed to enter the competition area. Therefore, the most common routines for camera calibration based on spatial control points or sets of well distributed homologous points (Direct Linear Transformation (DLT), wand calibration) cannot be applied. Alternative methods utilize geometric constraints of the sports field. Ariel et al.

(1997) previously used such geometric information as well as anatomical landmarks of the athletes for calibration. For example, the geometry of the discus throwing facilities (figure 1) can provide markers for the spatial position in a two-dimensional plane whereas the vertical component can be generated by the height of the athletes. Based on these spatial control points the DLT method can be applied. It has been shown by Drenk & Hildebrand (2002) that the reconstruction of 3D-data can also be solved by multiple

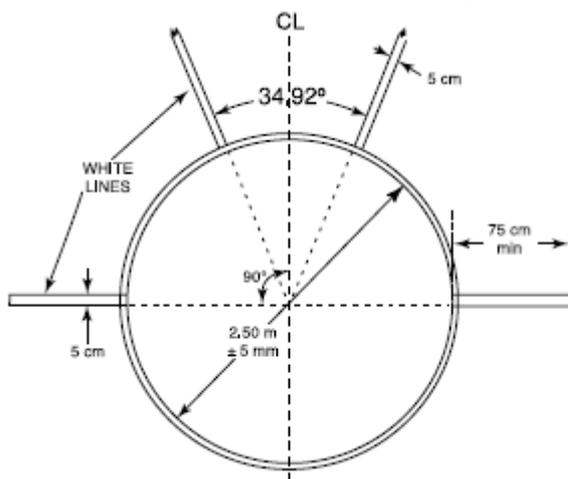


Figure 1: Layout of discus throw circle

views of the same plane from different panning angles.

Numerous studies of alternative calibration methods have been published in the field of computer vision. Here the reconstruction of the orientation parameters of the camera from planar geometric structures is a well studied problem. A solution presented by Zhang (1999) is based on the recording of a well known planar pattern from different perspectives. Sturm & Maybank (1999) allow an arbitrary number of views and calibration planes and the integration of existing interior parameters. Our approach aims at a geometric interpretation of orientation parameters as in Gurdjos et al. (2002). They calculate the centre circle from the homography between the object and image plane and show the connection to the Poncelet

theorem. Their method assumes the interior parameters to be unknown, so that several views are required. Moreover, in their cost function the distances of the projection centres to the centre planes defined by them have to be minimized. Therefore the application of the PTZ (Panning, Tilting, Zooming)-algorithm (Drenk 1994) for iterative solution finding is a new feature.

METHODS:

Figure 2 and 3 present the geometric relations and the recording setup for validation. Figure 3 shows the orientation of the calibration cube from the view of the camera. The model scene was constructed like this: The object plane is at $z=0$. The optical axis is tilted by 10° relating to the negative y -axis, its projection centre C is $(6.08, 8.10, 1.48)$. The rolling angle is 0° . The image area in pixels is $(768, 576)$, aspect ratio=1. The principal point is the image centre. The calibration frame is a cube with dimensions 1.50 m, translated from the origin by $(5.5, 3, 0)$.

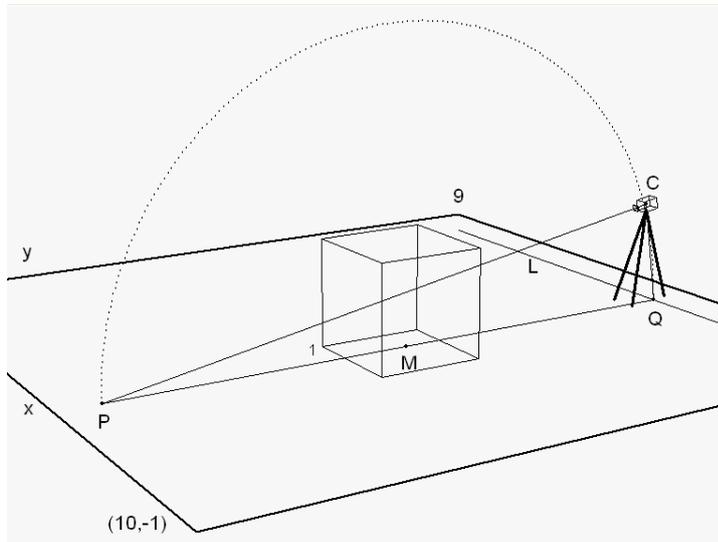


Figure 2: View of the model scene

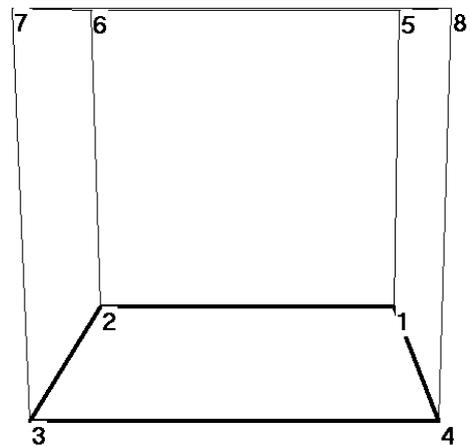


Figure 3: Cube seen from the camera

It is assumed that there is a camera image of a planar scene with four or more control points. Aspect ratio and position of the principal point of the camera must also be available. Normally, these parameters can be determined easily in advance. In addition, the camera configuration is assumed to be stable and well-known. The solution consists of the following steps:

1. Determination of the 2D DLT parameters a_1 - a_8 by evaluating the control points in the object plane $z=0$, i.e. in the bottom plane of the cube. The following holds:

$$x' = \frac{a_1x + a_2y + a_3}{a_7x + a_8y + 1} \quad y' = \frac{a_4x + a_5y + a_6}{a_7x + a_8y + 1} \quad (1)$$

2. Calculation of the following parameters in the object plane:
 - The intersection line L between the plane parallel to the image plane through the projection centre and the object plane. It is determined by the line equation in the denominator of (1).
 - The point P in the object plane that is assigned to the principal point is calculated by the evaluation of (1) for the principal point.
 - Perpendicular point Q from P to L
3. The half circle (Thales circle) over \overline{PQ} in the plane perpendicular to the object plane is the geometric locus of the projection centre. This follows from the optical axis being perpendicular to the image plane.
4. Modelling of a camera with these specifications:

- Principal point and aspect ratio as given
- Angle between axes of image coordinate system 90°
- The optical axis is line CP

The remaining parameters are noncritical and can be determined heuristically.

- The projection centre passes now through a half circle. For each local point the PTZ algorithm can be applied. This algorithm was expanded by a rotation about the optical axis (rolling). The PTZ algorithm answers the following question: how the camera has to be rotated in the centre of rotation C and how the focal length has to be adapted to locate the projection of the control points in the image plane as close as possible to the measured position (cost function: sum of squared Euclidean distances)?
- The search area will be reduced to a plausible section of the circle arc. The step width is chosen in a way that the projection centre can be calculated at designated accuracy (1 cm). The position of the projection centre with minimum distances is required, the camera calibration results from the output parameters of the applied PTZ procedure.

The Thales circle has been used earlier by Drenk & Hildebrand (2002) to calculate the projection centre. Due to the wide-ranging area of control points an alternative method has been used to determine the projection centre on the circle arc. The locus of the panning axis was reconstructed from multiple tripod based views with different panning angles and constant interior orientation. Additionally, the centre of the circle in the object plane covered by the intersection lines L was calculated. Then, the projection centre is located with good approximation on the panning axis.

RESULTS AND DISCUSSION:

The evaluation of steps 1-6 of our model scene resulted in the following:

Table 1 Validation results

	DLT	Plane-based calibration	Model
projection centre x y z	6.09 8.06 1.47	6.08 8.07 1.48	6.08 8.10 1.48
control point	image coordinates of control points		
	complete	lower plane	
1	494 398	494 398	
2	211 398	211 398	
3	143 509	143 509	
4	537 509	537 509	
5	499 110		
6	202 110		
7	126 108		
8	549 108		

Considering that the measurements were made without sub-pixel accuracy, the result is very satisfying. Geometric information about the orientation of lines at the discus throw circle can be derived from the competition regulations (figure 1). By simple intersection relations a sufficient number of control points can be generated. The discus throw circle is embedded in a quadratic platform of 4 m length. Instead of the reconstructable points of the throwing circle the vertices of this platform were used, because they cover a larger area of the object plane (figure 4). Therefore a higher accuracy for the calculation of the 2D DLT parameters can be expected. Video recordings were done by DV cameras with clearly defined principal point (360, 288) and aspect ratio (0.9375). The search area was delimited for the z-interval (0.5 m, 2m). Using the plane-based calibration first the projection centres (left: camera: (2,85,-4.55,1.07), right camera: (9.74,1.96,1.15) and then the complete calibrations were calculated. The resulting positions of the projection centres are very plausible.

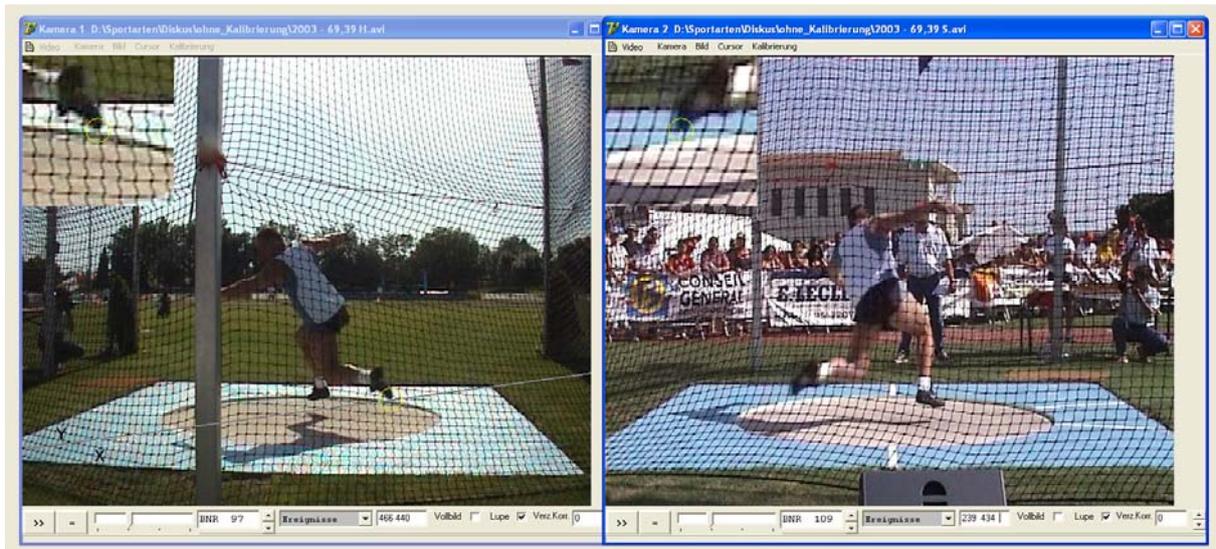


Figure 4: Screenshot of the implemented measurement program

The implemented measurement program allows to measure simultaneously in both views by displaying epipolar lines. If the epipolar line from the second view is collinear with the object point from the first view, the correct calibration of both cameras is confirmed. This was valid for the whole evaluated sequence. In figure 4 right the top of the left foot was selected. The analysis of this competition succeeded.

CONCLUSION:

Spatial calibration frames are part of standard equipment of biomechanic measurement teams. Their application guarantees a high accuracy of the measurements based on video recordings. It has been shown in this paper that 3D-analyses are also possible provided these calibration frames cannot be used. Despite reduced information on planar control points the orientation of the cameras can be calculated accurately. The spectrum of established calibration routines for sports (biomechanic) measurements is completed reasonably by the method presented in this paper. It has been applied additionally in canoeing and swimming. Further application areas are ball sports (e.g. volleyball, tennis), where the playground marks provide accurate planar information.

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