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Full Length Research Paper

Precision and repeatability analysis of Optotrak Certus as a tool for gait analysis utilizing a 3D robot

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In both scientific and clinical investigations, the precision and repeatability of instruments are demanded; however, precision of motion analysis systems has been reported in the literature rarely and studies are generally not comparable. This study introduces a new method of determining precision and repeatability of Optotrak Certus, a motion analysis tool for gait analysis using a three dimensional (3D) robot. Using 3D robot as reference of standard for distance, the angle and velocity measurement, the accuracy and precision of the Optotrak Certus in terms of angle, distance between markers were quantitated. The standard deviation (SD) and the coefficient of variation (CV) provide a measure of precision whereas the coefficient of multiple correlation (CMC) provides a measure of repeatability. Experimental results containing CMC, CV and SD values for variation of angle, volume, circular movement and speed were demonstrated to analyze the repeatability; hence the repeatability was satisfactory. Angle and distance between markers showed good agreement between measurements, and comparable measures of precision are reported as well as CMC and CV values. The investigation is ethical and practical in measurement analysis in terms of precision and repeatability.

Key words: Gait, CMC, CV, precision, repeatability, SD, 3D robot.

INTRODUCTION

Recently, the 3D motion analysis systems has been widely used in the field of gait analysis. It has been found that 3D motion analysis systems are always related to some errors and therefore, only obtained values. For 3D motion measurement systems, there are some internal and external influencing factors, which are responsible for errors such as sensor types, method application, data acquisition conditions, measurement range, object reflectance, precision, spatial resolution and measurement planning.

Optotrak Certus (OC) is a very popular tool used in industries, universities and research institutions around the world. OC obtains 3D positions utilizing infrared light-emitting diodes, which reflect light back to the sensor mounted in a stand. The markers are 16 mm in diameter and weigh 6 g. A position sensor consisting of three one-dimensional charge-coupled devices paired with three lens cells are permanently mounted in a 1.1 m long stabilized bar and calibrated by the manufacturer. The sensor captures the positions of the markers sequentially with a total sampling speed of 4600 Hz, and maximum frame rate of 400 Hz (NDI, 2007). In addition, OC can track up to 512 markers and the size and weight of OC makes it easy to move between locations. In the fields of engineering, accuracy is the degree of conformity of a measured quantity to its absolute value. Accuracy is closely related to precision, also called reproducibility or repeatability, the degree to which further measurements or calculations will show the same or similar results. The results of a measurement can be either accurate but not precise or precise but not accurate, neither or both. Accuracy is the degree of veracity while precision is the degree of reproducibility (Li, 1999; Richards, 1999; Currier, 1999). A result is called valid if it is both accurate and precise. In case of OC, precision refers to the angles and distance used between markers in gait analysis. The reliability test of motion analysis system in the aspects of

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Abbreviations: SD, Standard deviation; **CV,** coefficient of variation; **CMC,** coefficient of multiple correlation; **OC,** optotrak certus.

precision and repeatability was performed by Allard et al. (1995) in terms of the frame-to-frame repeatability of the measurement. The landmark, distance between markers and angles studies investigated using Optotrak system (Glossop et al., 1996; Li, 1999; States, 1997; Richards, 1999), suggested about the reliability of motion analysis systems. In this paper, the precision and repeatability of OC is investigated using a three 3D robot and CMC analysis based on marker position, angle, volume, circular movement and object moving at different speed. Furthermore, the repeatability analysis of dynamic objects with acceleration, constant speed and deceleration are investigated.

EXPERIMENTAL SETUP

The experimental set up includes three devices which are:

(1) 3D robot
(2) OC (Northern Digital, Waterloo, Ontario, Canada)
(3) PC with compatible softwares of OC and 3D robot

Our laboratory designed a 3D robot, which can move in the X, Y and Z coordinate in real time simultaneously. There are transmitters available which enables data transfer from the 3D robot to the remote pc. The highest limits for movement in X, Y and Z axis are 50, 30 and 50 cm, respectively. There is a flat plate available which is mounted in the Z axis that will be used later for placing markers.

Depth of the sensors measurement

For the measurement of the depth of the sensors, we did not forward to the extreme limit. We utilized one static marker at a certain distance from the sensors of the Optotrak Certus and measure the maximum and the minimum the depth of the sensors which were found at 1.5 and 6.9 m, respectively, although the manufacturer recommended the depth of the sensors between 2 and 6 m.

Precision analysis experiment

For precision experiment, we utilized the OC system with a strober along with 4 markers. One marker was placed in one corner of the flat platform where the origin of the 3D robot was placed as shown in Figure 1. From Figure 1, it can also be seen that the marker 1 is all the way static and the other three markers, that is, markers 2, 3 and 4 can move whenever the plate is moving. We measured the absolute distance of the markers 2 and 4 with the angle formed between the line formed by markers 1 and 4, and the line formed by marker 1 and marker 2. Afterwards, we measured the distance and the angle between markers 2 and 4 both in static and dynamic condition by taking three trials using OC system. The results with error (%) and standard deviation (SD) value are also provided.

Repeatability analysis experiment

In case of repeatability, we used coefficient of multiple correlation (CMC) approach being developed by Matlab program (Lee, 2006). For any measurement system for experimental design, the repeatability of data acquired by a measurement system (Portney and Watkins, 1993; Currier, 1999) is a major factor. Synonyms commonly used to describe repeatability are reliability, stability, consistency and predictability (Currier, 1999; Hislop, 1963). Any measurement device is called a reliable system if it can measure the same values in the same quantity with repeatability for its desired application. CMC is a powerful measure of the repeatability of waveform data (Neter et al., 1989; Kadaba et al., 1989), and it is applied in some gait analysis studies previously (Kadaba et al., 1989; Growney 1997). The repeatability of any measured data can be more accurately analyzed by the CMC analysis (Neter et al., 1989; Kadaba et al., 1989; Growney, 1997). When the waveform of every data set is similar to each other, the CMC value approaches close to 1. The CMC values can be interpreted as follows:

(1) Values ranging from 0.00 to 0.25 (little or no similarity)
(2) Values ranging from 0.25 to 0.50 (fair degree of similarity)
(3) Values ranging from 0.50 to 0.75 (moderate similarity)
(4) Values ranging from 0.75 to 1(high similarity)

The CMC analysis can provide us with the information of repeatability of measured data sets but it can't show if there is any error in the size of measurement. A useful statistical technique that addresses this issue is the coefficient of variation (CV). We perform repeatability analysis in the aspects of variation of angle, position, volume, circular movement and speed. In case of position and angle repeatability analysis, the experimental set up was same as in precision analysis. For circular movement repeatability analysis, we utilized the position of the marker 2. It may be mentioned here that our designed 3D robot can move to form a circle in two dimensional plane. Using the position of the marker 2 on the plate, the same circular movement was repeated three times which was later utilized for the repeatability analysis. Our markers (Markers 1, 2, 3 and 4) were placed in four corners of the flat plate of the 3D robot in the form of a rectangle having the same length and width as the rigid body dimension. The other four markers ((Markers 5, 6, 7 and 8) were placed in the four corners of the rigid body. Whenever the plate was moving along the Z axis the volume formed by the eight markers between the rigid body and the plate was also changing. Using the position of the markers, we calculated the volume for three trials obtained from OC and performed the repeatability analysis.

RESULTS

Precision test for distance between markers

For precision test to determine distance between markers, three trials taken from OC for both static and dynamic condition with error (%) and SD value for each trial are shown in the Tables 1 and 2.

Precision test for angles

For precision test in terms of angle, the angle data between the line formed by markers 1 and 4 and the line formed by markers 1 and 2 was taken in static condition from Optotrak Certus with SD value as well as error (%) are shown in Table 3.

Repeatability analysis for Position and object moving at different speed

The position of marker 2 was utilized for position repeatability analysis. In Figure 2, we have plotted the measured

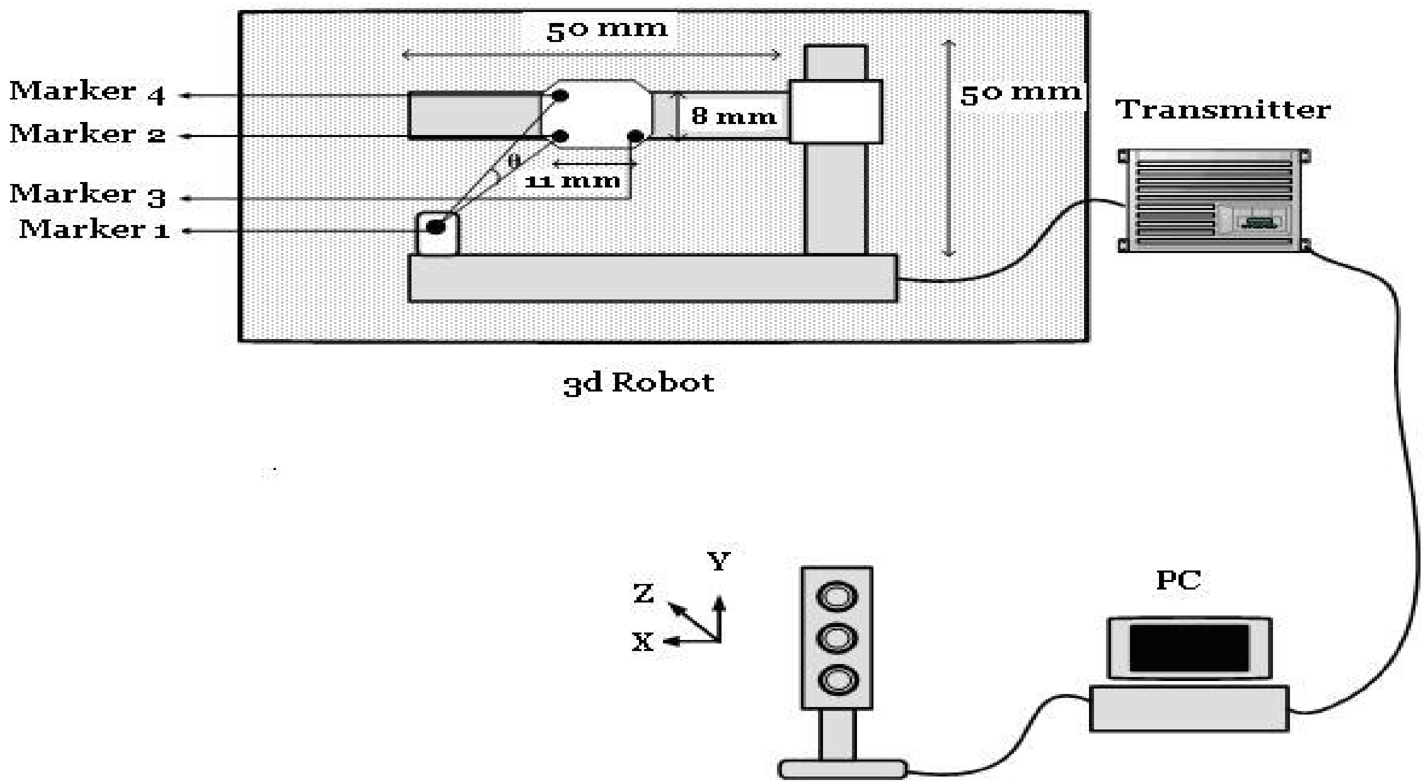

Figure 1. Experimental setup for precision analysis.

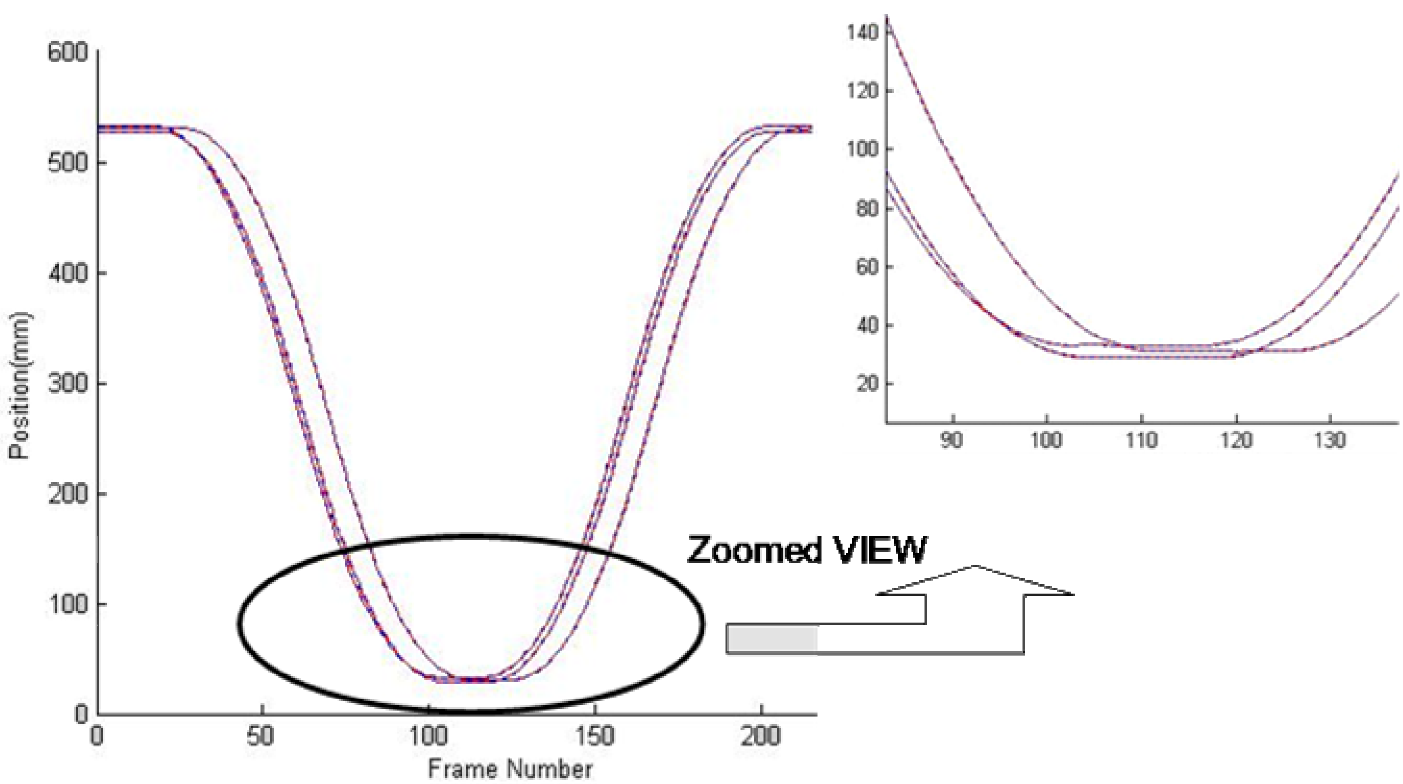

Figure 2. Three raw trail position data in the z axis.

three trial position data in the vertical axis whereas the horizontal axis contains the corresponding frame number in the Z coordinate. We also added a zoom view of each figure for better understanding of presence of three trial data. Similar figures can be plotted for the X and Y axis also. The CMC values, CV values (%) and SD values were found at 0.998, 0.7226 and 0.0161 for X axis; 0.9897, 0.3165 and 0.0017 for Y axis; 0.9897, 12.9263 and 0.1945 for Z axis, respectively which represent better repeatability and less error in position data. After this analysis, we performed the repeatability analysis for the dynamic object at difference speed. It may be mentioned that while doing the experiment, we used the trapezoidal velocity profile for the moving object which has an initial acceleration stage, the middle constant speed stage and deceleration stage. We performed the repeatability analysis for the acceleration, constant and deceleration speed, and the obtained CMC values, CV values (%) and SD values were 0.9926, 11.7747 and 7.5139 for acceleration stage; 0.6275, 1.2282 and 0.2217 for constant speed; 0.9855, 22.2025 and 7.4604 for deceleration stage. From the values, it can be seen that the constant speed profile has the low CMC value which means the repeatability was not very good for an object moving with constant speed whereas for the acceleration and deceleration stage, the CMC value were found better. But for the acceleration and deceleration stages, the CV values were found little higher which show some error in data.

Repeatability analysis for angle

As the plate was moving, the angle between markers 2 and 4 with reference to static marker was changing. Figure 3 is the plotting of the measured variation of angle between markers 2 and 4 versus corresponding frame number with a zoom view to show the presence of three trial data. The CMC, CV (%) and SD values were found as 0.9901, 1.2634 and 1.0917, respectively that prove better repeatability and less error.

Repeatability analysis for volume

For the repeatability analysis for volume, we used a rigid body. Figure 4 shows the plotting of the variation of volume between the plate and rigid body with a zoom view to show the three trial data. The CMC, CV (%) and SD values were calculated as 0.9999, 1.4151 and 0.0016 that show better repeatability and lower error.

Repeatability analysis for circular movement of markers

As the position of marker 2 was varied for the circular movement, Figure 5 shows the plotting of the measured variation of the position of marker 2 in the X coordinate for circular movement in X-Y plane. From Figure 5, one can understand the similarity between three trial data. Besides a zoom view is provided for better understanding of the three trial data. Same plotting can be obtained for Y axis movement. The CMC, CV (%) and SD values were calculated as 0.9949, 2.8104 and 0.0944 for the X axis and for the Y axis, the values were obtained as 0.9956, 0.7761 and 0.1062, respectively that proved better repeatability and less error.

DISCUSSION

The experimental results suggested that the OC exhibits very high precision and excellent repeatability for the measurement of distance, angle, volume and speed. Although precision and repeatability were not tested under human movement, however in the case of OC, the excellent precision of the system remove doubts from the researchers mind in aspects of distance, position and the depth of the sensors as the system shows high precision. Moreover, OC also has great repeatability. There was no significant difference in the measured data taken between sessions in either distance or angle measured. In the precision analysis for the distance between markers, the errors (%) and the SD values were found between 0.569 ~ 0.57 and 0.002 ~ 0.0043, respectively for static condition whereas for the moving condition, they were found as 0.572 ~ 0.578 and 0.0058 ~ 0.0086, respectively. In case of precision of angles between markers, the error (%) and SD values were found in between 4.01 ~ 4.013 and 0.000134 ~ 0.000192. As we can see in case of angle, the error is more comparing to distance. The repeatability analysis is summarized in Table 4. Finally, the viewing area for the OC was compatible with the manufacturer's suggestion of a depth of 2 – 6 m. A larger range was available under static conditions for the system and the 3D robot, although the extreme limit was not observed. To mention our limitation, it can be stated that all the viewing areas under the system were not analyzed. Despite the trials taken for the movement of 3D robot, all the way the 3D robot was near to the center of the viewable area of the system. Recently, some people suggested the availability of noise in 3D data although we did not put it into consideration. Finally, all the CMC values were close to one that shows better repeatability, the CV values were low and shows less error in measurement, and the SD values were also found very low. These results prove the reliability of OC as a motion analysis system. But as we did not deal with human motion, we cannot guarantee high reliability for any given application of human motion using OC. The reliability of a motion analysis system depends on lot of factors such as depth of the markers, motion of the markers in skin, position of the markers which means landmark, etc. From practical experience, we can say the markers sometimes go out of sight for the sensors during

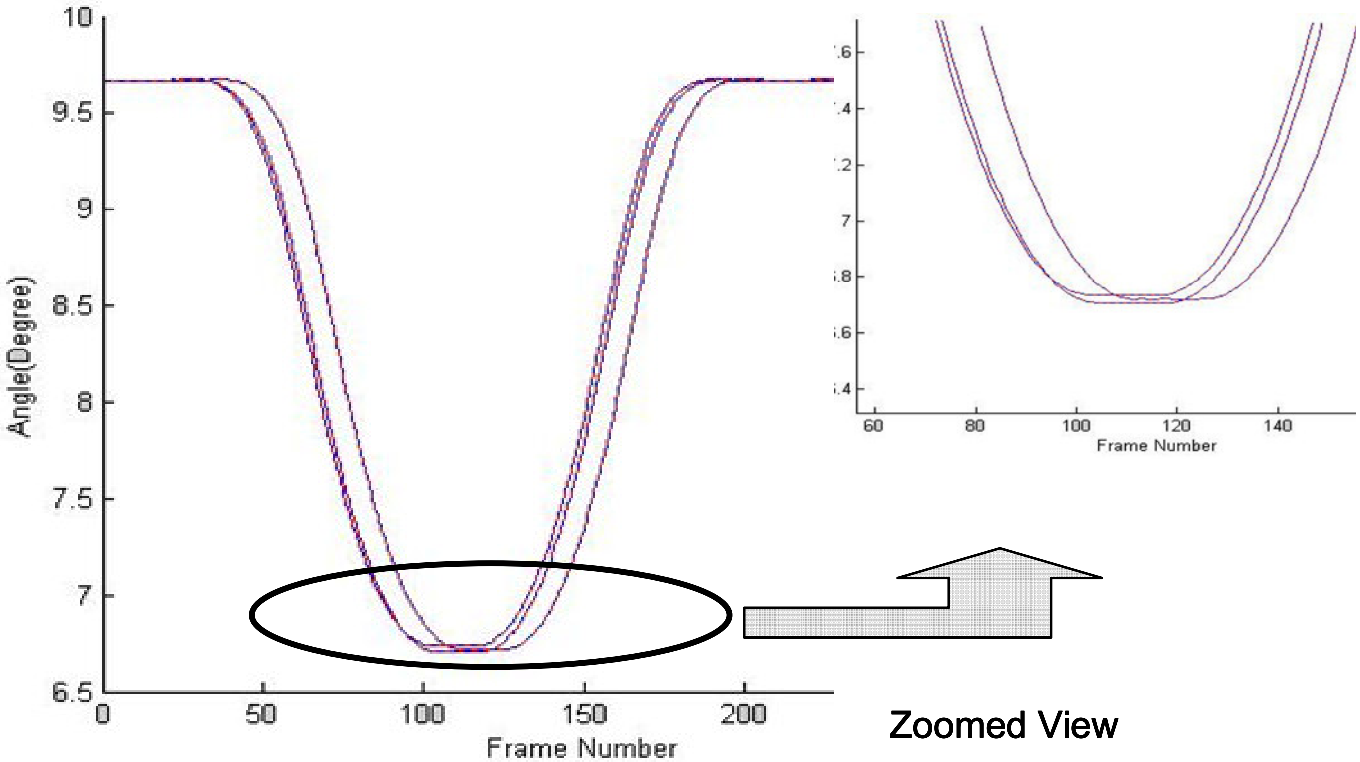

Figure 3. Variation of angle between marker 2 and marker 4.

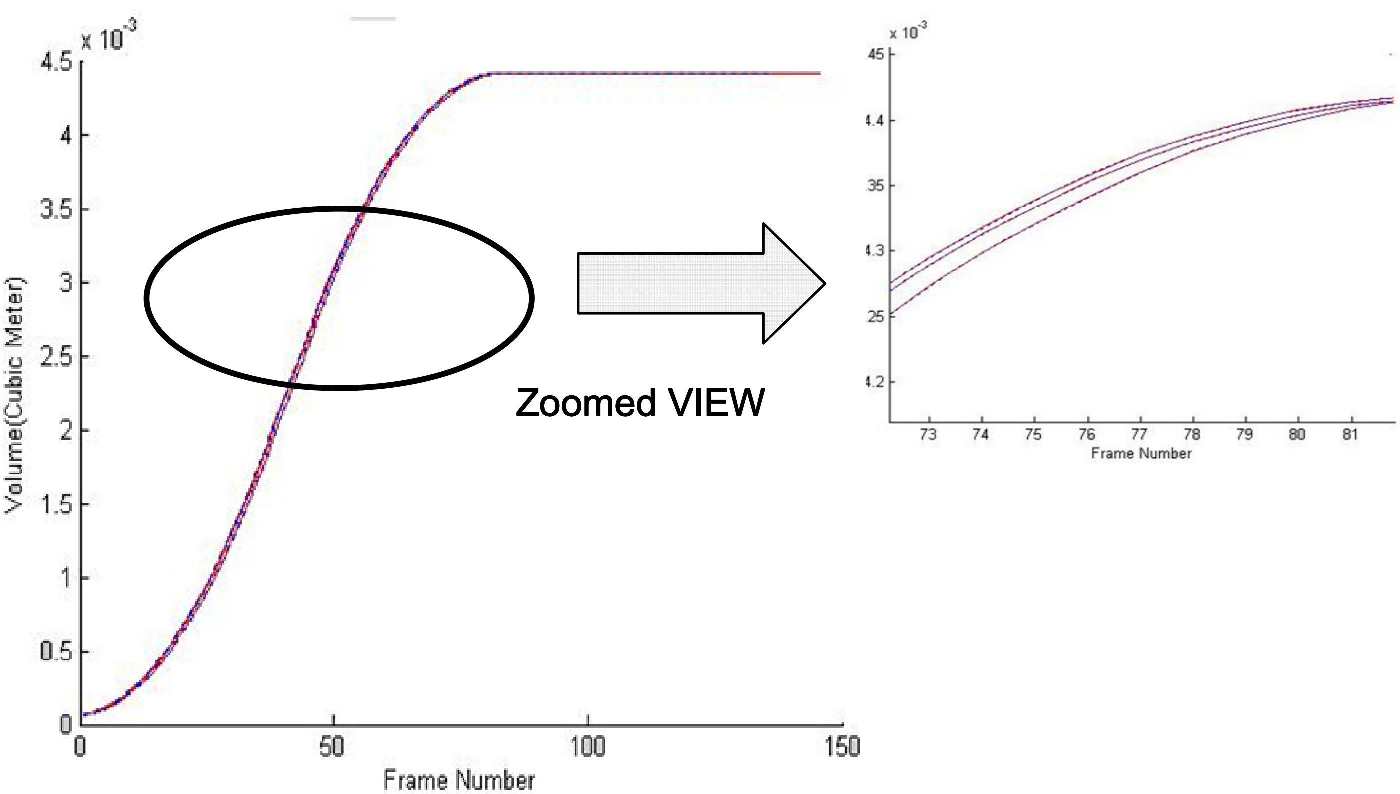

Figure 4. Variation of volume between the flat plate and the rigid body.

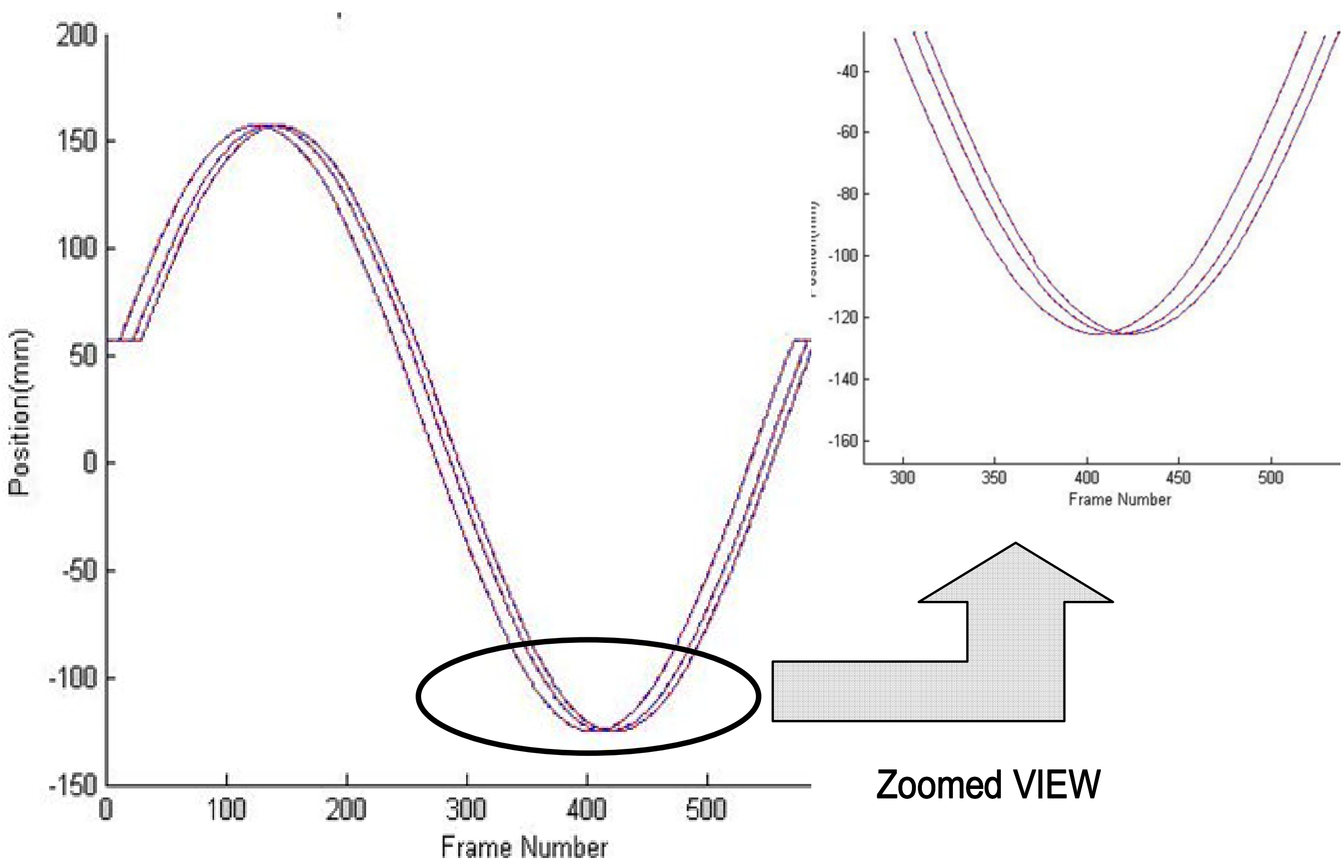

Figure 5. Position of marker 2 for circular movement in the x axis.

human motion whereas the other motion analysis systems are designed to overcome the out of sight problem better than the OC by providing cameras or sensors at various directions relative to the subject or utilizing electromagnetic device that does not care about out of sight problem. However, for any application of motion analysis system the device should be examined to find the accuracy and the reliability of the system. Finally the present study corroborated the idea that OC is an effective motion analysis tool in assessing motion of an object since they show better precision and repeatability. Regardless of these measurements, most of the motion analysis systems motion of the marker due to skin and landmarks are still the main issues to be considered. The results presented here can be used for further analysis and improvement of the performance of the motion analysis systems.

Conclusion

This study presents the analysis for assessing the performance of a commercially available motion analysis system (Optotrak Certus) utilizing a 3D robot. OC show minimal errors during our trails which suggest the measurement will not be subjected to a significant error for gait analysis. The precision and the repeatability analysis make us believe that OC is a highly reliable motion analysis system. Further studies should deal with the noise associated with the measured 3D data as well as the larger viewing area for the position and depth of the markers to apply in human gait analysis.

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