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A COMPARISON OF TWO CALIBRATION TECHNIQUES FOR LARGE VOLUME CALIBRATION

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The purpose of this study was to compare results produced using two different large volume calibration techniques with those produced by using an optical motion capture system. A volume measuring 2.5x8x2 m. was calibrated using 4 survey poles, a multiphase calibration, and with a motion capture system. Reconstructions using the survey poles and multiphase calibration technique produced similar movement patterns as the motion capture system for both the position of a single marker and for tracking the whole body center of mass (COM). The multiphase calibration resulted in larger DLT errors for reconstruction of the control points, however, compared to the motion capture system, it also resulted in smaller RMS differences for both a single marker and for the COM.

KEY WORDS: calibration, large volume, DLT.

INTRODUCTION: Being able to accurately locate points in 3-dimensional space depends on the accuracy of the camera calibration. One of the most commonly used reconstruction techniques is the Direct Linear Transformation (DLT; Abdel-Aziz & Karara, 1971). While the DLT is highly accurate when activity remains within the calibrated space, its accuracy drops when activity moves outside the calibrated volume (Dapena, 1985b; Hinrichs and McLean, 1995). This can be especially problematic for researchers studying activities taking place over large areas since building, accurately surveying, and transporting large calibration structures is difficult if not prohibitive. In light of these challenges researchers have examined other methods for enlarging calibrated volumes.

Challis (1995) proposed a multiphase DLT calibration where a smaller control object is moved multiple times throughout a volume, each time with a small overlap with previous positions. The process gradually builds up a larger volume and improved accuracy compared to simply extrapolating with a standard DLT. However, this method is still subject to practical limitations for even larger volumes. An alternative approach uses several survey poles placed around the activity space. Since no frames or structures are required this technique provides a flexible method for calibrating very large volumes. However, one drawback is the need to use a theodolite to accurately establish the position of the poles (Kwon, 1996). The required surveying is time consuming and, in many competition settings, impractical. However, as long as the poles are placed vertically, by measuring the distances between poles one should be able to determine the location of the control points geometrically. This method requires no frame structures and is highly portable, providing great flexibility to researchers.

There are currently no reports in the literature regarding how data collected with this method compares with other previously validated calibration techniques. Therefore the purpose of this paper was to compare data collected in a large volume calibrated using survey poles with pole locations determined geometrically and using the multiphase calibration technique. As a standard for comparison, data from both methods will be compared to results from an optical motion capture system set up to perform gait analysis over the same large volume.

METHODS: A 10-camera motion capture system (Motion Analysis Corp.) was used to calibrate the 40 m^3 (2.5 m. x 8 m. x 2 m.) volume within the laboratory (Figure 1). The capture volume was also calibrated with two additional methods: 4 survey pole poles (each 2 m. tall) placed at the corners and with a multiphase calibration procedure (Challis, 1995).

For the survey pole method distances between all poles were measured using a measuring tape and the location of the poles was determined geometrically. For the multiphase calibration, a calibration structure containing 68 control points, measuring approx. 2m x 2m x 2m, was placed in 4 locations throughout the volume. At least 3 control points overlapped on each placement. Data were collected on 5 trials from 1 female subject as she walked through the capture volume. Prior to motion capture, 28 reflective markers were placed on bony landmarks as described by Hahn & Chou (2004). The subject's gait was recorded simultaneously by the motion capture system and with two video cameras (GC-PX10, JVC Corp.), all sampling at 60 Hz. Twenty individual body landmarks were manually digitized from the two video cameras. The cameras were then synchronized based on the occurrence of heel strike and toe off frames within the videos (Dapena and Chung, 1988) and a DLT reconstruction was used to obtain 3D coordinates. Reconstructions were performed separately using both the survey poles and the multiphase calibration, so in total, three sets of marker coordinates were obtained. A thirteen segment model was used to calculate whole body center of mass (COM) based on Dempster's data (Winter, 2005). Comparisons between calibration techniques were based on how well the survey pole and multiphase calibrations tracked the trajectories of both a single marker, and the calculated COM, compared to the motion capture system, across two gait cycles.

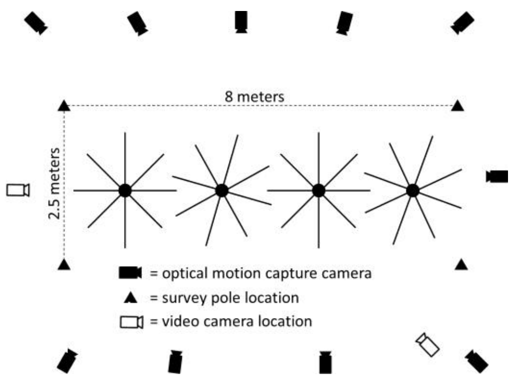

Figure 1. Schematic illustration of the experimintal set up.

RESULTS: The multiphase calibration technique resulted in the largest error for the reconstruction of the three dimensional locations of the control points (Table 1).

Table 1
Errors from the Reconstruction of the Control Points

Method	DLT Reconstruction Error (mm)
Survey Poles	1.750
Multiphase	2.710
Method	Average 3D Residuals (mm)
Mo. Cap. System	0.707

A marker located on the vertex was chosen for the individual marker comparison. For both the individual marker and the overall COM trajectory all three calibration methods produced similar marker trajectories (Figure 2). RMS differences comparing the survey poles and multiphase calibrations to the motion capture system showed the multiphase calibration performed slightly better than the survey poles calibration (Table 2). While this was true for the single marker and COM comparisons, the RMS differences for the COM trajectory was much higher than the single marker values for both comparisons.

Table 2
RMS Differences (mm) for Comparing Survey Poles and Multiphase Calibration with Results from the Motion Capture System

Method	AP Direction		ML Direction		Vertical Direction	
	Vertex	COM	Vertex	COM	Vertex	COM
Survey Poles	12.16	59.95	13.06	22.65	18.96	28.14
Multiphase	11.45	50.95	5.35	14.74	12.36	24.45

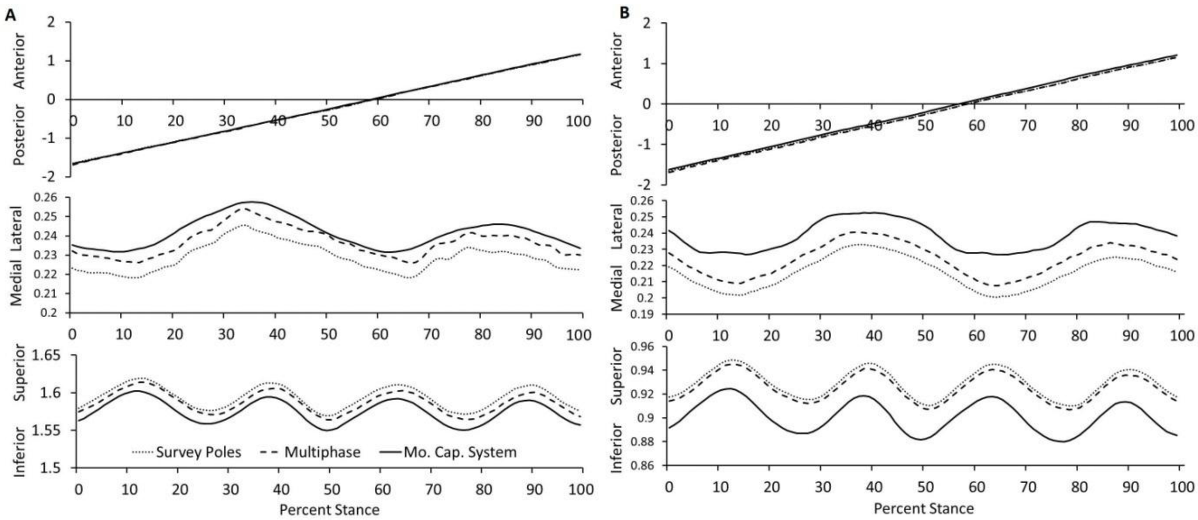

Figure 2: Anterior Posterior (top), Mediolateral (middle), and Inferior-Superior Trajectories for the Vertex Marker (A) and Whole Body Center of Mass (B).

Compared to the motion capture system, excursions for the single marker were smaller in the mediolateral (ML) and anterior posterior (AP) directions when calibrating with the survey poles (Table 3). Marker excursions in these two directions when calibrating with the multiphase calibration were not different than those obtained from the motion capture system. In the vertical direction both the survey poles and the multiphase calibration resulted in greater marker excursions than the motion capture system.

Overall, COM excursions from all three calibration methods were similar in the AP direction. However, there appeared to be a direction dependency for COM excursions in the ML and vertical directions (Table 4). Compared to the motion capture system, the survey pole calibration underestimated COM excursions in the ML direction while overestimating it in the vertical direction. The multiphase calibration overestimated COM excursion in the ML direction and in the vertical direction.

Table 3
Excursions and Coefficients of Variation (CV) in the Anterior posterior (AP), Mediolateral, and Vertical Directions for the Vertex Marker.

Method	AP (m)		ML (cm)		Vertical (cm)	
	Mean	CV%	Mean	CV%	Mean (±SD)	CV%
Survey Poles	2.81 (± 0.10)	3.61	2.04 (± 0.84)	41.17	4.29 (± 0.53)	12.45
Multiphase	2.84 (± 0.09)	3.03	2.11 (± 0.81)	38.33	4.11 (± 0.47)	11.40
Mo. Cap. System	2.84 (± 0.07)	2.34	2.09 (± 0.99)	47.45	3.91 (± 0.42)	10.81

Table 4
Excursions and Coefficients of Variation (CV) in the Anterior posterior (AP), Mediolateral, and Vertical Directions for the Whole Body Center of Mass.

Method	AP (m)		ML (cm)		Vertical (cm)	
	Mean	CV%	Mean	CV%	Mean (±SD)	CV%
Survey Poles	2.83 (± 0.09)	3.39	3.30 (± 1.76)	53.48	3.40 (± 0.30)	8.92
Multiphase	2.84 (± 0.07)	2.34	3.09 (± 1.59)	51.76	3.03 (± 054)	17.98
Mo. Cap. System	2.85 (± 0.05)	1.83	2.47 (± 1.31)	52.74	3.22 (± 0.52)	16.19

DISCUSSION: The main implication of this finding is that researchers studying activities which take place over a large volume can confidently use either the survey pole or multiphase calibration techniques, as both can yield results similar to those produced by an optical motion capture system. From an ease of use perspective the survey pole technique is simpler than the multiphase calibration, however, it has been suggested the positions of the survey poles need to be surveyed with a theodolite (Kwon, 1996) to know the exact locations of the control points. The results of this study suggest determining the control point locations geometrically may be an acceptable alternative for some researchers. While this suggests this technique should be accurate enough to use in the field a follow up study should compare results using surveyed pole location to those determined geometrically.

Errors in the DLT reconstruction of control points were slightly higher with the multiphase calibration than with the survey pole calibration. This may be because this method requires digitizing the control points in multiple locations. Therefore any errors that do exist at a given location would compound as additional locations are added. Additionally, the method requires calculating the transformation matrix describing the change in the control point's location from one position to the next. While Challis (1995) presents methods to minimize these errors, they may still exist and their presence would similarly compound errors as additional locations are added.

Despite higher errors in the DLT reconstruction of the control points, the multiphase calibration resulted in smaller RMS differences, when compared to the motion capture system, for tracking both the single marker and the whole body COM location (Table 2). One possible explanation may be that the technique resulted in control points filling the capture volume rather than only being located at the corners, a condition which has been reported to improve the accuracy of the DLT reconstruction (Chen et al., 1994). However, other authors have reported distributing control points around the outside of the volume resulted in more accurate reconstructions (Challis & Kerwin, 1992). In both the works of Chen et al. (1994) and Challis and Kerwin (1992) the calibrated volumes were significantly smaller than the one used in the present study. Perhaps additional control points located around the edges of the calibrated volume are required with larger volumes like the ones used in this study, however this remains to be seen.

CONCLUSION: Both the survey poles and the multiphase calibration technique produced similar kinematics as the optical motion capture system suggesting either would be suitable options for outside the lab studies taking place over large areas. If the survey poles technique is used, it appears the positions of the pole can be determined geometrically rather than through surveying, however further work is required to confirm this. These options provide additional flexibility for researchers studying activities taking place over large volumes.

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