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AN INNOVATIVE SURVEY POLES CONFIGURATION: AN ALTERNATIVE 3-D VOLUME CALIBRATING SYSTEM

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Abstract. The purpose of this study is to develop an alternative method for calibrating a three-dimensional volume. The new calibration frame uses a set of four poles, consisting of 20 control points. An experiment was conducted to compare the result obtained using two methods of calibration, the Peak calibration frame (the control) and the ISN-UM survey poles system (the new reference frame). It was found that the results obtained from the ISN-UM calibration frame are comparable to those obtained using the Peak calibration frame, despite the differences in the locations and the numbers of control points, as well as the physical characteristics of both structures.

Keywords: Calibration, survey poles system, sports biomechanics

Abstrak. Tujuan kajian ini adalah untuk membangunkan satu alternatif untuk mententukur satu isipadu tiga dimensi. Kerangka tentukuran baru ini menggunakan empat tiang yang mengandungi 20 titik kawalan. Satu eksperimen telah dilakukan untuk membandingkan keputusan yang didapati daripada dua kaedah tentukuran iaitu kerangka tentukuran Peak dan kerangka tentukuran ISN-UM (kerangka baru). Keputusan eksperimen menunjukkan bahawa kerangka tentukuran ISN-UM adalah sepadan dengan keputusan yang didapati daripada kerangka tentukuran Peak, walaupun kedudukan, jumlah titik kawalan dan sifat fizikal kedua-dua kerangka berbeza.

Kata kunci: Tentukuran, sistem tiang, biomekanik sukan

1.0 INTRODUCTION

In biomechanics research, a recording of human movements in an open space is necessary for analysis. Locating positions of significant body landmarks necessitates the use of a reference frame in a three dimensional space. The reference frame would give the coordinates of known points called the control points. The measurement of the locations of body landmarks could be determined from the existing 'coordinates' for further analysis.

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For the past thirty years, a number of researches focused on the problem determining the locations of body landmarks. One of the most popular techniques was the linear transformation (DLT) method [1]. The advantages of this method are that the optical axes of cameras are not required to intersect; the positions of the cameras might be arbitrary and are not measured; only two camera images of objects are required; and additional cameras could be accommodated. The only drawback of this method is that the control points (points with known locations) ought to be distributed within the activity space [2]. Marzan and Karara [3] extended the DLT model to incorporate corrections for lens distortion. Miller *et al*. [4] showed that parameters could be determined using only one camera, but accuracy was improved by utilizing data from two or more cameras. Hatze [5] presented a modified DLT approach (the MDLT), which increased the accuracy for the reconstruction of points.

Other researchers studied different techniques which included techniques suggested by Penrose *et al.* where cameras have to be at known locations. Another technique suggested by Cappozzo where the optical axes of the cameras need to intersect, and techniques invented by Woltring where the positioning of the cameras was flexible [2]. Both Putnam and Neal showed that camera positioning and orientation were not the critical factor in the refinement and error analysis during the calibration process [6].

Wood and Marshall [6] presented an analysis of errors arising from the DLT approach to three-dimensional reconstructions from two-dimensional images. They found that extrapolation occurred outside the control point distribution. Then Challis [7] came out with a new multiphase calibration procedure where the frame was moved sequentially, permitting calibration of a volume much larger than that encompassed by the calibration frame. Dapena *et al*. [8] and Dapena [9] proposed an alternative to the DLT method, the non-linear transformation (NLT) method which used a control object but the precise three-dimensional coordinates of points on the control object were unknown.

In comparing the NLT and extrapolated DLT, Hinrichs and McLean [10] found the standard non-extrapolated DLT to be the most accurate, especially when a large number of control points (40 – 60) were used. If one used 16 – 20 control points, as recommended by Chen *et al*. [11] based on the investigation on the accuracy of three dimensional space reconstruction using the DLT technique, either method provided similar accuracy. However, if the activity volume exceeded the size of the available DLT control object, the NLT was superior.

In biomechanics research of open games carried out by the present authors, such as the studies on badminton during the Thomas/Uber Cup 2000 and *sepak takraw* during the XXI SEA Games 2001, it is necessary to study three dimensional motions taking place in a very large volume (which is the size of the playing court). With the limitation of the standard DLT method as agreed by Hatze, Kennedy *et al.,* Shapiro, and Wood and Marshall, the need arise for innovating a practical calibrating system which could encompass a larger volume than that covered by the currently available frame [11].

Thus an experiment was conducted to compare the result obtained using two methods of calibration, namely the Peak calibration frame (the control) and the survey poles system (the new calibration structure). The parameters used for the comparison were the velocity of a flying object (*sepak takraw* ball) and velocity of the ankle, heel, and toe of a *sepak takraw* player in action. The acceleration graphs of the ball, ankle, heel and toe were presented as well.

2.0 METHOD

The currently available three dimensional object space, the Peak calibration frame, is commercially available from Peak Performance Technologies, Figure 1. It has the dimensions of 2.2 × 2.2 × 1.6 m. The structure contains 25 known points, with 8 rods protruding from the core of the structure. For standard orientation of the full 25-point calibration frame, rods 1, 4, 5, and 8 protrude from the bottom of the core and rods 2, 3, 6, and 7 protrude from the top. All control point coordinates are measured relative to a right-handed, rectangular Cartesian coordinate system 'imbedded' in the structure. The control point coordinates are arranged consecutively from rod 1 containing balls *A, B*, and *C* through rod 8 containing balls *V*, *W*, and *X* and the core gives the last control point *Y*. The positions of the balls are always measured from the outside of the rod to the inside going into the core. The origin is located at ball *A* where the *x*-axis

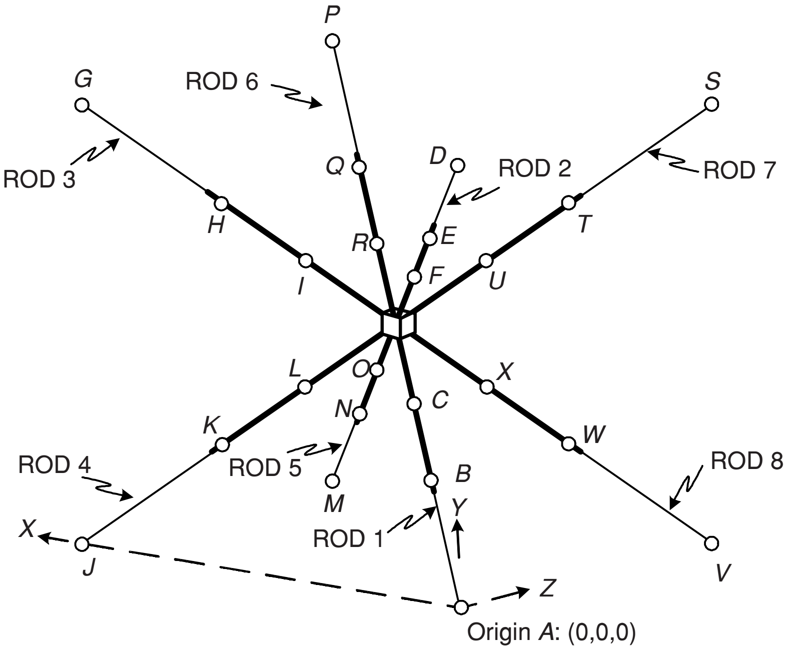


Figure 1 The peak calibration frame

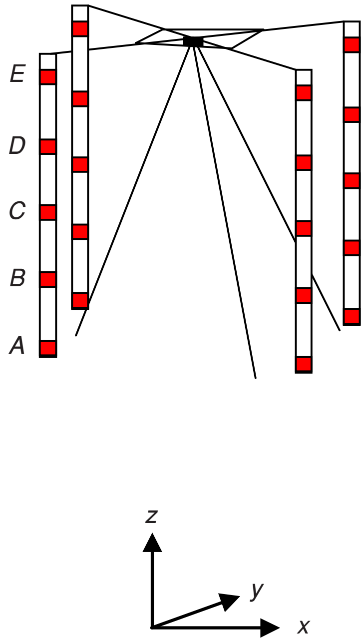


Figure 2 The ISN-UM survey poles (custom-made poles) and its coordinate reference system

runs from ball *A* through ball *J*. The *y*-axis runs perpendicular to both the *x*- and *z*-axes, following the right-hand rule.

The new cuboid-shape calibration frame of 20 control points was constructed using four survey poles hanging vertically from a custom-made "ceiling", consisting of two perpendicular rods intersecting at a common origin, Figure 2. The intersection point of the rods was mounted so that the poles were guaranteed to meet the free fall condition. This was necessary to ensure that the poles were vertical. Each white-painted pole had five red markers identified as the control points. The markers were placed at approximately 0.50 m intervals from one end to the other, vertically.

The dimensions of the structure were approximately 1.9 × 1.9 × 2.2 m (*X*, *Y*, and *Z* respectively). The structure was designed so that the control points surrounded the space in which the activity was to take place, as suggested by Challis and Kerwin [2]. The locations of the markers in the structure were flexible, but in the experiment, they were arranged as follows: markers *A* – *E* (on pole number 1) were fixed to one edge of the structure, with point *A* denoted the origin, markers *F* – *J* were fixed to the other edge on pole 2, while markers *K* – *O* on pole 3 and *P* – *T* on pole 4. The alphabetical labellings of the markers were done from bottom to top, left to right, and front to back (clockwise). Hence marker *A* was always located at the left lower front (net) corner followed vertically up-wards by markers *B* – *E*. The other front edge began from the bottom with marker *F*, followed vertically upwards by markers *G* – *J*, etc.

Three gen-locked Panasonic WV-CP450/WV-CP454 CCTV video cameras (8 mm lenses, color S-video and 6× zoom capabilities) were used to capture the 2-D images of all points used in the experiment. The cameras were directly gen-locked using three Norita SR-50 time-code generators for video to provide shutter synchronisation and identical frame rates.

For each camera, the zoom lens was set-up so that the total volume to be calibrated was visible. Three Fumiyama CA688 portable color television monitors enabled the field of view of the camera to be adjusted and observed. Video data were recorded on three Panasonic NV-SD570AM Peak–computerised and controlled video cassette recorder. A Peak Performance Technologies system was used to digitise the videotapes.

The three cameras were mounted so that the reference calibration frame position was central to the field of view. One camera (C1) was positioned with its optical axis nearly parallel to the court to obtain the front view of the calibration frame while another camera (C3) was placed with its optical axis approximately perpendicular to the court. Camera (C2) was placed approximately 45° to the court (Figure 3).

The position of the calibration frame was recorded at 50 Hz on videotapes. For each position of the camera, one frame was chosen to digitise 20 control points. Each point was digitised twice and the mean was used in the analysis to reduce the influence of random errors.

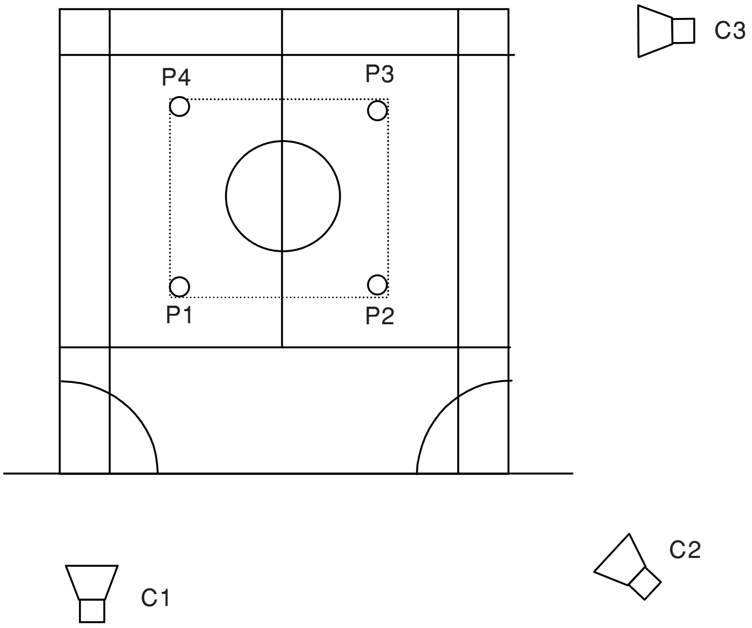


Figure 3 The two DLT control objects, ISN-UM frame with a set of four

To facilitate a direct comparison between the control Peak calibration frame and the new cuboid ISN-UM calibration structure, the position of the calibration structures was recorded one by one. During recording, the distances above the horizontal plane (from datum to marker) of rods 1, 4, 5, and 8 of the Peak calibration frame and the four poles of the ISN-UM frame, were measured and the mean was calculated. The mean value was 0.199 m and found to be the same. Without moving or changing the set-up, a recording of an amateur *sepak takraw* team playing a demonstration game was made.

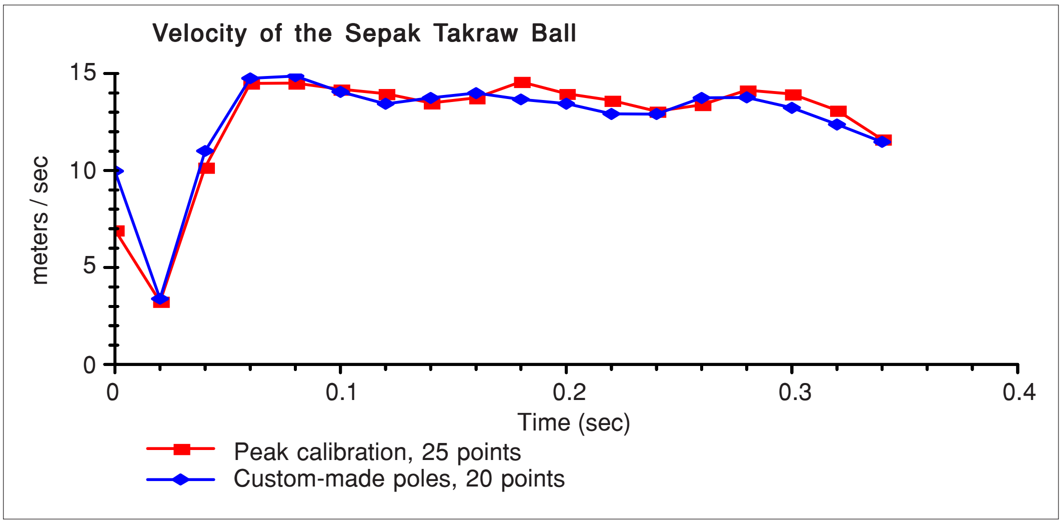
3.0 RESULTS AND DISCUSSION

The differences in object space calibration error and the mean square error between the results obtained for the two frames are presented in Table 1. As can be seen in Table 1, the mean square error of the object space obtained from the Peak calibration frame showed that the coordinates in the *z*-direction is significantly smaller than those of coordinates in the *x*- and *y*-directions. The mean square error obtained from the ISN-UM frame on the other hand, showed a significant increment in the *z*-direction. These differences indicated that the Peak calibration frame preserved the accuracy of the distributed control points within the activity space. A possible explanation for the phenomenon produced by the ISN-UM frame is that the coordinates were not precise. Another explanation is that the poles were not vertical when the recording was taken. This might be due to the built-up of the poles and/or the disturbance in the environment.

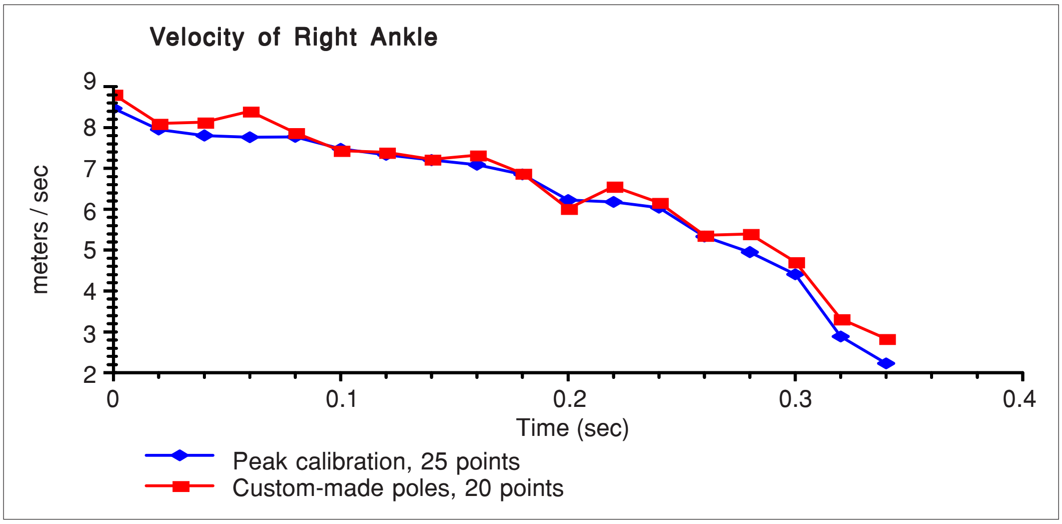
Table 1 Mean square and object space calibration error of Peak calibration frame and the ISN-UM frame

Peak Calibration Frame				
	X	*Y*	*Z*	Position
Mean Square	0.0049	0.0043	0.0038	0.0076
Object space %	0.2249	0.2298	0.2398	0.2300
ISN-UM Frame				
	X	*Y*	*Z*	Position
Mean Square	0.0051	0.0066	0.0089	0.0122
Object space %	0.2775	0.3544	0.4602	0.3747

The graphs of the velocity and acceleration of the *sepak takraw* ball, and of the right ankle, right heel, and right toe of the *sepak takraw* player showed that the results are very similar, as shown in Figures 4 and 5. Slight differences of the two graphs are

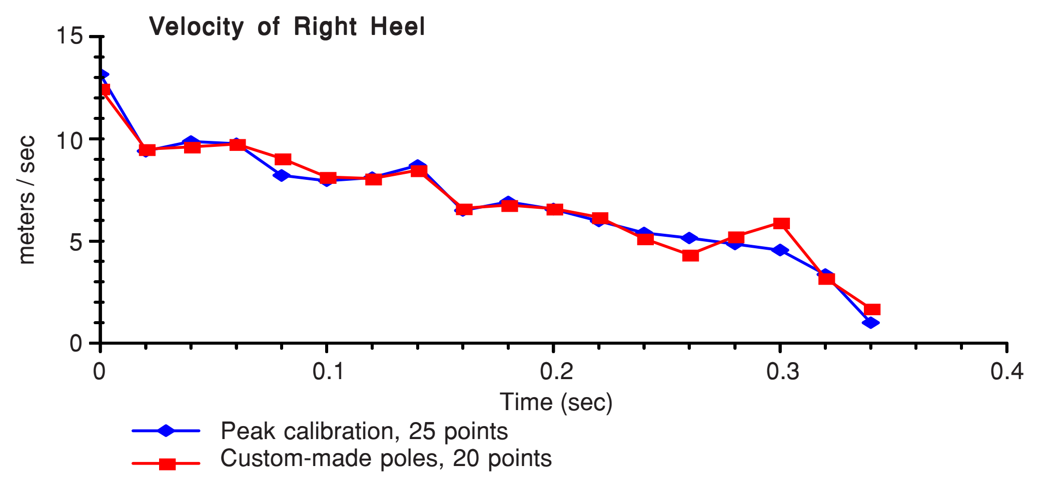


(a)

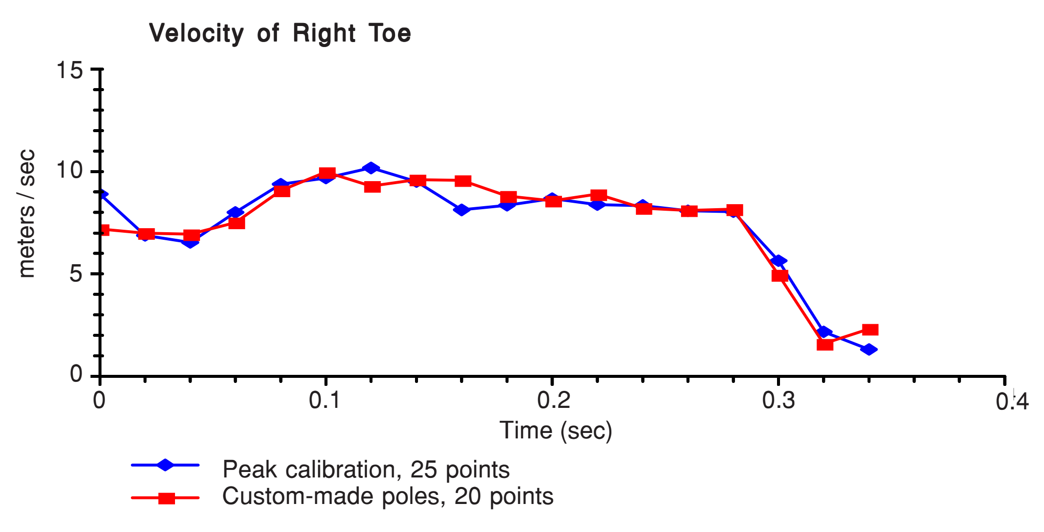


(b)

Figure 4 (a), (b) – Graph of the velocity of the parameters from the two systems

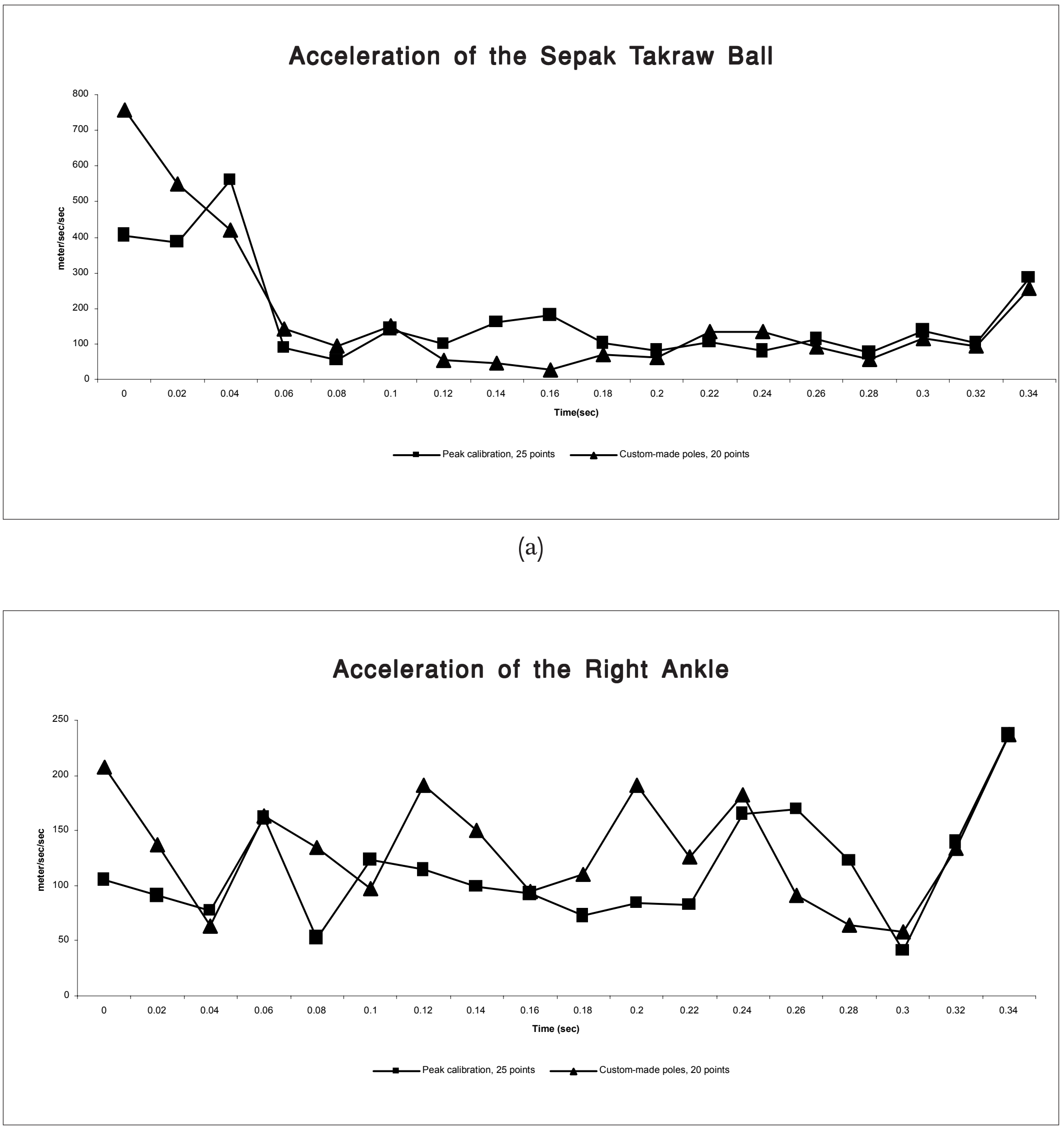


(c)



(d)

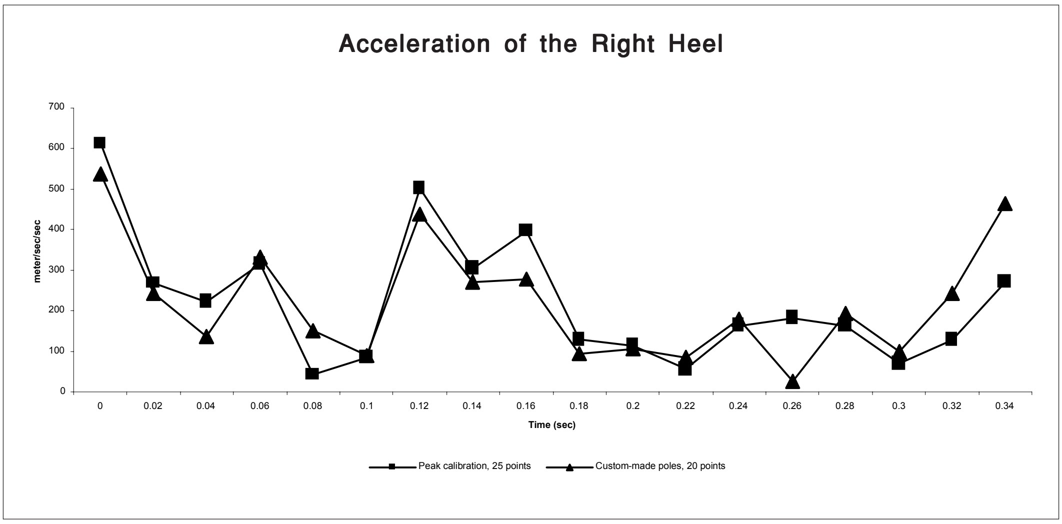
Figure 4 (c), (d) – Graph of the velocity of the parameters from the two systems



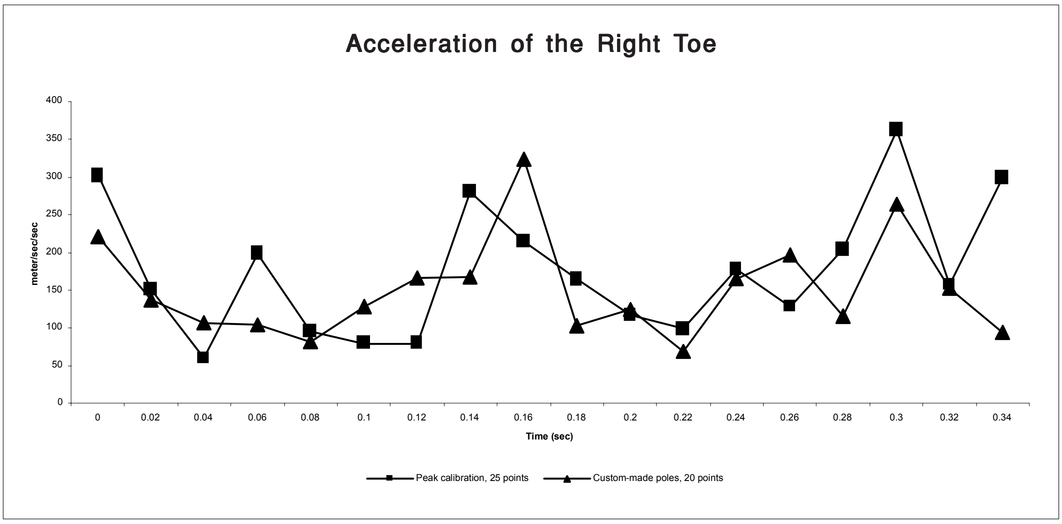
(a)

(b)

Figure 5 (a), (b) – Graph of the acceleration of the parameters from the two systems



(c)



(d)

Figure 5 (c), (d) – Graph of the acceleration of the parameters from the two systems within the digitising error. Despite the difference in the location of control points, one distributed within the activity space and the other surrounding the activity space, the physical characteristics of the structures, as well as the total control points, convincing results were obtained. Hence, it is possible for the ISN-UM system to be moved outside of the activity space, and enlarge the calibrated volume.

4.0 CONCLUSION

Despite the difference in the locations and the number of control points of the two methods, as well as the physical characteristics of the structures, results obtained by using the custom-made ISN-UM frame are comparable to those obtained using the control (Peak calibration frame). Thus the ISN-UM system provides an acceptable alternative for a three dimensional volume. It has an additional advantage of using a set of poles most convenient to move and set up, although the dimensions of these two calibration structures are about the same.

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