M. Mössner, P. Kaps, and W. Nachbauer,
Smoothing the DLT-Parameters for Moved Cameras,
XVth Congress of the International Society of Biomechanics, 1995

Reference: M. Mössner[1], P. Kaps[2], and W. Nachbauer[3], *Smoothing the DLT-Parameters for Moved Cameras*, Book of Abstracts: XVth Congress of the International Society of Biomechanics (ISB) (Jyväskylä, FI) (K. Häkkinen, K.L. Keskinen, P.V. Komi, and A. Mero, eds.), University of Jyväskylä, 1995.

Introduction

For many sport-biomechanical analyses, e.g. in Alpine ski racing, the athletes have to be filmed over a large object space. To digitize body landmarks a sufficiently large image of the athlete is necessary. Thus, one has to follow the athlete with the cameras and to zoom the lenses. Our group collected data of the jumping movement during the downhill events of the 1994 Winter Olympic Games in Lillehammer. For 3-D reconstruction the DLT-parameters were calculated for every frame of each camera separately [1]. The data reconstructed by this method were suitable for computing resultant knee joint forces and moments by inverse dynamics [2]. Since the control points were surveyed geodetically, errors in the reconstruction are mainly caused by digitization. In [2] the errors in calibration were averaged by using 10 control points. If only 6 control points are available the reconstruction error might be enlarged by more than an order of magnitude. For frames with less than 5 control points the DLT-parameters can not be determined. In the present paper the DLT-parameters are smoothed to overcome these difficulties.

Method

Direct Linear Transformation. Between a space point with object coordinates $(X,Y,Z)^t$ and its image coordinates $(x,y)^t$ it holds the relation:

$$(1) \qquad x = \frac{b_1X + b_2Y + b_3Z + b_4}{b_9X + b_{10}Y + b_{11}Z + 1}, \qquad y = \frac{b_5X + b_6Y + b_7Z + b_8}{b_9X + b_{10}Y + b_{11}Z + 1}\,.$$

The coefficients $b_1, \ldots, b_{11}$ are called DLT-parameters. From the basic photogrammetric relations Hatze [3] obtained a condition for the DLT-parameters which can be written as follows [1]:

$$(2) \quad (b_9^2 + b_{10}^2 + b_{11}^2)(b_1b_5 + b_2b_6 + b_3b_7) = (b_1b_9 + b_2b_{10} + b_3b_{11})(b_5b_9 + b_6b_{10} + b_7b_{11})\,.$$

Calibration. The DLT-parameters are computed for every frame of each camera. The image and the object coordinates of at least 6 control points are inserted into Eq 1. By multiplying Eq 1 with the denominators one obtains an overdetermined linear system for the DLT-parameters. The results can be used as initial guess for

[1]Dept. of Sport Science, Univ. Innsbruck, AT. email: Martin.Moessner@uibk.ac.at
[2]Inst. for Basic Sciences in Engineering, Univ. Innsbruck, AT
[3]Dept. of Sport Science, Univ. Innsbruck, AT

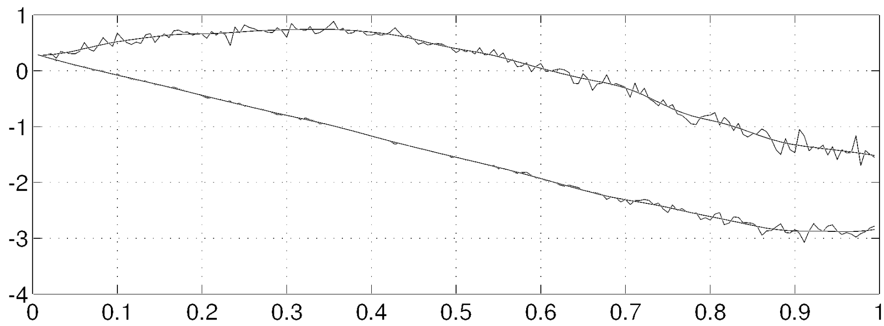
solving the nonlinear system Eqs 1,2 by standard Newton techniques. For smooth camera movements the DLT-parameters are smooth functions of time which are approximated by smoothing splines.

Reconstruction. The 3-D object coordinates of an unknown space point are computed from its coordinates in synchronized images of two cameras. Inserting the DLT-parameters and the image coordinates into Eq 1 yields four linear equations in the unknown object coordinates.

Data Collection. The investigation is based on a data set which shows the flight and the landing phase of a ski racer [2]. The 3-D reconstruction of 23 landmarks was done for 180 frames taken at a rate of 180 fps. In 95 % of the frames 10 control points were used for calibration. The smoothing spline approximations to the reconstructed 3-D coordinates of the landmarks are the best solutions available and therefore taken as „true“ solutions for error estimations. The error of a certain reconstruction is defined by the absolute values of the differences to the „true“ solutions averaged over the 23 landmarks, the 180 time steps, and the 3 coordinates. The error of the above data is 3.8 cm.

Results

For illustration we give a plot of the DLT-parameters b_5 and b_6 together with the corresponding smoothing splines:



Smoothing the DLT-parameters reduced the error to 3.3 cm. The effect of smoothing the image coordinates was investigated, too. It reduced the error to 2.9 cm. Smoothing both DLT-parameters and image coordinates halved the error to 2.0 cm. The smoothing parameter had to be chosen carefully, since oversmoothing resulted in drifting away from the true solution.
To estimate the effect of hidden control points frames 50 to 70 as well as frames 110 to 130 were not calibrated. As DLT-parameters we used the interpolation values of the smoothing spline. This resulted in an error of 2.3 cm.
A reconstruction based on a calibration using only six control points gave an error of 70 cm. By omitting time steps with obviously wrong DLT-parameters and successive smoothing the error could be reduced to 6.7 cm.

Discussion

The results show that smoothing of DLT-parameters can successfully be applied to reduce the influence of digitization errors on the calibration and to interpolate the DLT-parameters in cases where the calibration is impossible over same frames. However, the smoothing parameter can not yet be determined automatically.

References

[1] M. Mössner, P. Kaps, and W. Nachbauer, *A Method for Obtaining 3-D Data in Alpine Skiing Using Pan and Tilt Cameras with Zoom Lenses*, Skiing Trauma and Safety, 10th vol., ASTM STP 1266 (Philadelphia, US-PA) (C.D. Mote, R.J. Johnson, W. Hauser, and P.S. Schaff, eds.), American Society for Testing and Materials (ASTM), 1996, pp. 155–164.

[2] W. Nachbauer, P. Kaps, B.M. Nigg, F. Brunner, A. Lutz, G. Obkircher, and M. Mössner, *A Video Technique for Obtaining 3-D Coordinates in Alpine Skiing*, Journal of Applied Biomechanics **12** (1996), 104–115.

[3] H. Hatze, *High-Precision Three-Dimensional Photogrammetric Calibration and Object Space Reconstruction Using a Modified DLT-Approach*, Journal of Biomechanics **21** (1988), 533–538.