AN INVESTIGATION ON THE ERROR OF CALIBRATING EXTERIOR POINTS WITH INTERIOR POINTS

Yanyan Du, Man Hou and Yuhui Cai
College of P.E. and Sports, Beijing Normal University, Beijing, China

This study was to investigate the accuracy of calibrating exterior points with interior points using a frame with the same structure as Peak frame. Two cameras were used. Some points of the frame were used as control points to calibrate others using the DLT method. When we calibrated exterior points with interior points, the minimal and maximal errors were 0.171 cm and 1.797 cm respectively in the horizontal direction (X), 0.213 cm and 4.856 cm in the horizontal direction (Y), 0.103 cm and 1.608 cm in the vertical direction (Z). When we calibrated the interior points with exterior points, almost all errors were less than 1cm. It was concluded that to get the most accurate 3D reconstruction of human movement, it is necessary to make sure that the space formed by control points contains the objects to be calibrated.

KEY WORDS: DLT, calibrate, interior points, exterior points

INTRODUCTION: Three-dimensional data are needed for a full understanding of complex human motion. At present, we commonly use the direct linear transformation (DLT) arithmetic which is a technique used to locate spatial points filmed with two or more cameras, (Marzan & Karara, 1975). Many studies have been made on the accuracy of spatial calibration. The DLT method needs a minimum of 6 control points. And 16 points is advised if more accurate results are asked. Challis & Kerwin did a research of the accuracy of five kinds of model (shown in Figure 1). The result was that (b), (c) and (e) were the better. Chen et al. (1994) studied 30 different kinds of structure of control points. They argued that the space formed by control points should contain the space to be measured, all control points should be distributed uniformly, and the number should not be too small.

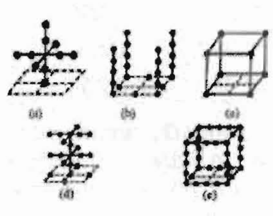

Figure 1 5 kinds of model studied by Challis & Kerwin.

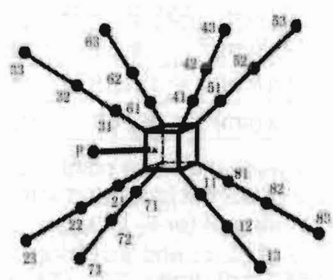

Figure 2 Frame used in this study.

In China, most of institutions and labs use the PEAK frame to calculate the coordinates. In this paper, we took the frame made by EMIG graduate school as an object (shown in Figure 2) to study the error caused by calibrating exterior points with interior points. This frame has the same structure as the PEAK frame.

METHODS: Two JVC GR-DVL 9800 cameras were used to film synchronously. They had same interior parameters and had the same height as the center of frame. Frame was located between the two cameras. At the beginning, the two cameras had a distance of 4.735 m; the point 23 (0, 0, 0) of the frame and camera had a distance of 13.5 m.

The position of 13.5 m was named position 1, frame filmed there was named frame 1. We moved the frame towards the cameras for 5 times, 0.5 m each time, and frame filmed every time was named frame 2, frame 3, frame 4, frame 5 and frame 6 respectively. Then, we moved the frame to the cameras by 1m and took it as frame 7. During the whole process, the rail of the frame was parallel to the line linking the cameras. At last, we made the rail to be vertical to this line, filmed, named frame 8.

We used the Ariel performance analysis system (APAS) to analyze images. 100 images were trimmed for every frame and every two images were digitized, thus we got 50 data at a time. In addition to this, we repeated every process for three times.

Initially, point P (the point on the rail of frame 8) was calibrated with frame 8. According to the results, we determined whether it was necessary to consider the error caused by optical distortion in this study. Secondly, point P was calibrated with all frames from frame 1 to frame 8. By this means, we found out the relationship of distance, distribution of control points and the error. Finally, further investigation was made to study the error caused by calibrating points in large space with control points in small space. In the last process, except for the point in the rail, all points of frame 3 were used. Points 11, 21...81 are the interior points; points 12, 22... 82 are the middle points and points 13, 23... 83 are the exterior points. The procedures followed were: (1) calibrated the interior 8 points with all middle and exterior points, (2) calibrated the middle 8 with all interior and exterior points and (3) calibrated the exterior 8 points with all interior and middle points.

RESULTS AND DISCUSSION: In this study, the main aim was to analyze the error caused by calibrating exterior points with interior points using the frame developed by EMIG. For this reason, we wanted to disregard the optical distortion. Frame 8 took the widest view of the two cameras; the results of calibrating point P with frame 8 are shown in Table 1. The average errors are 1.056 cm in the horizontal direction (X), -0.587 cm in the horizontal direction (Y) and 0.252 cm in the vertical direction (Z). Notice that the direction of X is in line with the camera view, which makes digitizing difficult. Thus, in this study, the error caused by optical distortion need not to be considered any more and care must be taken when digitizing with the camera view in line with the image.

Table 1 Results of calibrating point P with frame 8.

Point p	Given coordinates	Computed coordinates			Average error
		1	2	3	
X(cm)	18.39	19.458	18.91	19.972	1.056
Y(cm)	111.15	110.97	111.022	111.282	-0.587
Z(cm)	82.65	82.796	82.96	82.95	0.252

The tape shows that a same point in space wasn't always bilaterally symmetrical. The error of Z-coordinate of point P calibrated with all 8 frames is shown in Table 2. The distance between frame 1 and frame 7 (or 8) is 3.5 m. It means that the point P wasn't in the space formed by frame 1, 2, 3, 4, 5, 6, and as observed, the error is larger when point P was calibrated with frame 1 (1.257 cm), frame 2 (1.473 cm), frame 5 (9.8193 cm), frame 6 (7.518). But when it was calibrated with frame 3, errors are only -0.568 cm, -0.682 cm and -0.416 cm respectively in three times. Errors caused by calibrating with frame 7 which contains point P are 2.644 cm, 2.7 cm and 3.928 cm respectively over three trials. What does it mean? Error is not only determined by distance but also determined by distribution, inaccurate operation and some other factors. According to the location of the point P in every frame and the distance, it is concluded that if the object to be calibrated was in the space formed by control points, the error is less, and the location of the control points is more symmetrical, the error is less. In addition, although the results of calibrating with frame 3 are very good, and as we can see from the tape that Point P is bilateral symmetry in two cameras, it is not possible to conclude that once the object was bilateral symmetry in all cameras, the result would be good. In fact, it is difficult to place frame as frame 3 in practice. To get an ideal result, you should avoid calibrating objects outside the space formed by control points.

In order to make the conclusion more clearly, the change of the error caused by different calibration with frame 3 was studied. The results are summarized in Table 3. The interior, middle and exterior points were all calibrated with the other 16 points of frame 3. Considering all data, it is obviously that most of errors are larger than 1cm when the exterior points were calibrated with the interior and middle points. In this study, the results may be accepted. But with the increasing of the distance between interior points and exterior points, we can't sure that they are accepted any more. That is to say, if you want to get an ideal result, you should avoid calibrating space outside the space formed by control points. From these data, we can also find that the results of calibrating the middle points were better than the results of calibrating the interior points. It means that better results would be gotten if the object to be calibrated were not too close together on the center of frame.

Table 2 Results of Z-coordinate of point P calibrated with all 8 frames.

		Z1(cm)	Z2(cm)	Z3(cm)	Z4(cm)	Z5(cm)	Z6(cm)	Z7(cm)	Z8(cm)
error	1	1.126	1.678	-0.568	0.772	9.82	7.524	2.644	0.146
	2	0.954	0.82	-0.682	0.768	9.872	7.642	2.7	0.31
	3	1.692	1.92	-0.416	0.77	9.766	7.388	3.928	0.3
average		1.257	1.473	-0.555	0.77	9.8193	7.518	3.091	0.252

Table 3 Results of every point calibrated with different control points.

points		error	points		error	points		error
11	X(cm)	-0.173	12	X(cm)	0.232	13	X(cm)	-0.248
	Y(cm)	-0.599		Y(cm)	-3.218		Y(cm)	4.856
	Z(cm)	0.024		Z(cm)	0.569		Z(cm)	-0.103
21	X(cm)	-0.439	22	X(cm)	-0.137	23	X(cm)	-0.171
	Y(cm)	-0.313		Y(cm)	-0.803		Y(cm)	3.068
	Z(cm)	0.291		Z(cm)	0.418		Z(cm)	-0.272
31	X(cm)	0.777	32	X(cm)	0.356	33	X(cm)	-1.283
	Y(cm)	-0.143		Y(cm)	-0.57		Y(cm)	0.213
	Z(cm)	-0.515		Z(cm)	-0.218		Z(cm)	1.377
41	X(cm)	-0.457	42	X(cm)	0.0453	43	X(cm)	-0.313
	Y(cm)	-0.543		Y(cm)	-0.236		Y(cm)	3.981
	Z(cm)	-0.333		Z(cm)	0.00533		Z(cm)	1.608
51	X(cm)	0.004	52	X(cm)	0.327	53	X(cm)	-1.121
	Y(cm)	0.183		Y(cm)	-2.149		Y(cm)	3.547
	Z(cm)	-0.197		Z(cm)	0.151		Z(cm)	0.171
61	X(cm)	0.156	62	X(cm)	-0.014	63	X(cm)	-0.833
	Y(cm)	-1.831		Y(cm)	-0.108		Y(cm)	3.779
	Z(cm)	-0.257		Z(cm)	0.3813		Z(cm)	1.267
71	X(cm)	-0.857	72	X(cm)	-0.04	73	X(cm)	-0.267
	Y(cm)	1.695		Y(cm)	0.004667		Y(cm)	3.384
	Z(cm)	-0.206		Z(cm)	0.205		Z(cm)	0.647
81	X(cm)	0.441	82	X(cm)	0.979	83	X(cm)	1.797
	Y(cm)	2.067		Y(cm)	-2.823		Y(cm)	-0.31
	Z(cm)	-0.0633		Z(cm)	0.172		Z(cm)	1.341

CONCLUSION: In this paper, we studied the error caused in the process of calibrating with the frame which is widely used in China. We concluded that all calibration should occur with the movement being filmed within the control area. Otherwise, the results wouldn't reflect the real situation and the project we made based on the results may be improper or even false. It will be a waste of manpower and material resources. Further investigation should be done to study the change of error with the increasing of the distance between the exterior and control points.

REFERENCES:

Challis J H, Kerwin D G. Accuracy assessment and control point configuration when using the DLT for photogrammetry. *J. Biomechanics*, 1992, 25(9): 1053-1058.

Chen L., Armstrong C. W., Raftopoulos D. D. An investigation on the accuracy of three-dimensional space reconstruction using the direct linear transformation technique. *J. Biomechanics*, 1994, 27(4): 493-500.

Shapiro, R., Direct linear transformation method for three-dimensional cinematography. *Res. Quart.* 1978, Vol. 49, No.2: 197-205.

Acknowledgment

The authors express appreciation to the associate professor of Capital Institute of P.E. Qian wen, the director of the Biomechanics Research Laboratory, the assistants Guan Xiaoming, Pan Yonggang and classmates: Liu, Qi, Li, Xin and Xue, Chunhua.