MEASUREMENT ERROR IN SIMULATED 2D GAIT DATA EXTRACTED BY A VIDEO-BASED MOTION MEASUREMENT SYSTEM

Noel Lythgo and Rezaul Begg*
School of Exercise Science, Australian Catholic University, Melbourne, Victoria, Australia
***Centre of Research for Exercise and Sports Science, Victoria University, Melbourne, Victoria, Australia**

An instrument reliability study was conducted in order to quantify the measurement error contained in 2D spatial data (linear and angular) commonly collected in gait and long jump studies (e.g. footfall position, toe-board-distance or limb orientation) by video-based motion measurement systems. Three experiments examined the effect of camera-to-object distance (5 to 10 m) and field of view (2.5 to 4.5 m) upon marker sets (stationary) representative of walking or running motion. The results show 7 to 10 m camera-to-object distances to be associated with the least error (mean absolute error = 0.59 cm) or about a third of the error found for the 5 m distance (mean absolute error = 1.5 cm). No systematic changes in measurement error were found across the differing camera fields of view with the mean absolute error falling below 0.66 cm and 0.6 .

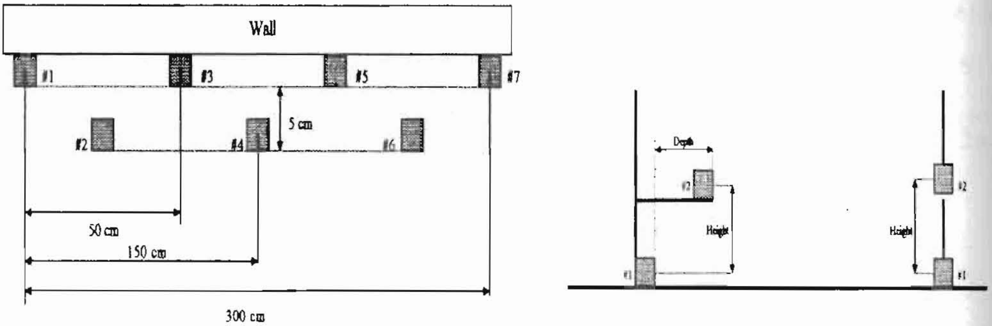
KEY WORDS: measurement error, 2D spatial data, instrument reliability.

INTRODUCTION: 2D spatial coordinate data (linear and angular) extracted by video-based motion measurement systems contains measurement error produced by factors such as lens or image distortion, perspective error, parallax error and digitization error (Bartlett, 1992). The magnitude of the perspective and parallax errors has been directly linked to camera-to-object distance. Some long jump studies (e.g. Montague et al., 2000), however, have failed to report the distance, therefore, it is impossible to ascertain the likely measurement error contained in the data. As such, this study examined the measurement error associated with filming processes by employing a variety of camera setups (distance and field of view) and stationary marker sets involving two experiments.

METHOD: Experiment 1 involved varying camera-to-object distance (the perpendicular distance from the 2D measurement plane) from 5 to 10 m (horz. camera field of view = 3 m) to record a set of stationary markers positioned at: (1) varying depth (5, 10 and 15 cm) from each other (refer to figure 1A); and, (2) varying depth and height (5, 8 and 11 cm) from each other (refer to figures 1B & 1C). These magnitudes were chosen to represent typical foot placement (walking base) and foot-obstacle clearances reported in the gait literature (e.g. Whittle, 1991; Begg & Sparrow, 2000). Both of these actions contribute to the magnitude of the depth/ perspective error contained in non-planar 2D spatial coordinate data extracted from markers placed on body segments such as the feet; that is, any placement of the feet away from a walkway centre-line, where a 2D calibration rod would be positioned, results in perspective error. camera-to-object distances of 5 to 10 m (1 m increments) were selected in order to ascertain perspective error across distances commonly used in gait research (e.g., Cutlip et al., 2000; Prince et al., 1994).

Experiment 2 involved varying the camera FOV (fixed distance = 10 m) for a set of 25 stationary markers positioned within the same 2D measurement plane (refer to figure 2). Linear and angular data were calculated across FOV conditions. The angles selected were considered to best represent angular data (e.g. foot, head, trunk) collected in gait research and involved calculating the orientation of the vertical line joining two adjacent markers.

Two measures of measurement error (absolute magnitude) were calculated: (1) mean error ( ) or the average absolute error across three images; and, (2) maximum error (Maxerror) or the largest absolute error across three images. These measures were found by comparing known distances or angles between markers to those derived from filming and digitization processes. The same equipment and setup procedures were employed across experiments. A camera height of 0.85 m (height of optical axis of lens from the ground) was used since it represents bout half the typical height of an adult (ABS, 1995). The following equipment was used: (1) Panasonic Colour CCTV 50 Hz camera (model no. WV-CL830/G) with a shutter rate of 1/500 s; (2) Computar camera lens (model no. H6Z0812, 8-45 mm, 1:1.2); (3) Panasonic VCR (model no. AG4700); (4) 3M reflective tape - high gain sheeting (make: 7610WS); (5) Peak Motus Motion Measurement System - 2000 version; and, (6) metal calibration rod (2.55 m in length).



A (view from above) B (side view) C (front view)

Figure 1: A - Schematic representation of ground-level markers mounted on the front of 2 cm cubic blocks representing footfalls (superior view). Adjacent markers are shown as being a depth of 5 cm from each other and a horizontal distance of 50 cm from each other. Markers are shown against the wall and forward of the wall. Note that the diagram is not drawn to scale. Figures 1B and 1C: Schematic representation of the experimental set-up used to examine the effect of perspective error on vertical marker positions. Reflective tape was attached to the front of two plastic cubes (2 2 2 cm) that were placed on a stand. The stand allowed marker #2 to be positioned at depths of 5, 10 and 15 cm from #1, and at heights of 5, 8 and 11 cm above #1. Marker #1 was fixed to the base of the stand. B. Side view of set-up. C. Front view of set-up.

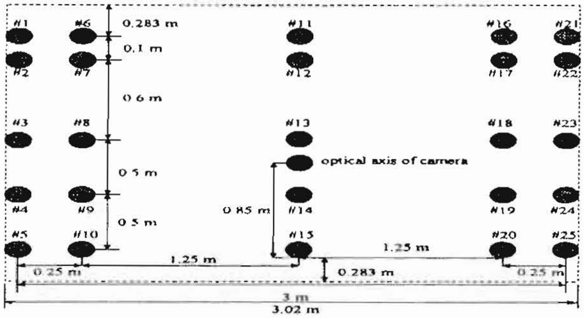


Figure 2: Schematic representation of fixed marker locations (#1 - #25) on the wall of the laboratory (frontal view) for a camera filed of view of 3 m.

RESULTS: Experiment 1 - camera-to-object distance: The depth condition results show large and systematic reductions (refer to figure 3) in measurement error (mean and maximum) as the camera-to-object distance increased from 5 to 7 m. Compared to the 5 m camera-to-object distance, distances of 7 m or more reduced measurement error by about half. Measurement error appears to stabilize by about the 7 to 8 m camera-to-object distance with relatively smaller reductions found as the camera-to-object distance increased to 10 m. At the 10 m distance, the mean and maximum errors were found to fall below 0.86 cm and 1.25 cm respectively. Overall, the 5 cm depth condition exhibited the least error (less than 0.6 cm for both error measures).

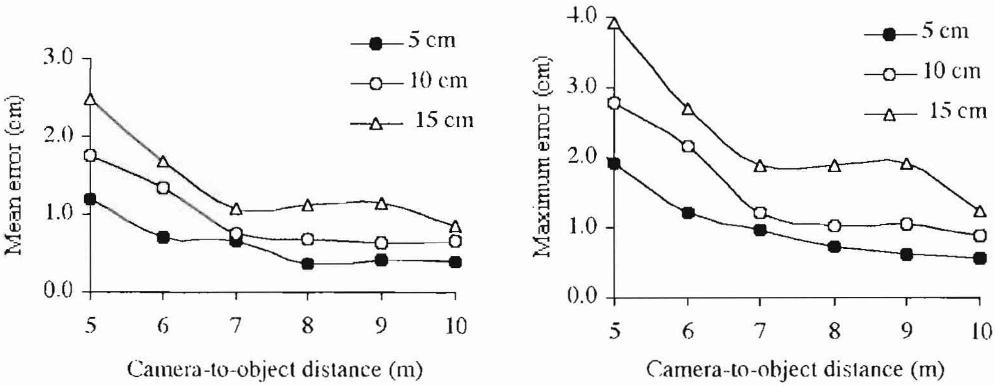


Figure 3: A. Plots of mean error ( ) found for footfall markers across depth conditions and camera-to-object distances. B. Plots of maximum error (Maxerror) found for footfall markers across depth conditions and camera-to-object distances.

The depth and height condition results show marked and systematic increases in measurement error (mean and maximum) as the depth of separation increased (refer to table 1). Overall, the maximum error fell below 1 cm across all depths, and below 0.57 cm for the 5 and 10 cm depths.

Table 1 Measurement error (and Maxerror) found for vertical separations (5, 8, 11 cm) across depths of 5 to 15 cm.

Vert. separation	5cm			8 cm			11 cm		
Depth	5 cm	10 cm	15 cm	5 cm	10 cm	15 cm	5 cm	10 cm	15 cm
$\bar{x}$ (cm)	0.14	0.28	0.82	0.15	0.32	0.70	0.17	0.24	0.44
SD (cm)	0.06	0.12	0.10	0.10	0.21	0.06	0.27	0.31	0.15
Max_{error} (cm)	0.21	0.41	0.93	0.26	0.56	0.77	0.40	0.51	0.60

Experiment 2 - camera field of view: In Experiment 2, the mean error ( ) found in the distances (horizontal and vertical) between markers was less than 0.66 cm. No systematic reduction in the magnitude of the measurement error was found across FOV conditions; only small differences less than 2 mm were found. Maximum error (Maxerror) ranged from 1.29 to 1.91 cm. Again, no systematic reduction was found across FOV conditions. The mean error in the angular data were found to range from 0.45 to 0.61 with the maximum error ranging from 1.48 to 2.38 with increasing FOV.

DISCUSSION: Experiment 1 examined the error, across varying camera-to-object distances, contained in data representing footfalls and foot-obstacle-clearances in gait. The results show the 10 m camera-to-object distance to be associated with the least error. For example, the magnitude of error found for this distance was about a third of that found for the 5 m distance. The largest depth condition (15 cm separation) was associated with the largest error. If these data are ignored, measurement error (mean) drops below 0.66 cm for the footfall data and 0.33 cm for the foot-obstacle-clearance data. It is reasonable to exclude these data since typical walking bases have been reported to range between 5 and 10 cm (Whittle, 1991).

The findings of this study are important to gait and long jump research. It is clear that camera-to-object distance has a significant effect on the accuracy of 2D spatial data. Unfortunately, many gait studies do not report the camera-to-object distance, therefore, it is impossible to ascertain the likely measurement error present in the data. In addition, previous studies used camera-to-object distances of 5 or 6 m (e.g. Prince et al., 1994; Redfern & DiPasquale, 1997; Cutlip et al., 2000). Clearly, large errors (2 to 4 cm) may occur in the data reported.

Experiment 2 examined measurement error, across varying camera fields of view, contained in data representing anatomical landmarks on a person. No systematic changes in measurement error were found across the FOVs. Overall, the mean error fell below 0.66 cm and differed by no more than 1.6 mm across the FOVs. Maximum error fell below 1.91 cm across FOVs. These findings are similar to those reported by Ehara et al. (1995) who used the PEAK Motion Measurement System to determine the accuracy of 3D spatial data (FOV 2.4 to 3.0 m). The data was captured from a rod (900 cm long) carried by person who moved along a walkway. A mean error of 0.53 cm and a maximum error of 1.41 cm were reported.

The mean error ( ) contained in the angular data (relative to earth-based horizontal axis) fell below 0.62 . This value is similar to that reported by Scholz and Millford (1993) who found mean error to range from 0 to 0.8 for a 3D accuracy study involving angular data extracted from a pendulum by the PEAK Motion Measurement System. In this study, high maximum errors were found across the FOVs. This study found maximum errors to range from 1.48 to 2.18 with the 2.5 and 3 m FOVs associated with the least error of 1.48 .

CONCLUSION: It can be concluded that the experimental set-up likely to produce the least error in 2D spatial data commonly collected in gait research or studies of the long jump involves a camera-to-object distance of 7 m or more and a field of view ranging between 2.5 to 3 m.

REFERENCES:

Australian Bureau of Statistics. (1995). How Australians measure up? Commonwealth of Australia, Australian Government Publishing Service, Canberra.

Bartlett R. (1992). Biomechanical Analysis of Sport. British Association of Sport and Exercise Science.

Begg R.K., & Sparrow W.A. (2000). Gait characteristics of young and older individuals negotiating a raised surface: implications for the prevention of falls. Journal of Gerontology: Medical Sciences, 55A, M147-M154.

Cutlip R.G. et al. (2000). Evaluation of an instrumented walkway for measurement of the kinematic parameters of gait. Gait & Posture, 12, 134-138.

Ehara, Y. et al. (1995). Technical note: comparison of the performance of 3D camera systems. Gait & Posture, 3, 166-169.

Montagne, G. et al. (2000). A perception-action coupling type of control in long jumping. Journal of Motor Behaviour, 32, 37-43.

Prince F. et al. (1994). Anticipatory control of upper body balance during human locomotion. Gait & Posture, 2, 19-25.

Redfern, M.S., & DiPasquale, J. (1997). Biomechanics of descending ramps. Gait & Posture, 6, 119-125.

Scholz, J.P., & Millford, J.P. (1993). Accuracy and precision of the PEAK Performance Technologies Motion Measurement System. Journal of Motor Behaviour, 25, 2-7.

Whittle, M. (1991). Gait Analysis: an introduction. Oxford: Butterworth Heinemann.