A comparison of gait analysis data obtained simultaneously with optical and inertial motion capture systems

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Abstract— **This study was conducted with the purpose of identifying the differences within two of STT System's motion capture products in their most common usage, which is gait analysis. In order to obtain the data, a healthy subject walked in a straight line while both systems recorded the motion. The resulting data was processed using the STT applications for each of the used systems (*Clinical 3DMA 6.11* for the optical system and *iSen 3.07* for the inertial system) and *GNU Octave 4.2.1.* for the final comparison. Even though the final results showed some differences in the gait curves, the general movement of all joints was consistent in both systems.**

I. INTRODUCTION

The existence of several different methods to record and analyze human motion brings forth the question of how these different systems compare to each other in a specific setting. Both inertial and optical motion capture systems have advantages as well as limitations regarding their intended use and the data that needs to be collected using them, but this is a matter of how the system capabilities and features adjust to a determinate study or field.

The main goal of this study is to obtain a standard gait analysis curve set from each of the systems after recording a healthy walking subject with both methods simultaneously in order to pinpoint the specific differences between the systems.

II. EXPERIMENTAL PROCEDURE

A. Marker & Sensor Placement

Both optical and inertial motion capture systems require the placement of devices on the subject in order to record the movement. In the case of the optical system, a basic lower train gait analysis protocol was used, which required 15 passive reflective markers distributed as shown on Figure 1, this is called the Helen Hayes Model. For the inertial system, the protocol required 7 inertial sensors placed as shown on Figure 2.

Due to the nature of the system, the inertial sensors could be placed with a much less strict guide, minus the Right Tibia sensor, which worked as the reference point during the initial calibration of the protocol and needed to be perfectly aligned with the tibial length direction. Similarly, the optical system markers needed to be placed at specific anatomical landmarks, and required to be as visible and unobstructed as possible throughout the recording.

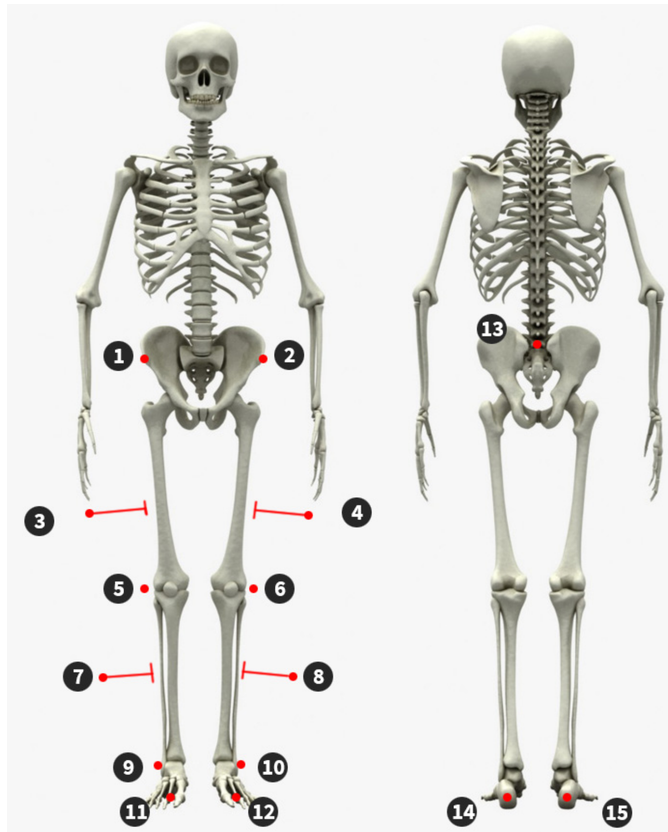

Fig. 1. Anatomical protocol used for the optical system marker placement.

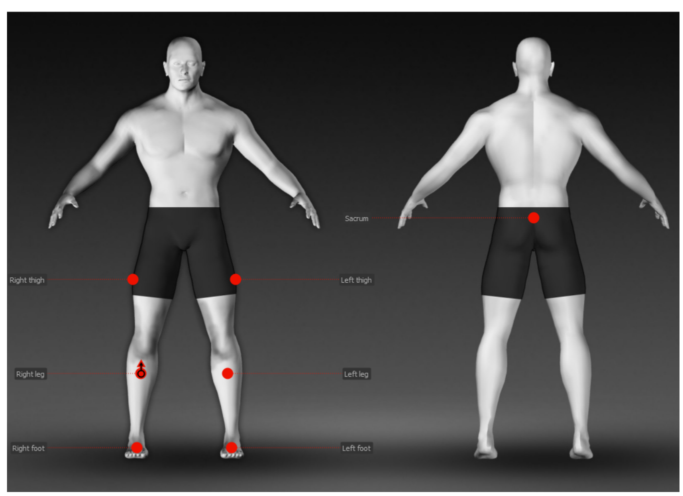

Fig. 2. Anatomical protocol used for the inertial system sensor placement.

*This is an internal study and its results are not meant for publication or use outside of the company or its authorized clients.

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The simultaneous placement of all devices was unproblematic for the most part, since the sensors on thighs, calves and feet did not coincide with the anatomical landmarks for the markers. However, in the case of marker #13, the sacrum inertial sensor is meant to be placed in the same spot to be able to correctly measure pelvic and hip motion. To solve this, the marker was placed on the sensor, guaranteeing that it was not going to be blocked during the capture.

B. Gait Analysis Trials

After both systems were set up for capture (for the optical system: 6 cameras plugged in and calibrated recording at 100Hz, and for the inertial system: 7 sensors powered on and connected to the network recording at 100Hz), all recordings were done in three steps:

1) **Subject calibration in the optical system:** An initial recording was done with the subject standing in anatomical position in the middle of the optical capture volume, in order to calibrate the model for further recordings.
2) **Subject calibration in the inertial system:** The subject was asked to stand outside the optical capture volume at the spot where the walking line would start, and stand still in anatomical position while the inertial sensors began recording. In this position, the inertial system was calibrated by sensor (the position of all the sensors in the moment of calibration will be known and from then on the system will operate with these values as offsets).
3) **Data collection:** After the inertial system was successfully calibrated, the optical system was set to record as well and the subject was told to walk in a straight line until they exited the capture volume, at which point both recordings were stopped.

The data was only collected for one walking direction, since a 180° turn offsets the pelvic rotation value of the inertial sensors. In order to avoid any possibility of drift in the inertial sensors data overtime, the recordings were stopped in time with the optical system and restarted and re-calibrated for every trial, as it was done for the optical system. Finally, this process was repeated 4 times, resulting in a total of 8 left steps and 9 right steps recorded simultaneously.

III. DATA PROCESSING

A. Data Export

All of the STT applications (*3DMA* and *iSen*) provide an export option for several types of data, in this case, the joint angles were exported as CSV files containing the desired angles throughout the whole capture time, all of these angles are listed on Table I.

It is also worth to recall that the optical system protocol also provides Foot Rotation data for both feet, but since the inertial system protocol does not, these values were ignored for this study.

TABLE I
JOINT ANGLES

Joint/Plane	**Sagittal**	**Coronal**	**Transverse**
Pelvis	Tilt	Obliquity	Rotation
Hip	Flexion	Adduction	Rotation
Knee	Flexion	Varus	Rotation
Ankle	Flexion	Adduction	Rotation

In order to separate these data in steps, the times for all events ”Right Foot Initial Contact” and ”Left Foot Initial Contact” were also exported. The exported data was then copied into a .MAT file and processed with GNU Octave to obtain the final results.

B. Step Selection & Filter

The key aspect for data processing was the identification of the steps recorded by the inertial system that were also recorded by the optical system. Since the optical system depended on the subject being inside the capture volume, a few more steps were recorded with its inertial counterpart.

Using Octave, the times of both feet initial contacts with the ground were used to separate all joint angles values into right and left steps. After testing how many steps were taken before the subject entered the capture area, the beginning and end of the inertial system captures was trimmed and it resulted in a selected group of simultaneous steps captured with both systems.

In order to show the data just as the final user would see it, no extra filtering was applied to the curves of either of the systems.

C. Trial Merger

After obtaining a set of curves for each angle and joint, means and standard deviations were calculated along the gait cycle (starting at 0% at the initial contact of right or left foot and ending at 100% at the immediately subsequent initial contact of the same foot). The results of each joint and angle for the two systems were plotted over the same axis in order to visually compare the final curves.

Aside from the plots, the average time of step was measured and compared, resulting in a difference of under 2/100th of a second between systems for all of the steps recorded.

IV. RESULTS

The resulting plots were arranged by joint and are shown on the following figures. One of the key expectations was to obtain similar (if not identical) plots in shape and magnitude for both systems, which would prove that they are equally capable of capturing gait motion data and because of that, can be used interchangeably.

A. Pelvic Joint

As it can be seen on Figure 3, the resulting plots for the angles of pelvic tilt and obliquity are quite similar for the two systems. For the pelvic tilt, a slight 2° offset in magnitude can be observed throughout the curve, the optical system registering a slightly more anterior tilt that the inertial system throughout almost the entirety of the gait cycle, except for the part right after toe-off (between 70% and 90% of the gait cycle) that shows identical results between the systems.

In the case of the pelvic obliquity, the general aspects of the curves are very similar, but the inertial system data seems to exhibit a wider standard deviation by around 2°. Finally, in the pelvic rotation plot, the optical system shows a more pronounced range of motion differing up to 10° in both internal and external rotation.

B. Hip Joint

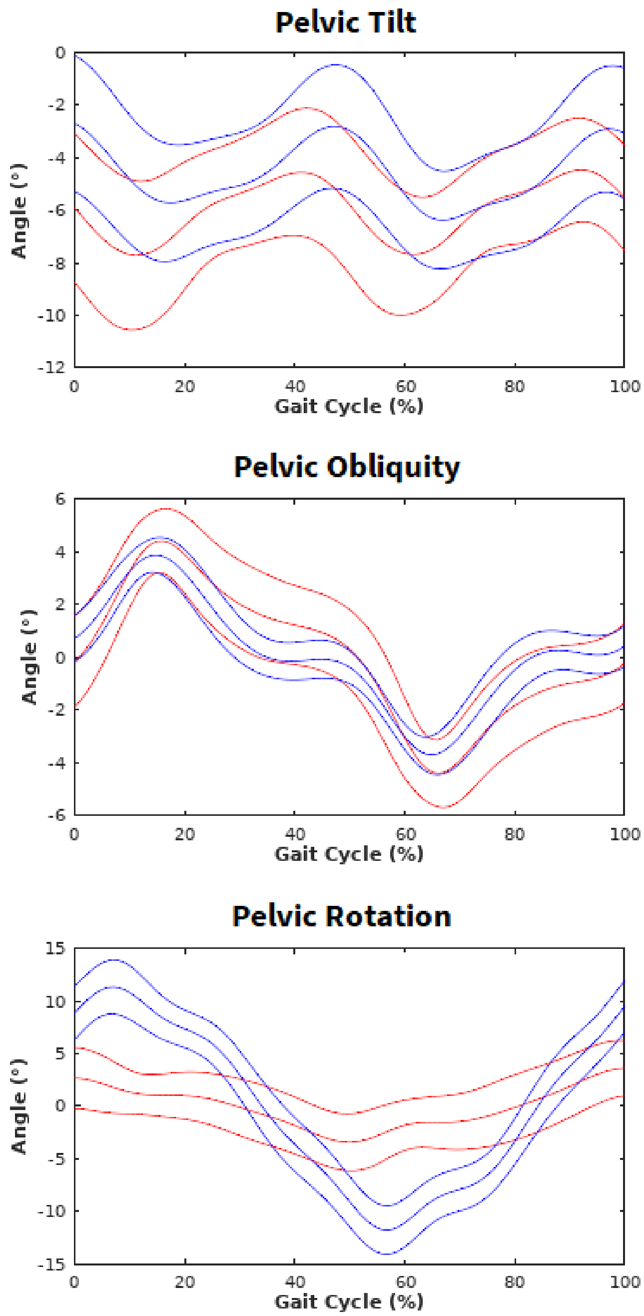

Fig. 3. Results for the pelvic joint in three planes: **(a) Sagittal Plane** for Pelvic Tilt, **(b) Coronal Plane** for Pelvic Obliquity, and **(c) Transversal Plane** for Pelvic Rotation. In blue, data collected using the optical system and in red, data collected using the inertial system. The middle line represents the mean of the gait cycles recorded, while the top and bottom lines represent the standard deviation for the trials.

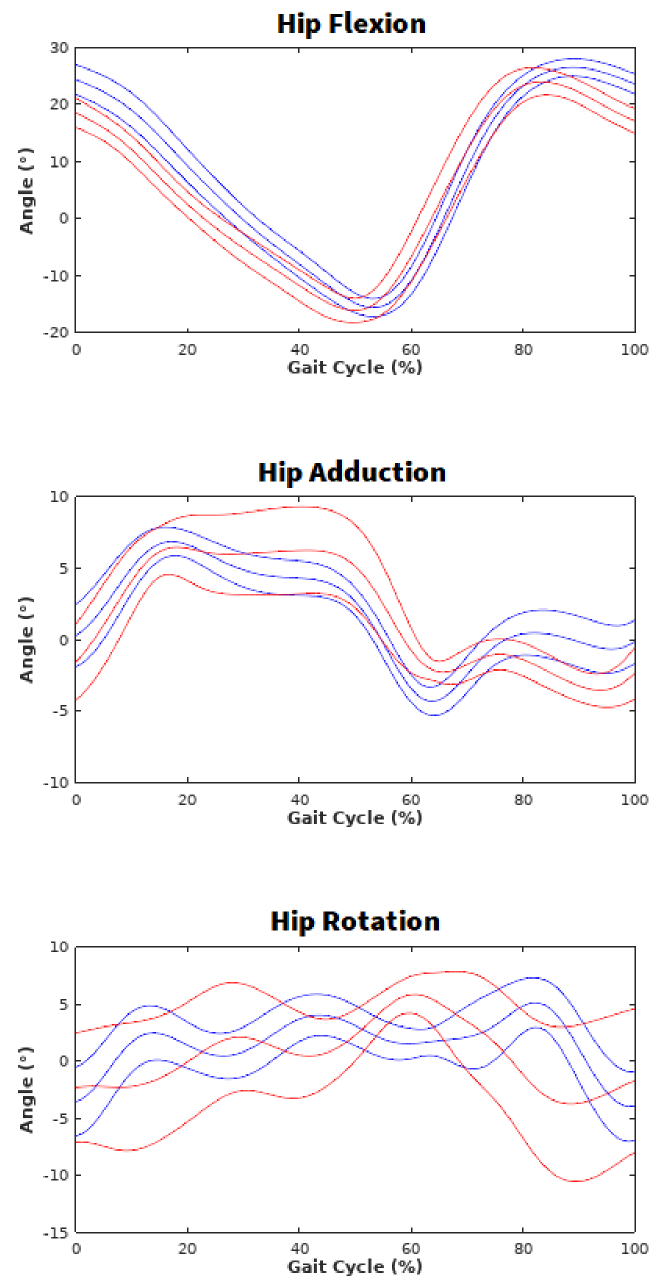

Fig. 4. Results for the hip joint in three planes: **(a) Sagittal Plane** for Hip Flexion, **(b) Coronal Plane** for Hip Adduction, and **(c) Transversal Plane** for Hip Rotation. In blue, data collected using the optical system and in red, data collected using the inertial system. The middle line represents the mean of the gait cycles recorded, while the top and bottom lines represent the standard deviation for the trials.

For the hip curves shown on Figure 4, hip flexion and hip adduction seem very similar between the two systems, however, the hip rotation curve shows some differences. Even though the general shape of the curve presents some variations depending on the recording system (a diminished angle in hip adduction around 40% of the gait cycle in the optical system), the general magnitude of the curves remains less than 5° apart throughout the entire gait cycle.

C. Knee Joint

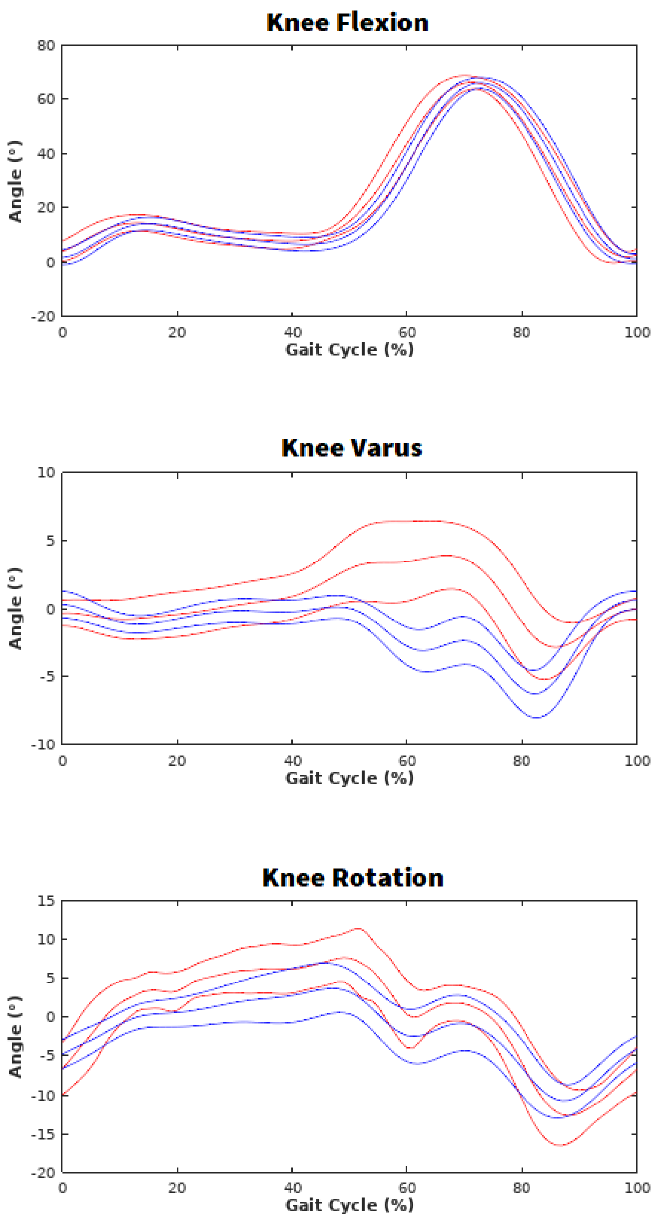

Fig. 5. Results for the knee joint in three planes: **(a) Sagittal Plane** for Knee Flexion, **(b) Coronal Plane** for Knee varus, and **(c) Transversal Plane** for Knee Rotation. In blue, data collected using the optical system and in red, data collected using the inertial system. The middle line represents the mean of the gait cycles recorded, while the top and bottom lines represent the standard deviation for the trials.

The curves for knee flexion and rotation coincide quite well between the two systems, showing only a slight difference in the maximum value for the knee rotation. The knee varus, however, shows what appears to be a sign inversion that will be thoroughly checked in both systems in order to reach a directionality consensus.

D. Ankle Joint

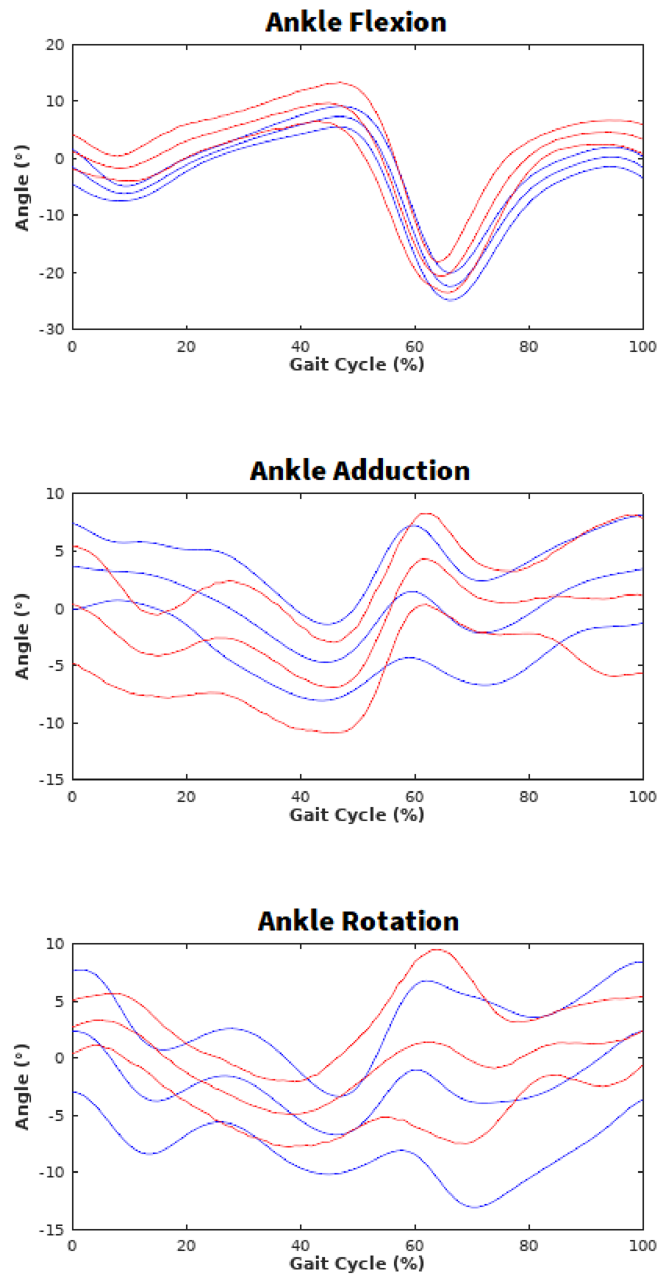

Fig. 6. Results for the ankle joint in three planes: **(a) Sagittal Plane** for Ankle Flexion, **(b) Coronal Plane** for Ankle Adduction, and **(c) Transversal Plane** for Ankle Rotation. In blue, data collected using the optical system and in red, data collected using the inertial system. The middle line represents the mean of the gait cycles recorded, while the top and bottom lines represent the standard deviation for the trials.

Finally, the curves obtained from the ankle data seemed very similar between the systems for all three angles, showing only a few distinctions in the standard deviation magnitude and shape but the main curve generally remaining comparable for the two.

V. CONCLUSIONS

The expected similarity between the systems was met, minus a few specifics that were set for review. The congruence of these systems suggests that they are both equally capable of recording and analyzing gait data and could be used interchangeably depending on the surrounding environment (inertial sensors being good for recording outside of a closed environment and markers being good for tracking displacement).

After analyzing the entire set of curves, it is obvious that the sagittal plane is the most congruent one for the systems, as it shows the least divergence in the mean curve as well as the standard deviation curves.

The ranges of motion for all curves were similar between the systems except for the pelvic rotation, where the optical system was capable to record a much wider range of motion. This shows a possible limitation on this particular measurement for the inertial system, due to the use of only one sensor to record the movement of the pelvic joint.