SMOOTHING THE DLT-PARAMETERS FOR MOVED CAMERAS

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Introduction

For many sport-biomechanical analyses, e.g. in Alpine ski racing, the athletes have to be filmed over a large area. 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 flight and the landing phase of a ski racer during the downhill event of the 1994 Winter Olympic Games in Lillehammer. Here smoothing techniques are investigated to improve the accuracy of reconstruction.

Data Collection

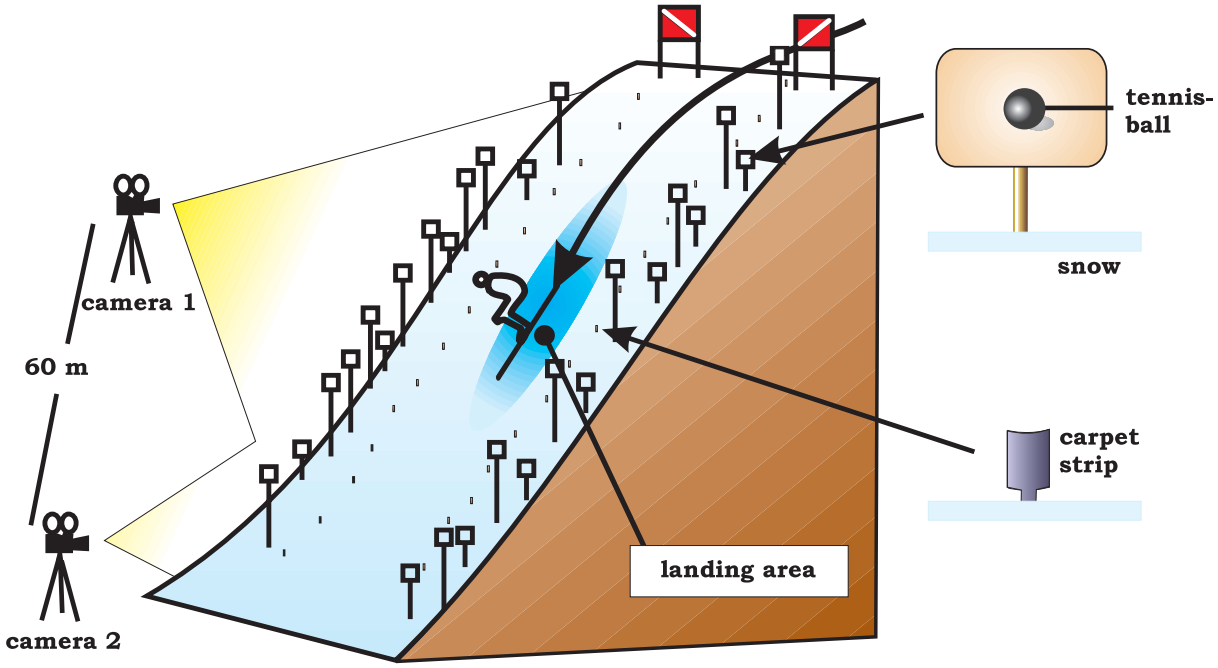


Fig. 1: Schematic illustration of the experimental setup

Control points (carpet strips, tennis balls) were distributed over the slope and their coordinates determined by geodetical surveying techniques. The movement of the skier was recorded by two high speed video cameras at a sampling rate of 180 Hz.

The method of reconstruction requires at least 6 control points visible in each frame. The use of 10 or more control points is recommended. The image coordinates of the control points and 23 landmarks were digitized on a 15" screen (Photo). In 95 % of the frames 10 control points were digitized.

Direct Linear Transformation (DLT)

For 3-D reconstruction we use a direct linear transformation technique. Between a space point with object coordinates $(X, Y, Z)^t$ and its image coordinates $(x, y)^t$ it holds the relation:

$$(1) \qquad \begin{aligned} x &= \frac{b_1 X + b_2 Y + b_3 Z + b_4}{b_9 X + b_{10} Y + b_{11} Z + 1}, \\ y &= \frac{b_5 X + b_6 Y + b_7 Z + b_8}{b_9 X + b_{10} Y + b_{11} Z + 1}\,. \end{aligned}$$

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

$$(2) \quad (b_9^2 + b_{10}^2 + b_{11}^2)(b_1 b_5 + b_2 b_6 + b_3 b_7) = (b_1 b_9 + b_2 b_{10} + b_3 b_{11})(b_5 b_9 + b_6 b_{10} + b_7 b_{11})\,.$$

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 equation (1). By multiplying (1) with the denominators one obtains an overdetermined linear system for the DLT-parameters. The results can be used as an initial guess for solving the nonlinear system (1,2) by standard Newton techniques.

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 (1) yields four linear equations in the unknown object coordinates.

Smoothing. In order to minimize reconstruction errors one attempts to smooth internal data such as the calibration parameters. Since in normal cases the movement (panning, tilting, ...) of the cameras is smooth relative to the skier, smoothing this data by spline techniques is safe. In Fig. 2, we illustrate the benefit of smoothing on the DLT-parameters b_5 and b_6.

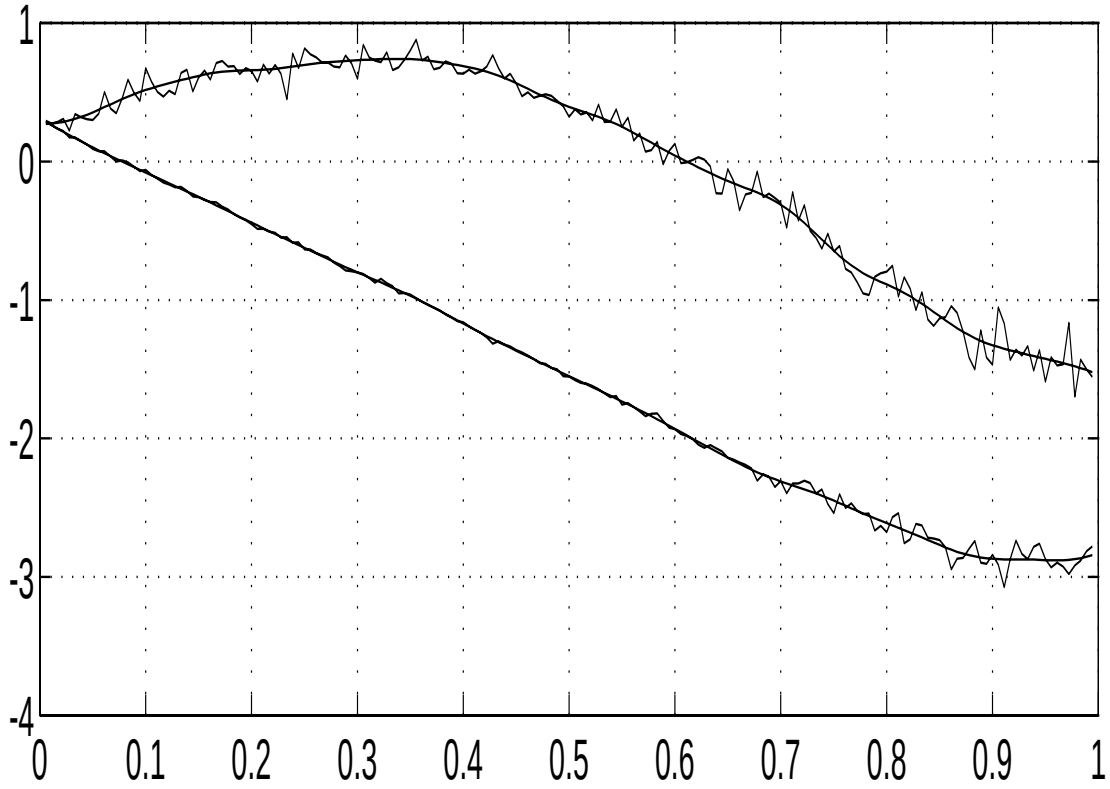
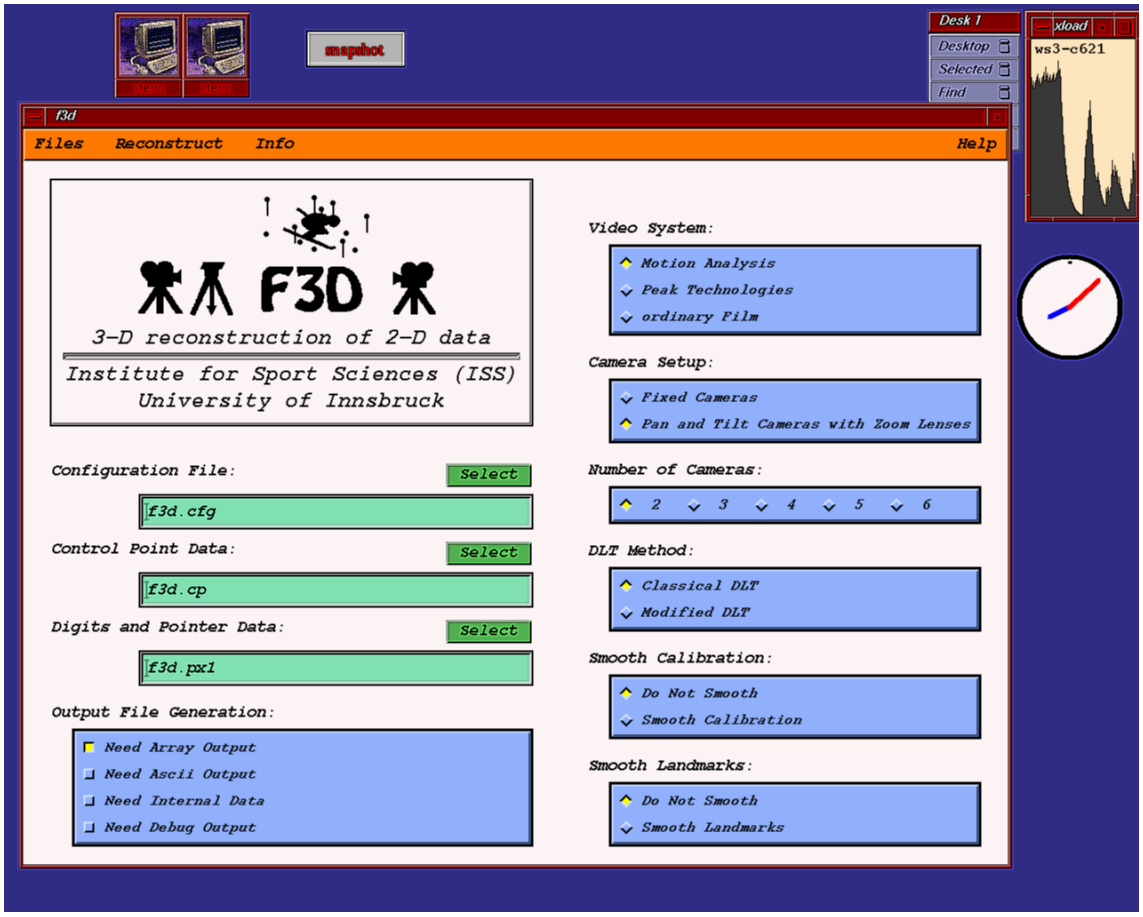


Fig. 2: Calibration parameters b_5 and b_6, unsmoothed and smoothed.

Smoothing the image coordinates requires experience to get valuable results. Especially in the case of impact forces (landing phase), smoothing could lead to erroneous reconstructions. In any case, the average amount of image coordinate smoothing should be less than the size of one or two pixels.

The Reconstruction Software

f3d is a software package for 3-D reconstruction of 2-D data. In its current version 3.0, it consists of the XMotiv-style input menu f3d and the working program f3d_core. The package works on an HP 715 workstation. It will be ported to other platforms soon.



f3d reads files for control points, pointers, and image coordinates. The first two files contain control point related information and have to be supplied by the user. The third file, the image coordinates, can be supplied from either Motion Analysis or Peak Technologies Videosystem directly. Depending on the selections of the user, f3d performs a reconstruction for fixed or for panned and tilted cameras with zoomed lenses. Data from up to 6 cameras are supported by the software. Additionally, the user may decide to use the standard or the modified DLT approach and to apply smoothing. For further details, we refer to the instruction manual [2] which will soon be available in an updated English version.

Results

Smoothing spline approximations of the reconstructed 3-D coordinates of the landmarks are taken as "true" values for the error estimation. These values are the best solutions available. The error of a certain reconstruction technique is defined by the absolute values of the differences between the "true" solutions and the reconstructed values averaged over the 23 landmarks, the 180 time steps, and the 3 coordinates.

Error reduction by smoothing. Without applying the proposed smoothing technique, the error of the reconstruction was 3.8 cm. By smoothing both, the calibration parameters and the image coordinates of the landmarks, the error was reduced to 2.0 cm (Table). The smoothing parameters had to be chosen carefully, since oversmoothing resulted in drifting away from the true solution.

Method	Error [cm]
no smoothing	3.8
smoothing the DLT parameters	3.3
smoothing the image coordinates	2.9
smoothing both	2.0

Table: Effect of smoothing on the reconstruction error

Uncalibrated frames. To imitate the effect of missing 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 splines. This resulted in a slightly higher error of 2.3 cm.

Minimal number of control points. Using only six control points for calibration resulted in an error of 70 cm. By omitting frames with obviously wrong DLT-parameters and successive smoothing, the error could be reduced to 6.7 cm.

Conclusion

The results show that smoothing of the DLT-parameters or the image coordinates of the landmarks 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 some frames. However, the smoothing parameter cannot yet be determined automatically.

References

[1] H. Hatze (1988) High-precision three-dimensional photogrammetric calibration and object space reconstruction using a modified DLT-approach, *Journal of Biomechanics*, **21**, 533–538.

[2] M. Mössner (1994) F3D, Version 2.2, Instruction Manual, Department of Sport Science, University of Innsbruck, Austria (German).

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