ORIGINAL RESEARCH

Kinematic Measurement from Panned Cinematography

Pierre Gervais, E. Wendy Bedingfield, Craig Wronko, Iraklis Kollias, Gordon Marchiori, Jon Kuntz, Norma Way and Daan Kuiper
University of Alberta
Edmonton, Alberta

Catalogue Data:
GERVAIS, P., BEDINGFIELD, E.W., WRONKO, C., KOLLIAS, I., MARCHIORI, G., KUNTZ, J., WAY, N., and KUIPER, D. (1989). Kinematic measurement from panned cinematography. **Can. J. Spt. Sci.** 14:2 107–111.

ABSTRACT

Traditional 2-D cinematography has used a stationary camera with its optical axis perpendicular to the plane of motion. This method has constrained the size of the object plane or has introduced potential errors from a small subject image size with large object field widths. The purpose of this study was to assess a panning technique that could overcome the inherent limitations of small object field widths, small object image sizes and limited movement samples. The proposed technique used a series of reference targets in the object field that provided the necessary scales and origin translations. A 102 m object field was panned. Comparisons between criterion distances and film measured distances for field widths of 46 m and 22 m resulted in absolute mean differences that were comparable to that of the traditional method.

Key Words: rotating camera; large object field width; average scale.

RÉSUMÉ

La cinématographique traditionnelle en deux dimensions implique l'utilisation d'une caméra stationnaire avec les axes optiques perpendiculaires au plan de mouvement. Cette technique a donc exercé certaines contraintes quant à la grandeur de l'objet dans le champ optique, ou a introduit des possibilités d'erreurs lorsqu'une petite image est couplée à l'utilisation d'un champ d'objet très large. et qui pourrait éliminer les problèmes inhérents champ d'objet de largeur réduite, à des petites images et à un échantillonage limité des mouvements. La technique proposée utilise une série de cibles de références dans le champ de l'objet ayant servi à établir les échelles nécessaires et les translations d'origine. L'objet a été suivi sur un champ de 102 m. La comparaison des distances de référence et les distances mesurées à partir du film pour les champs optiques de 46 et 22 m de largeur respectivement, a permis d'observer des différences absolues moyennes similaires à celles obtenues par la technique cinématographique traditionnelle.

Mots clés: caméra rotative; champ optique; échelle de référence.

Introduction

Cinematography is commonly used as a means of studying human movement. The high-speed camera, in 2-D cinematography, is normally positioned in a stationary location perpendicular to the plane of motion (Miller and Nelson, 1973). A number of methods have been proposed to assist in the control and correction of errors that appear through the use of cinematography (Doolittle, 1971; Karara and Abdel-Aziz, 1974; Van Gheluwe, 1975). However, these methods are limited in the sample of motion they obtain. Usually only one phase of a movement can be obtained on the film from a single camera position. The use of multiple cameras can provide for a greater field of view in order to obtain a greater sample on film but this method can be complex, time-consuming and expensive (Fukashiro *et al.*, 1981; Dillman *et al.*, 1985). In addition to the expenses of multi-camera methods, most labs are not equipped with more than one or two cameras let alone eight, as in Fukashiro *et al.*'s study. Another method to obtain a larger sample of movement on film is by a system of tracking (Fredricson *et al.*, 1970). This procedure involves moving a camera parallel to the line of motion of the subject to be filmed. However, this method is impractical for many movement patterns and data collection environments.

Since many human movements, especially sports events, occur over a distance, a technique to obtain more than one sample of a cyclic sequence could be accomplished through the panning of a camera from a single position. The use of panning could give flexibility to the design of research procedures, as well as flexibility in subject-to-camera distance. Panning could also maximize image size, reduce lens distortion (since the subject could remain in the center of the field of view), and could reduce error in data reduction.

The purpose of this study was to assess the accuracy of a panning cinematographic technique in determining the two-dimensional spatial coordinates for a known object system.

Methods

Since all kinematic measures evolve from the measurements of displacement and time, this study was based on obtaining these measurements from cine film and comparing them to criterion measures.

An object line 102 m in length was overlaid by a surveyor's chain marked at two-metre intervals. Parallel lines were designated one metre in front of and one metre behind the object line. A theodolite was set on the centre of the object line and a line perpendicular to the object line was sighted. The camera station was positioned along this line 30 m from the object line. The theodolite was removed from the object line and set at the camera station. The leftmost end of the object line was located optically and the horizontal motion clamp on the theodolite was locked.

Along this optical line, the front reference target was positioned on the front reference line at an elevation of 0.6 m. Similarly, along this same optical line the back reference target was placed on the back reference line at an approximate height of 1.7 m. The theodolite was then used to locate optically the adjacent two-metre mark on the object line, and the preceding procedure was repeated. The placement of the front and back reference targets continued until the 102 m field was marked with 52 pairs of reference targets. A schematic illustration of the filming set up is given in Figure 1.

The method used to relate image size to object size was based on the lens formula and the concept of an 'average scale' used in aerial photogrammetry for variable terrain (see Appendix A for more detail). Panning provides a different oblique view at each instant in time. This necessitates having a known distance in the movement plane for each frame of film, even during actual filming of a subject. In addition to this requirement, a reference system must also be provided for coordinate translation throughout the object field. Since it is not feasible to have objects of known length in the movement plane obstructing a subject's performance, the above system of referencing was used. The system of reference targets provides for known distances in the plane of motion that would not interfere with the movement of a subject. Using adjacent pairs of reference targets, a scaling factor can easily be found as follows:

$$\text{Scale Factor} = \frac{\text{Known distance (AB)}}{\text{Image distance (ab)}} = \frac{2\ \text{m}}{\dfrac{X_{fi} + X_{bi}}{2} - \dfrac{X_{fi+1} + X_{bi+1}}{2}} \qquad [1]$$

where the denominators are simply the horizontal image coordinates for the reference distance in the plane of motion.

Because the location of a point on a human subject can introduce error unrelated to data collection methodology, this study used a series of well defined points, *i.e.*, subject targets. The subject targets represented the translation of a point through the plane of motion and as such, were positioned at the centres of the 2 m intervals (quadrants), on the object line and at an approximate height of 1 m. The translation of the subject targets, criterion measures (the linear distance between adjacent subject targets), were measured using a surveyor's chain.

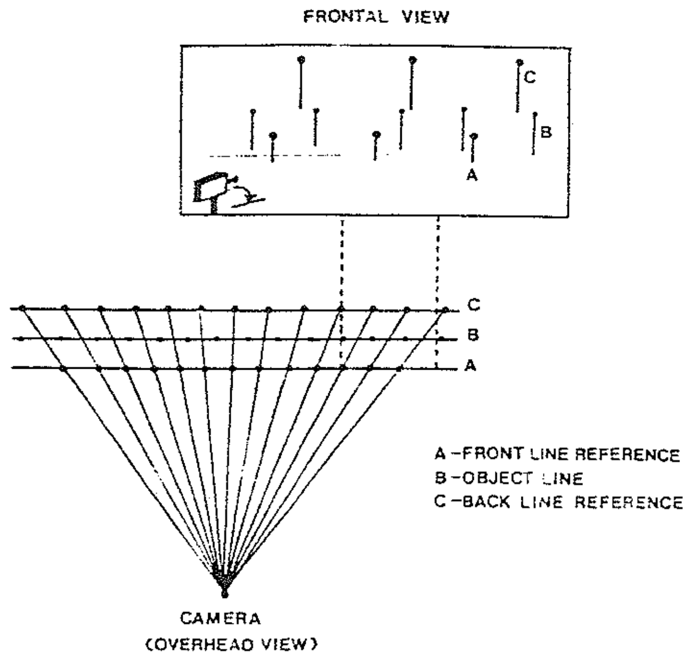

Figure 1 *Filming set-up.*

The theodolite was removed from the tripod and replaced by a Photo Sonics 1PL pin registered 16 mm camera such that the camera's focal point was intersected by the axis of rotation of the tripod head. An Angenieux 20-120 mm zoom lens was set at a focal length of 80 mm which provided a field of view encompassing a minimum of two pairs of reference targets at any one time. The camera was set to operate at 100 frames per second with an exposure time of 1/1200 s. The object field was panned from left to right through its width of 102 m which resulted in a panning angle of approximately 120°.

The processed film was projected via a Triad VR100 pin registered film analyzer onto a Bendix digitizing board interfaced to a Hewlett Packard 9825B micro computer via a Hewlett Packard 9864A digitizer. The 2D coordinates of the subject targets were determined in the following manner:

1. The frame where that subject target was approximately centred was selected, so as to represent the approach one would take when panning a live subject, *i.e.*, keeping the subject in the centre of the frame of film.
2. The origin was set on the front left reference target.
3. The back left reference (X_{bi}) target was digitized.
4. The front (X_{fi+1}) and back (X_{bi+1}) right reference targets were digitized.
5. The scaling factor was calculated using equation [1] with X_{fi} equal to 0.0 as the origin.

6. The subject target was digitized (X_s, Y_s) and its real life location displayed as:
   Subject X coord. = S.F. * ($X_s - X_{bi}/2$) [2]
   Subject Y coord. = S.F. * Y_s

All front reference targets were set at the same elevation, although not necessarily at the same height from the ground. Step 7 was used to assure that all vertical measures were referenced to the leftmost front reference target and secondly to furnish flexibility to the method when the front targets may not all be at the same elevation.

7. The next frame of film for analysis was selected and the origin was digitized. The vertical coordinate (V) was retained for origin translation/correction in the vertical direction.
8. Steps 1 through 3 were repeated.
9. This and subsequent subject targets were digitized (X_s, Y_s) and calculated as follows:
   Subject X coord. = S.F. * ($X_s - X_{bi}/2$) + T [3]
   Subject Y coord. = S.F. * (Y_s + V)
   where T was the horizontal translation of the origin, *i.e.*, the distance between horizontal marks on the object line, 2 m in this case. (See Appendix B for a generalized description of the panning technique.)

Distances between subject targets were calculated using the Pythagorean Theorem. Repeated measures were randomly performed throughout the digitizing process to assess human precision in data reduction.

Results

Fifty-one subject targets were spaced along a 102 m object line forming 50 inter-subject distances at an average distance of 1.999 m (S.D. = 0.038). The calculated distances from film averaged 1.998 m (S.D. = 0.044) with an average absolute difference between criterion and film measured distances of 0.015 m (S.D. = 0.015, see Table 1). An inspection of the individual distance differences revealed that a significant reduction in error was found in the centre portion of the object field (Figure 2). Reducing the object field down to 46 m and 22 m, corresponding to 75° and 40° panning angles respectively, resulted in an average absolute difference of 0.005 m (see Table 1). The differences between the criterion distances and measured distances for these reduced object field widths ranged between 0.0 m and 0.012 m and 0.0 m and 0.011 m for the 46 m and 22 m fields respectively.

The conduct of this experiment was such that systematic errors were maximally controlled given the accuracy of the instrumentation. Repeated measures randomly performed throughout the digitizing process to assess human precision resulted in a correlation coefficient of r = 0.999.

Discussion

This study was designed to assess the accuracy of a cinematographic technique that would overcome the limitations of a small image size and a narrow field width associated with the single fixed camera. The absolute mean error in this study, between calculated and criterion distances, was 0.015 m for an object field width of 102 m and 0.005 m for object field widths of 46 m and 22 m. The results of the 46 m and 22 m fields compared favourably with that of a fixed-camera study by McLaughlin *et al.* (1977), who reported an average error of 6.0 mm (S.D. = 2.4 mm) between measured and film calculated distances for a typical biomechanics experiment (p. 573).

McLaughlin *et al.* (1977), suggested that the total error, when using known distances for error estimation, was equally distributed between the two points digitized. The error band for estimating a point in space in this study was ±7.5 mm and ±2.5 mm for object field widths of 102 m and for 46 m and 22 m both, respectively (or panning angles of 120° and 75° and 40° both, respectively).

Two questions were recently asked about the present investigation: (1) whether or not the error was contained in only one coordinate and what the relative magnitudes might be and (2) what the results might be if the object targets were in positions

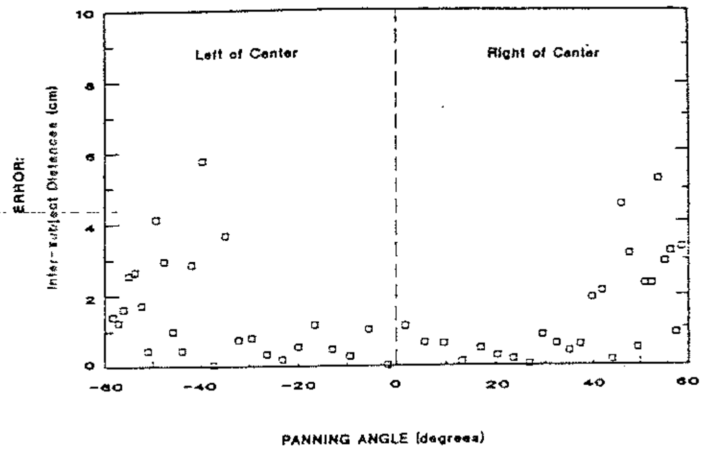

Figure 2 *Error vs. panning angle.*

Table 1
Film Measured Distances vs. Criterion Distances

Object Field Width	n	Criterion (m)	Film (m)	Error (m)
102 m	50			
m		1.999	1.998	0.015
S.D.		0.038	0.044	0.015
Range		(1.848, 2.167)	(1.838, 2.164)	(0.000, 0.058)
46 m	22			
m		2.000	2.001	0.005
S.D.		0.052	0.053	0.003
Range		(1.848, 2.167)	(1.838, 2.164)	(0.000, 0.012)
22 m	10			
m		2.001	2.002	0.005
SD		0.077	0.079	0.004
Range		(1.848, 2.167)	(1.838, 2.164)	(0.000, 0.011)

other than in the approximate centres of the quadrants. There was no attempt made in this study to differentiate between the relative errors in the horizontal or vertical coordinates, since the overall objective was to assess the method's general ability to locate a point accurately in space. It is hypothesized that both coordinates are susceptible to error. This question will be addressed in a future study.

In a recent study that used the panning technique (Gervais and Wronko, 1988), an assessment of accuracy similar to this study was undertaken, although not reported at that time. A camera was positioned 15.8 m from the centre of the object field. A cart, with four marked distances (.28 m, .591 m, .67 m and .284 m) was panned while it was pushed through an object field of 14 m (or a panning angle of 48°). Forty frames of film were digitized, providing object points at various locations within each of the seven 2 m reference quadrants. The absolute mean error was found to be 0.017 m (s = 0.01, n = 160). This would indicate a mean accuracy of ± 8.5 mm in locating a point in space. The middle quadrant, which approximates the traditional still camera technique, provided an absolute mean error of 0.021 m (s = 0.0004, n = 16). Although the results from Gervais *et al.* (1988) experiment are higher than those for the present study, due possibly to the film's graininess, since filming was indoors and the film was pushed, it is comparable to the results for the middle quadrant.

The panning method allowed for the collection of data that would not have been feasible or highly accurate with a fixed camera. Filming an object field width of 102 m with the traditional method, for all intents and purposes, would be impossible. A still camera set-up, using a 20 mm lens, for a plane of motion 46 m in width would require that the camera station be positioned approximately 92 m from the plane of motion. If we were filming the triple jump, a 22 m object field width would not be unreasonable. Using a 20 mm focal length, the fixed-camera technique would require that the camera be positioned approximately 44 m away. In addition to the possible lens aberrations inherent in the use of a short focal length, both of these set-ups would produce rather small subject image sizes. These image sizes would contribute considerably to the amplification of random error associated with any data collection from the film (Dainty and Norman, 1987).

Dainty *et al.* (1987) recommended that 'the accuracy of the displacement histories ... of the digitized points in the photographic plane should be within 1% of the true value' (p. 76). A panning angle of 75° or less produced a maximum error of 0.012 m or 0.6% of the true value.

In conclusion, panned cinematography can be a particularly useful tool for the sports scientist. In activities such as speedskating and nordic skiing, for example, the placement of a fixed camera to encompass even two strides within the field of view results in an image size small enough to introduce considerable error in the subsequent analysis. By comparison, the panning technique introduced in this paper maintains a large image size over what traditionally would be a large field width for static filming without any undue sacrificing of 2-D coordinate accuracy.

Received 4 April 1988; accepted in final form 30 November 1988.

REFERENCES

Dainty, D.A. and Norman, R.W. (1987). **Standardizing Biomechanical Testing in Sport.** Champaign, IL: Human Kinetics.

Dillman, C.F., Cheetham, P., and Smith, S.L. (1985). A kinematic analysis of men's Olympic long horse vaulting. **Int. J. Sport Biom.** 1(2): 96–100.

Doolittle, T.L. (1971). Errors in linear measurement with cinematographical analysis. In: **Kinesiology Review 1971.** Washington: AAHPER, pp. 32–38.

Fredricson, I., Andersson, S., Dandanell, R., Moen, K., and Andersson, B. (1970). Quantitative analysis of hoof motion patterns, using high-speed films on harness horses. In: W.G. Hyzer and W.G. Chase (eds.), **Proceedings of the 9th International Congress on High Speed Photography**, Denver, CO, pp. 346–350.

Fukashiro, S., Iimoto, Y., Kobayashi, H., and Miyashita, M. (1981). A biomechanical study of the triple jump. **Med. Sci. Sport** 13(4): 233–237.

Gervais, P. and Wronko, C. (1988). The marathon, skate in nordic skiing performed on roller skates, roller skis, and snow skis. **Int. J. Sport Biom.** 4(1): 38–48.

Karara, H.M. and Abdel-Aziz, Y.I. (1974). Accuracy aspects of non-metric images. **Photogramm. Eng.** 40(9): 1107–1117.

McLaughlin, T.M., Dillman, C.J. and Lardner, T.J. (1977). Biomechanical analysis with cubic spline functions. **Res. Q.** 48(3): 569–582.

Miller, D.I. and Nelson, R.C. (1973). **Biomechanics of Sport.** Philadelphia: Lea & Febiger.

Van Gheluwe, B. (1973). Errors caused by misalignment of the cameras in cinematographical analyses. **Res. Q.** 46(2): 153–161.

Wolf, P.R. (1974). **Elements of Photogrammetry.** New York: McGraw-Hill.

Appendix A: Scale

The lens formula suggests that the scale used for converting photo image units to life size units is

$$S = \frac{\text{Image size}}{\text{Object size}} = \frac{\text{focal length}}{\text{D(object} - \text{lens distance)}}$$

In aerial photography, the photogrammetrist may use an average scale for a photograph taken over a variable terrain (Wolf, 1974, p. 110). The conversion factor or scale in the panning method is an adaptation of this method for photos in a vertical plane using an average scale as though the object field had a variable object-lens distance or terrain (Figure 3). It must be point out that using this 'average scale' is only exact at those points which are at D_{avg} from the lens. If a researcher had the instrumentation in the camera to record the panning angle for each frame of film shot, a scale factor might possibly be calculated for every point digitized. This could be accomplished using the methods of photogrammetry for tilted photographs (Wolf, 1974 pp. 249–255). The efficacy of such an approach will be investigated at a later date.

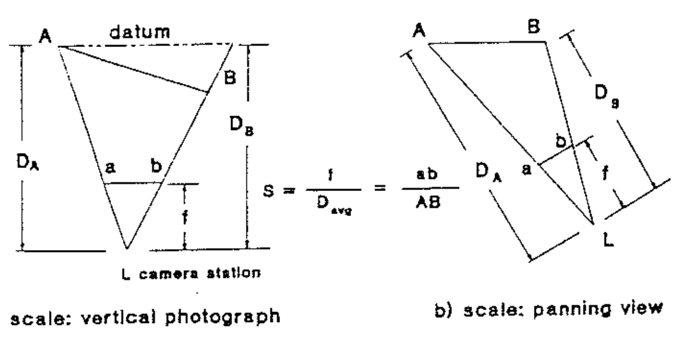

Figure 3 *Scale factor.*

Appendix B: Set-up Procedure For Panning

1. Determine plane of motion.
2. Mark parallel lines of reference on either side of the plane of motion.
3. Mark centre of plane of motion.
4. From the centre mark, measure and mark reference distances along the plane of motion. Ensure that these reference distances will assure a minimum of two target reference pairs in the film view when panning.
5. Either optically or using simple geometry and chains, locate the camera station along a line perpendicular to the plane of motion intersecting at its centre.
6. From the camera station, optically sight a reference mark location on the plane of motion. Along this line of sight place front and back reference targets. Continue this procedure throughout the plane of motion. Ensure that the vertical heights of the front targets are low enough not to obscure the view of the performer.
7. When filming, pan so that the subject remains in the approximate centre of the frame of view.
8. When reducing the data, use equations [1], [2], and [3]. Note: The above procedure is best achieved using a theodolite and elementary surveying techniques. Yet, a cine camera with cross hairs in its viewing optics or a camera with a compass transit placed along the optical axis should provide the necessary precision for the panning set-up.