PHOTOGRAMMETRIC EVALUATION PROCEDURES FOR PANNABLE AND TILTABLE CAMERAS OF VARIABLE FOCAL LENGTH

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INTRODUCTION

In many sports there is a wide range of action in relation to the body height. Therefore the camera has to track the athlete for photogrammetric recordings to keep him/her within the image. Depending on the kind of action and the camera location panning, tilting or zooming of the camera is required or a combination of these opportunities. Thus competition analyses become possible in many cases at all.

Necessary prerequisites to' apply these motion opportunities of the camera are adequate photogrammetric evaluation procedures. This paper presents a general functional approach for the photogrammetric procedure of pannable, tiltable cameras of variable focal length.

For an accurate quantitative evaluation of wide-range athletic movements additional presuppositions concerning the conditions for recording and for an evaluation have to be fullfilled. An essential additonal effort is the permanent operation of the camera. Our procedures additionally require recordings with the camera fixed on a tripod and, as a rule. measuring additional control points which have to be digitalized in any frame.

METHODOLOGY

By tilting and panning the optical axis the exterior orientation of a camera and by varying the focal length the interior orientation of a camera are permanently changed. As a rule any picture has other orientation parameters. In case of tripod based camera turns the changes in orientation conditions can be functionally described in relation to the tripod geometry. The tripod based camera turns are principally done by panning the camera around a fixed-standing, axis. The tilting axis is turned along. It stands perpendicular to the panning axis and does not change its relative location towards the panning axis. The optical axis is moved along when panning and tilting the camera, it intersects the panning axis and is perpendicular to the tilting axis.

Presupposed the locations of the spatial axes around which the optical axis is rotated, the values of the respective angles of rotation and the variations in focal length in relation to an initial image are known the new camera orientation is geometrically definite. But the direct description of the transformation conditions of the'perspective image is complicated, especially when the camera orientation of the initial image is in DLT-parameters which is common for biomechanical application's.

The solution presented is based on the finding that the rotation of the camera axis and the contrary rotation of the spatial system have the same effect in the image. Thus the calculation of the transformation parameters can be separated from the determination of the camera orientation.

We define

a1,a2,...,a11 as DLT-parameters for a certain frame (calibration image, initial image)

p=(x,y,z) as control point

p'=(x',y') as image point of p in the compararor plane according to the projection model

pm'=(xm',ym') as measured image coordinates of p in the comparator plane

c	as factor of variation in focal length with respect to the calibr. image
d,M,w	as polar vector of a rotation axis, any point on it, angle of rotation
D=D(d,w)	as Euler's rotation matrix for the rotation defined by d and w
ds,Ms,ws,Ds	as respective terms for panning axis rotation
dn,Mn,wn,Dn	as respective terms for tilting axis rotation
xvh',yvh'	as principal image point displacements with respect to the location of the principal point in the calibration image.

A spatial point is taken to a new position by rotation **D(p-M)+M** (1)

From the general approach for the projective relation in the calibration image

$$x' = \frac{a_1x + a_2y + a_3z + a_4}{a_9x + a_{10}y + a_{11}z + 1}, \qquad y' = \frac{a_5x + a_6y + a_7z + a_8}{a_9x + a_{10}y + a_{11}z + 1}, \tag{2}$$

the following equations derive from the rotations of the spatial point around the panning axis .and around the turned along tilting axis as well as from the variation in focal length and the principal image point

$$\begin{aligned} x' &= F1(a_1, a_2, a_3, a_4, a_9, a_{10}, a_{11}, D_s, M_n, D_n, M_n, c, xv_h, p) \\ y' &= F2(a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11}, D_s, M_n, D_n, M_n, c, yv_h, p) \end{aligned} \tag{3}$$

For several control points a non-linear equation system is derived from the equations (3). This system is solved iteratively according to the least squares method which is common in the photogrammetry - to find the best synchronization of image coordinates of p' and pm'.

The general approach allows a calculation of all unknown parameters in (3), presupposed there are sufficient control points in the image. But in practice we mostly only have to calculate the panning and tilting angle and the variation in focal length. The other parameters are to be measured respectively to be considered unchanged. To do this two control points are sufficient.

The spatial parameters of the panned along tilting axis are not to be iteratively calculated in (3). but we get it in any iteration step in accordance with the following procedure:

Calculation of the location of the optical axis from the actual JILT-parameters.

Panning of the optical axis around the panning axis with the actual panning angle.

Calculation of the location of the tilting axis from its parameters of the relative location with respect to the panning axis (measured before) and using the fact. that ist perpendicular to the panning axis as well as to the optical axis.

The actual DLT-parameters are calculated from the DLT-parameters of the calibration image by:

Executing the transformations for p in the equations (2) on the right hand side and by applying the variation factor for focal length.

Standardizing upon the standard form - free coefficient in the denominator is 1.

Executing a coefficient comparison.

Approaches proposed by other authors do not start from the general functional model (3) but from simplified models. The model simplification becomes possible by the request for additional measuring values and for additional recording conditions (Hildebrand. 1984; Wolf. 1993).

RESULTS AND DISCUSSION

Application programmes based on these algorithms have been integrated both in our own motion analyzing systems and in the commercial system PEAK (Drenk, 1993).

Essential moduls of the core modul are:

iteration limits 0.0001– for angles and 0.0001 for variation factor of focal length

up to 35 additional control points within an image (high-precise computation of the panning axis is possible)

convergence even with rough initial values.

We make especially high demands on the accuracy of initial values - DLT-parameters of the calibration image and spatial location of the panning axis. It, is, as a rule. advantageous and sometimes even necessary to optimize these values. Stivers et al. (1993) refer to the necessity of an optimization and adequate developments with respect to the single-axle panning with measuring angles.

When the recording conditions are carefully met an accuracy which is typical for fixed cameras is reached. To check the correctness of our algorithmic, numerical. and programme solutions we executed additional calculations using model data. Additionally the calculations prove the following interesting estimation enabling an essential reduction in recording efforts by disclaiming additional control points surveying:

$$|w-w_F| < 2\arcsin(r\sin(w/2))/(a-r) \qquad (4)$$

w - real angle of rotation

w_F - angle of rotation above a stationary point with unknown coordinates

r - distance between the rotation point and the center of perspectivity in the panning plane

a - distance between the stationary point and the rotation point in the panning plane.

Detailed information on the algorithmic basics, on the practical application and the use of application programmes can be obtained from Drenk (1988, 1992) .

There is a couple of technical solutions which record panning and tilting angles synchronously to the image (for example Camusso et al., 1987; Scheirman, 1992). The presented procedure integrates the processing of these measuring values. We do not know measuring solutions for focal length.

CONCLUSIONS

We present a photogrammetric evaluation procedure for cameras that track moving objects by panning, tilting and zooming. We cover the geometric correlations which are common for camera rotations on common tripods by equations, and we analyse them in photogrammetric adjusting sense. Because of the general approach the calculation both of the panning, tilting angle and the variation in focal length as well as of additional parameters as for example the location of the panning axis is possible. The accuracy of the procedure has been proved by calculations using model data. With the application of conditions which can be well obtained in practice one can even substitute control points in good approximation by stationary points with unknown coordinates. Thus any additional recording efforts with respect to the recordings with fixed cameras is not longer required. These procedures have been succesfully applied for a longer period both in Leipzig and in other institutes (Drenk, 1992) to analyse wide-range spatial athletics movements.

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