A 3D VIDEO TECHNIQUE FOR ANALYSIS OF SWIMMING IN A FLUME

Volker Drenk, Falk Hildebrand, Matthias Kindler and Dieter Kliche[1]
Institute for Applied Training Science, Leipzig, Germany
[1]Olympic Training Centre Hamburg/Kiel, Hamburg, Germany

The photogrammetric evaluation of video recordings in a flume is complicated. Depending on the perspectives of cameras strong geometric distortions occur. Very short focal length, caused by lack of space, and transitions water/air or water/glass/air result in distortions in the recorded images. Using the photogrammetric evaluation we have to correct these geometric errors. The technological solution (recording setup, calibration, measurement in the images) for the swimming flume Hamburg is presented. Two lateral cameras, convergently geared, are applied to record the swimmer, simultaneously under and above the water. For the calibration of cameras a fine-meshed grid frame was placed several times in the object space. The measurements within the video image sequences were done analytically and simultaneously with special software.

KEY WORDS: 3D, videography, flume, swimming

INTRODUCTION: Flumes are popular to study technical problems in water sports, especially in swimming. Normally, for analyses of swimming styles after training sessions, several cameras record the swimmer from different directions during the exercises. The standard calibration method for the quantitative analysis of video recordings is DLT. But caused by strong geometric distortions the use of DLT without modification is problematical:

1. Strong lens distortion in the shape of a cushion, conditional on short focal length (wide-angle lens, fish-eye lens) (figure 2), caused by the cramped room (figurel)
2. Multiple refractions of beams of light because of several refractions in the water, air and glass (figure 2).

Figure 1 - Overview of swimming flume Hamburg

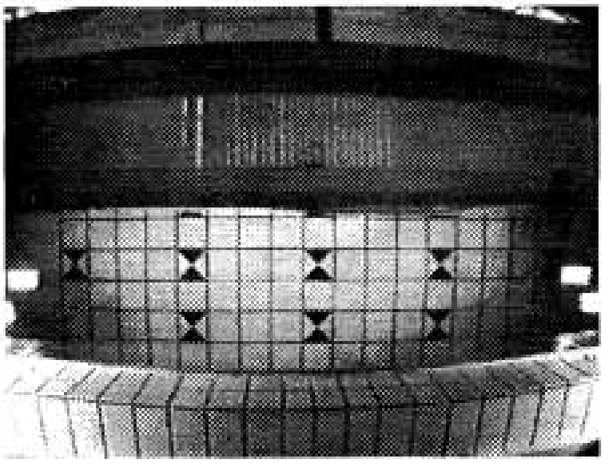

Figure 2 - Lateral view in the flume

The conventional DLT approach for fixed cameras including only the correction of distortion is not enough. The multiple refractions affect the supposed central projection to such a degree that it cannot be ignored. We had to develop a modification designed for our specific recording conditions. References for photogrammetric handling of multiple media images can be found in the specialised literature for photogrammetry, for example Regensburger (1990, pp.111ff). Yanai et al. (1996) report on acceptable results for underwater videography.

METHODS: Video recording setup: We tested several recording arrangements: Camera adjustment diagonal under or above the water, lateral-perpendicular or at a certain angle. We have already achieved good measurement results with the camera combination: lateral-perpendicular camera and underwater camera figures 3, **4** (Drenk and Hildebrand, 1997).

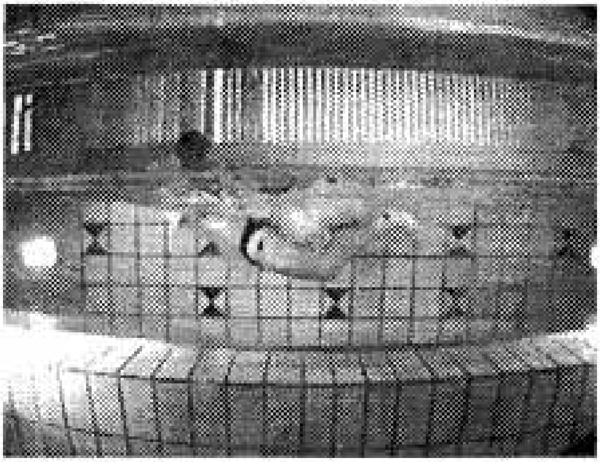

Figure 3 - Lateral camera, perpendicular

Figure **4** - Underwater camera

But the technical effort was great: Two gen-locked cameras, two recorders and two time-code generators. In addition the underwater camera cannot (such as the above water camera) view through the surface of water, as a rule, by active use of flume. Therefore, we developed the following solution: Two gen-locked cameras record the swimmer laterally. The cameras are fixed on the level of the water surface. The convergent optical axes have a horizontal angle of approximately 60°. They are vertically crooked, so that the swimmer is located in the left camera images in the upper half and in the right camera images in the lower half. Both images of the cameras can be mixed vertically and thus only one video tape is necessary to record the motion sequence (figure 6). Time-coding becomes unnecessary.

Calibration: For the correction of distortion and for handling of multiple refractions of beams of light classical photogrammetrical methods can be applied. But photogrammetrical literature is restricted to the commonly applied actual procedures with the optical axis of camera approximately being perpendicular to the interfaces water/air respectively water/glass/air (Regensburger 1990, p.112), which generally applies to underwater cameras. But this does not apply to our problem. The two errors jam in an unknown manner. Additionally, the simultaneous presentation of areas above and under water with different projection properties in the same image makes the photogrammetric handling even more complicated. Thus we developed the following robust calibration method (Drenk & Hildebrand, 1997): Embracing the object space two planes of control points were defined by placing a regular fine-meshed grating (element of palings) vertically at selected positions in the object space (figure 5). Each single field of the calibration frame has the dimension 5 cm x 20 cm. The calibration frame reaches up to above water area thus creating a common frame of reference. The error of distortion within a single field can obviously be ignored. Consequently the formulas of 2D DLT are sufficient for the projective relation between the position of a field in object space and in a camera image. An actual pixel is assigned to that control point's square (field of calibration frame) including this pixel respectively being closest to it.

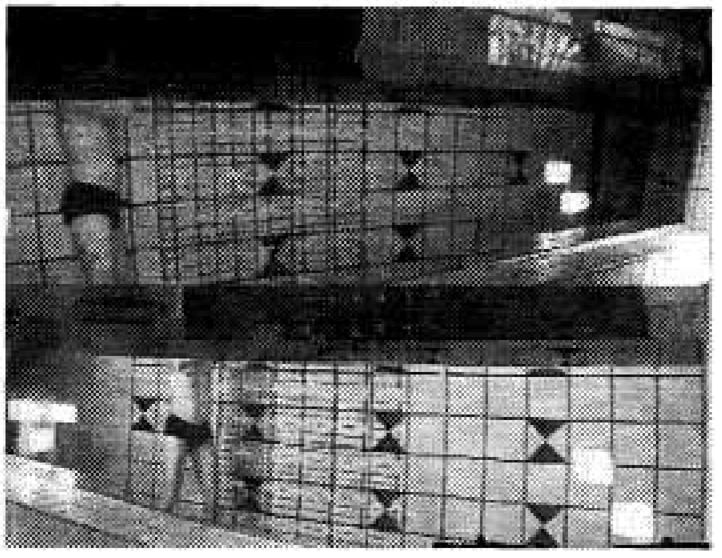

Figure 5 - A position of the calibration frame during calibration recordings

Measurements in the images: For the measurements in the images we separated the mixed images back and scaled it bilinearly so far that both camera perspectives can be placed simultaneously, large-format and in original aspect ratio on the same screen. We simultaneously measured in both perspectives. Each camera image (perspective) has its own cursor. The one cursor can be moved freely to place on the body landmark of interest. Simultaneously we inserted in the other image the projection line of this pixel (hot spot of cursor). We can move the other cursor on this projection line. This accelerates the evaluation and avoids severe digitalisation errors. A screenshot of this evaluation program is shown in figure 6. Current body landmark is the left heel. Input data are the digital video image sequences (AVI-files) and the calibration parameters. Output data are 3D coordinates of body landmarks.
At the moment no commercial motion analysing systems can provide this calibration and evaluation technology.

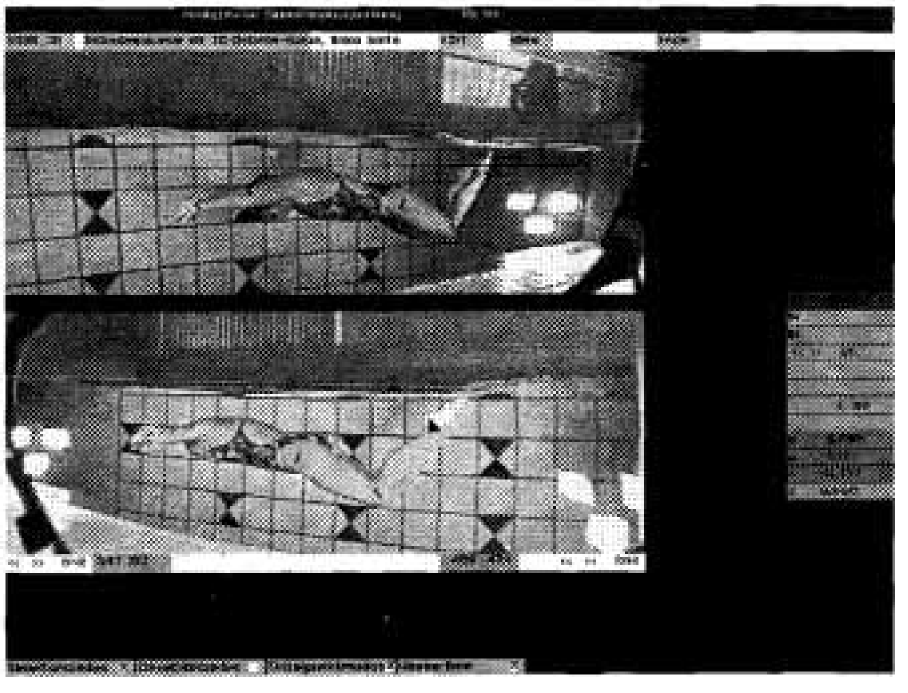

Figure 6 - Screenshot of evaluation program

RESULTS AND DISCUSSION: The complex 3D measurement system for the swimming flume at the Olympic Training Centre Hamburg/Kiel has been developed in our project. Two Panasonic VW-CP457 cameras record swimmers laterally and oblique. Both images were vertically mixed with a mixer Panasonic Digital AV Master WJ-AVE55 and recorded at the recorder Panasonic NV-HS 1000. The problems of calibration were solved by creating and evaluating several planes of control points in the object space. At the end the calibration is done locally by double application of 2D DLT (in each vertical plane) using those grid-fields of the calibration frame in the images which are included or closest to the actual body landmark. For each pixel in an image we get two points in object space defining the wanted projection line.

The attainable accuracy mainly depends on accuracy pixel resolution in the measuring images – caused by closely packed distribution of control points. The measuring error in the vertical swimming plane amounts to max. 5 mm, in the depth, because of the somewhat acute convergence angle of cameras - max. 10 mm. But in practice the accuracy which can be obtained is often limited by water-whirls and air bubbles in the water and on the water surface making the detection of body landmarks very difficult. The measurement of the images and the calculation of the 3D coordinates is done using a specially developed analytical measurement program, which measures simultaneously in both camera perspectives. Because of simultaneous measuring the accuracy of measurement can be obtained immediately at measuring display, and it can be influenced. The advantage of the chosen camera arrangement is that the video images can be mixed vertically and we can measure above and under water. However, this advantage is offset by the typical disadvantage of this camera arrangement that there are hidden body landmarks for both camera perspectives at the same time. We relinquish the digitisation of these body landmarks from the right side of the body. Instead they are determined from the mirror image of corresponding body landmarks from the left side of the body.

Results of swimming style analyses performed at the swimming flume in Hamburg are presented in a separate paper.

CONCLUSION: For quantitative technical analyses of swimming in a flume special video recording and calibration problems have to be solved. According to circumstances in the swimming flume at the Olympic Training Centre Hamburg/Kiel the developed solutions for recording setup, calibration and measuring are presented. Especially, the solutions for calibration and measuring in the video images should be suitable as a model for other swimming flumes. This 3D video technique for analysis of swimming has been used in Hamburg for one year approximately.

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