AN INTEGRATED METHOD TO OBTAIN THREE-DIMENSIONAL COORDINATES USING PANNING AND TILTING VIDEO CAMERAS

Gerald Scheirman, John Porter, Michael Leigh, Dennis Musick,
Peak Performance Technologies, Inc., Englewood, CO, USA

KEY WORDS: kinematics, three-dimensional, measurement, panning, tilting

INTRODUCTION: Kinematic measurements of sports performances have generally been gathered using stationary cameras. Many activities, however, cover dimensions that are much larger than the athlete, resulting in measures that are less accurate than desired. One solution is to increase the resolution of the acquisition equipment. Hardware providing sufficient resolution, if possible to find, may be prohibitively expensive. Another solution is to use rotating cameras to follow the athlete's movements. Dapena (1978), de Haan and den Brinker (1988), Yeadon (1989), Yu, Koh and Hay (1993), and Nachbauer, Kaps, Nigg, Brunner, Lutz, Obkircher and Mossner (1996) reported various methods that employed foreground and background markers to determine the cameras' positions. Unfortunately, the procedures involve time consuming calibrations and on-site measurements. Stivers, Ariel, Vorobiev, Penny, Gouskov and Yakunin(1993) reported a mechanical technique that reconstructed Three-Dimensional coordinates, but only from cameras rotating about a single axis.

METHODS: An efficient and flexible method was developed to quantify Three-Dimensional motion from rotating video cameras. At least two cameras are necessary, but up to six cameras are allowed. The procedure uses two 20,000 count/revolution optical encoders embedded in specially machined tripod heads to sense the cameras' angular positions. One encoder is aligned vertically to measure pan positions, while the other is aligned horizontally to measure tilt. The tripod heads must be leveled to assure proper alignment. The pan and tilt angles are written onto each video image by an interface unit. Consequently, additional hardware is not necessary to store the angular information and the count is always synchronized with the video. The images are then recorded onto videotape and imported into a computer using a commercial frame grabber. Locations on the body may be identified manually or automatically if markers are placed on the athlete. As the points are tracked, the pan and tilt angles are decoded and stored with the digitized data. Custom software modules use these data to compute the 3-D coordinates via ray-tracing techniques.

Calibration, conducted before or after the performance, requires three to nine vertical rods of known length be placed near the volume of interest. Two points on each rod are digitized from two tilt positions from each camera. This information is used to calculate the internal scaling camera parameters, the external camera parameters, and to establish the location and orientation of the global coordinate system. The rod placement, however, does not define or restrict the measurement volume. The cameras do not need to be placed at the same elevation or in view of one another. Thus, all requisite parameters may be determined without taking any on-site measurements or using background markers. Furthermore, the calibration

method does not restrict camera positioning, rather the locations depend upon the focal length of the camera lenses, the resolution of the encoders, the shape of the movement volume, and the speed of the athlete.
Walton (1981) reported a method to assess the dynamic accuracy of a measurement system by moving a rod of known length though a measured volume. Once the Three-Dimensional coordinates of the endpoints of the rod are determined, the length of the rod is calculated. The mean length and Root Mean Square Error can then be computed to measure system accuracy.

PROCEDURES: Two gen-locked Panasonic WV-D5100 NTSC video cameras were placed approximately 12 meters apart and 15 meters distant from a 15 m x 4 m x 2 m volume. This volume was merely a subset of a potentially larger measurement volume. The cameras' focal lengths were set such that their fields of view averaged 3 m and their electronic shutters were set to 1/1000 s exposure time. Six calibration rods .031 m in diameter and 3.4 m in length were positioned roughly 3 m apart in two rows across the central portion of the volume. A 0.900 m long rod was moved through the volume and video images were recorded onto Panasonic AG-7400 SVHS video cassette recorders. Nine hundred video images were grabbed into a PC-based computer for analysis. The rod endpoints were digitized from the video images using a Peak Performance Technologies Motion Measurement System and their three-dimensional coordinates were computed. The distance between the points was then calculated from the coordinate data. Neither the raw nor the processed data were filtered.

RESULTS: The mean length of the rod was 0.896 m with a 0.001m standard deviation. The Root Mean Square Error was 0.004 m. Yu et al. (1993) reported distance errors of .006 m with a RMSE of .020m using a panning DLT method for long jump. This system's results compare favorably to those that Yu reported. Figure 1 depicts a graph of the computed rod length vs. time.

CONCLUSION: The system's accuracy, ease of set up and calibration, and camera position flexibility warrants its use in many difficult sporting applications. Standard off-the-shelf NTSC or PAL format video cameras can be used as well as specialized high frame rate cameras. The system has been used to gather data from international competitions including high jump, gymnastics floor exercise, sprinting, pole vault, and ski jumping.

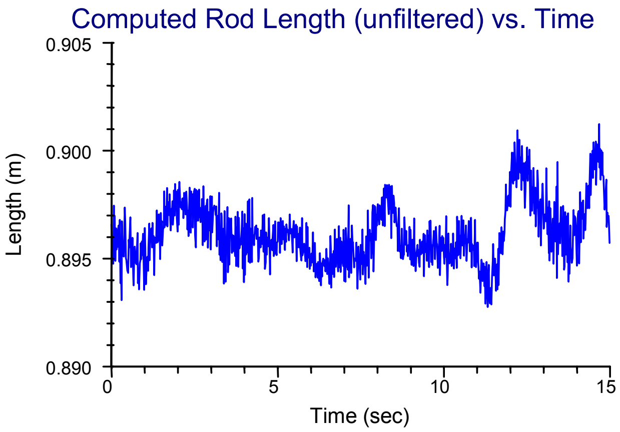

Figure 1: Computed length of a 0.9 meter rod as it moved through a 15m x 4m x 2m volume

REFERENCES:

Dapena, J. (1978). Three-Dimensional Cinematography with Horizontally Panning Cameras. *Sciences et Motricite* **1**(3), 3-15.

de Haan, T., den Brinker, B. (1988). Direct Linear Transformation Method for 3-D Registration Using Subject Tracking Cameras. In P. A. G. de Groot, W. Nachbauer, P. Kaps, B. Nigg, F. Brunner, A. Lutz, G. Obkircher, M. Mössner (1996). A Video Technique for Obtaining 3-D Coordinates on Alpine Skiing. *J. of Applied Biomechanics* **12**, 104-115.

Stivers, K. A., Ariel, G. B., Vorobiev, A. G., Penny, M. A., Gouskov, A. M., Yakunin, N. A. (1993). Photogrammetric Transformation with Panning. In *Abstracts of International Society of Biomechanics XIV* (p. 769).

Walton, J. S. (1981). Close-Range Cine-Photogrammetry: A Generalized Technique for Quantifying Gross Human Motion. Unpublished Doctoral Dissertation. University Park: Pennsylvania State University.

Yeadon, M. R. (1989). A Method for Obtaining Three-Dimensional Data on Ski Jumping Using Pan and Tilt Cameras. *International Journal of Sport Biomechanics* **5**, 238-247.

Yu, B., Koh, T. J., Hay, J. G. (1993). A Panning DLT Procedure for Three-Dimensional Videography. *Journal of Biomechanics* **26**(6), 741-751.