COMPARISON OF ANGLE MEASUREMENTS BETWEEN VICON AND MYOMOTION SYSTEMS

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STUDY INFORMATION

This study was carried out by Shruthi Balasubramanian, Master's student and Research Assistant at the Center for Adaptive Neural Systems, Arizona State University.

The data collection for the entire study was carried out at the Center for Adaptive Neural Systems (ANS), Arizona State University. This study was also co-guided by Dr. James Abbas, the Director of the ANS lab.

ABOUT THE LAB

The Center for Adaptive Neural Systems is focused on research that involves bioengineering, neuroscience and rehabilitation. Scientists and engineers at ANS are involved in designing and developing technology to offset the effects of spinal cord injury, orthopedic injury, Parkinson's disease and cerebral palsy. The center is equipped for neurotechnological implementation, imaging, biomechanical assessment and physical assessment.

EXECUTIVE SUMMARY

Problem: The main objective of this study is to compare the angles measured by Noraxon's MyoMotion (MM) system with Vicon Motion Capture System (Vicon) and other angle measurement methods.

Methods: Four separate experiments were conducted to compare the accuracy and precision between the MyoMotion and Vicon systems.

1. MyoMotion and Vicon outputs were compared against a standard goniometer.
2. The static and dynamic angle outputs of Vicon and MyoMotion were validated against angles set using a robot and laser setup.
3. A testing environment was constructed purposely without metal to reduce strong magnetic fields while Vicon and MyoMotion results were compared.
4. True anatomical knee flexion angle outputs from the two systems were compared.

Results: Results suggest that Noraxon's Inertial Measurement Units can be used as an alternative to Vicon Motion capture system, for orientation and anatomical angle measurements. The root mean squared error obtained with Noraxon's IMUs was 0.2^{o} for static trials and 0.5^{o} for dynamic trials, when compared against standard angles set using all collected methods. The correlation coefficient between Vicon and MyoMotion was 0.99.

BACKGROUND

The primary aim of human motion tracking and kinematic angle measurements is to design systems that can accurately measure movement. Optical motion capture systems use passive or active reflective markers and a series of cameras to track the marker positions. Subsequently, the orientation and anatomical angles can be calculated. Currently, one such motion capture system, Vicon, is considered the gold standard for human movement analysis in the field of Biomechanics [1].

The Vicon system used consists of 10 high resolution cameras that collect the infrared light reflected by retro-reflective markers. The raw video information is sent via Vicon data station to Vicon workstation software for reconstruction and labelling. The main disadvantages of such optical systems include the cost, portability and the necessity for a clear line of site between the camera and the markers [2].

Inertial Measurement Units (IMUs) have been widely recognized as a means to overcome the disadvantages of existing optical systems. IMUs are devices capable of measuring various kinematic parameters such as object orientation and velocity using accelerometers, gyroscopes and magnetometers. The biggest hurdle with the camera based systems is marker occlusion and limited tracking volume. IMUs overcome these challenges by being portable, real-time and relatively low-cost.

Noraxon's IMUs consist of tri-axial accelerometers, tri-axial Gyroscopes and a tri-axial magnetometer. A small individual radio module transmits the motion related signals to Noraxon's data acquisition and analysis software, MR3. The sensors are completely wireless, with a transmission range of 30 meters. At present, it is claimed that Noraxon's IMUs are capable of measuring angles with a static accuracy of $\pm 0.4^{o}$ and dynamic accuracy of $\pm 1.2^{o}$ [3]. The main challenge is to determine how these IMUs compare with the conventional motion capture systems.

COMPARISON AGAINST STANDARD GONIOMETER

Method: Various two-dimensional angles were measured using a goniometer (Prestige Medical) and verified using a large printed protractor. One IMU and three non-collinear reflective markers were placed on each of the two goniometer segments. One Logitech 920 camera (USB HD webcam with 30 fps) was used to record the movement of the goniometer against the protractor. Synchronization was performed using a direct connection to the MyoMotion system and two Noraxon Sync lights; one visual spectrum for the Logitech camera, one infrared (875nm) for Vicon. During post processing the synchronization signal was located in the MyoMotion data and aligned to the first frame in which each camera detected the light. Raw marker positions were exported from Vicon to calculate the Euler angles using MATLAB software.

A peak detection algorithm was used to detect local maxima in the angular measurements of a single trial. These peak values were then identified in MR3 and the angle read from the video were recorded.

Results: The difference in angles measured between the goniometer and MyoMotion system was less than 0.3^{o} and smaller than 1^{o} for Vicon after all trials. Measured angles were verified using the video footage showing the goniometer against the protractor and were estimated with an accuracy of 0.5^{o}. When this error margin was considered, Mean Squared Error (MSE) reduced to 0.2^{o} for MyoMotion and 0.5^{o} for Vicon.

All data collections were obtained without synchronization between the three systems. Therefore, only static measurements of the maximum values were compared.

Conclusion:

When comparing the orientation angles given by the MyoMotion IMUs and positional data provided by the Vicon system the MSE for angles measured were found to be 0.2^{o} and 0.5^{o} respectively.

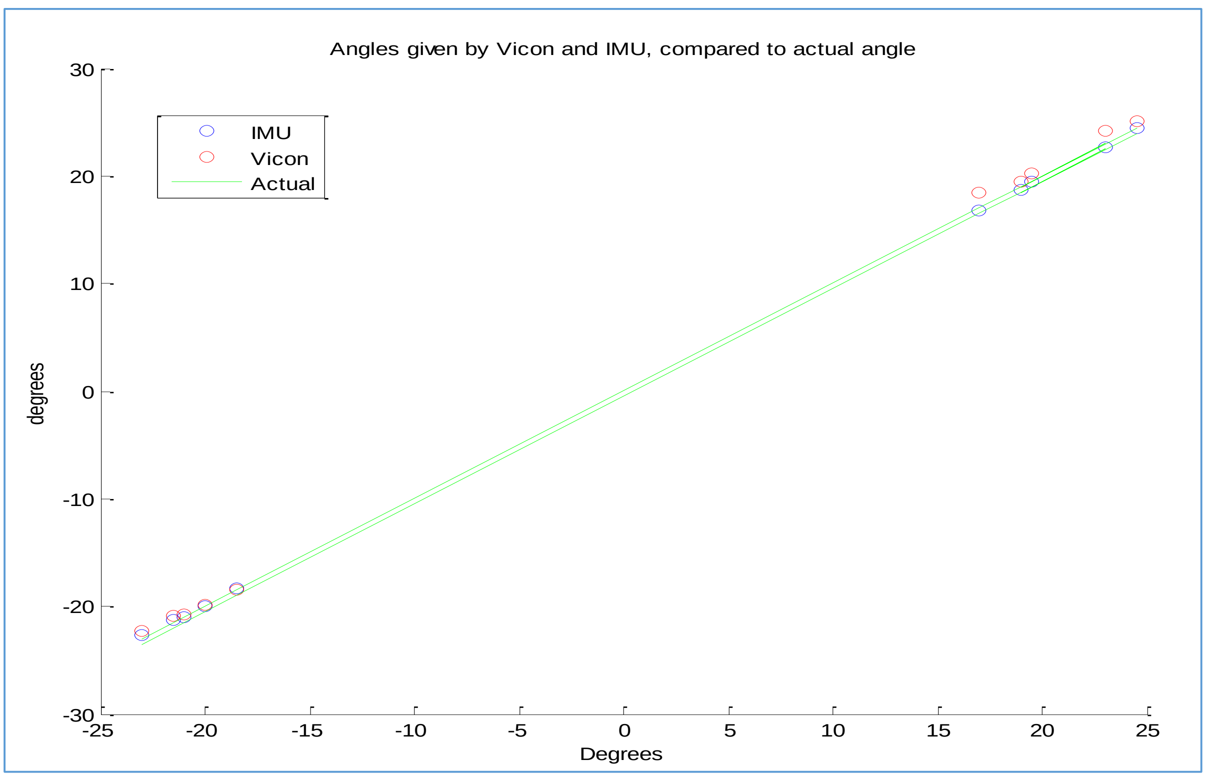

Fig 2: Peak values of Roll angle from Vicon and IMU across trials. X axis denotes the angles set for different trials. Vicon results for positive angles have a higher degree of error due to occlusion of the Vicon cameras by the Logitech camera that was placed near the markers.

VALIDATION USING GIMBAL ROBOT WITH LASER

Method:

A visible light laser was fixed to a gimbal robot, whose position and sequence could be controlled precisely by varying the X, Y and Z coordinates within software. From basic geometry, as the robot moves vertically upwards such that the laser sweeps the height of the wall, the angle made by the robot segment with respect to the wall can be calculated as:

$$\theta = \tan^{-1}\left(\frac{Height\ of\ laser\ from\ the\ ground}{Distance\ of\ the\ laser\ from\ the\ wall}\right)$$

The height and distance from the wall were measured using a Bosch laser distance measure DLR130K, which has an accuracy of 1/16th of an inch [4], or 1.59mm. An error margin of ±5mm was assumed in measuring all heights and distances to account for inaccuracies introduced by the experimenter.

During the static trials, the robot was precisely moved to specific positions representing 2.5^{o}, 5^{o}, 10^{o} and 15^{o} holding static while measurements were taken.

Similarly, for dynamic measurements with two degrees of freedom (Course and Roll),

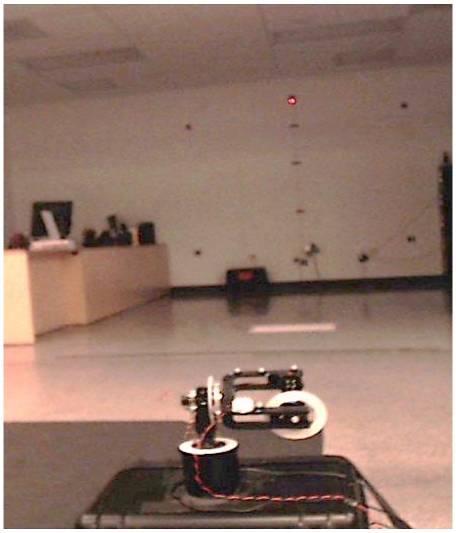

Fig 3: Setup for Static Trials

the robot was programmed to follow a particular sequence, which resulted in a box like pattern traced by the laser on the wall. The roll and course angles that correspond to the four corners of the box were similarly calculated as before using the Bosch laser distance measure and geometry. Both the Noraxon IMU and Vicon systems were calibrated using the same starting position (Bottom Left) of the box.

A remote trigger circuit was created to use the Vicon system's Start and Stop command switches to generate the synchronization pulses. The delay was quantified and found to be less than 15 ms.

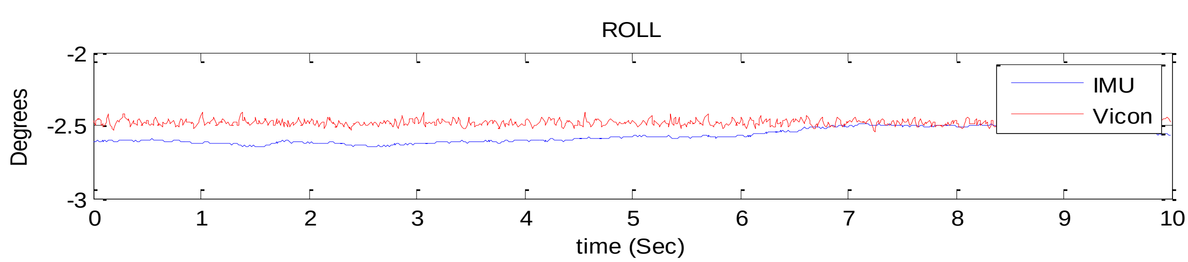

Fig 4: Roll angles when IMU was placed straight and held static at 2.5^{o} (Head)

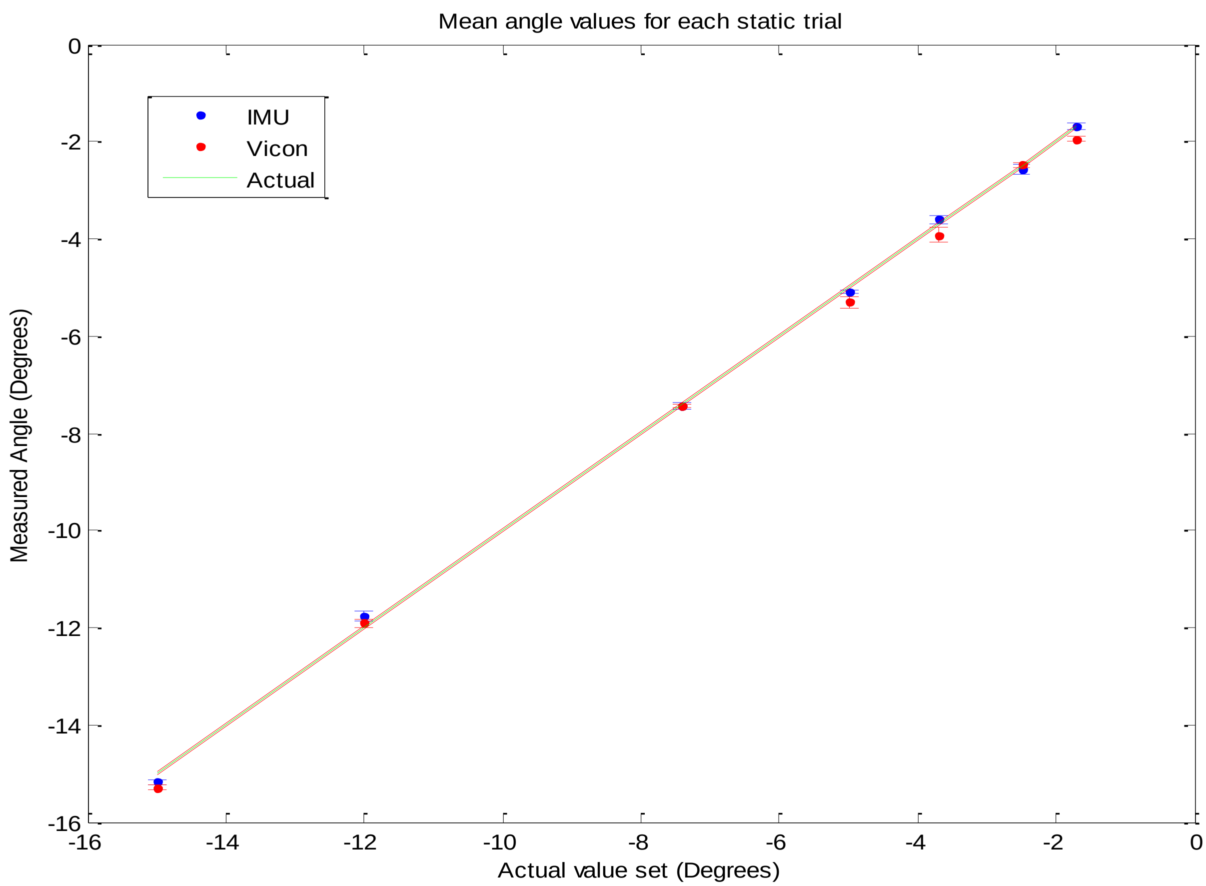

Fig 5: Mean Roll angles across trials when IMU was placed straight and static. Red line denotes the error margin of ±5 mm that was considered while calculating the height using laser range finder. X axis denotes the angles set across different trials.

Results:

Vicon and MyoMotion reproduced angles with MSE of 0.2° and 0.3° respectively. However, the angles could not be precisely compared since the data given by Noraxon's IMUs fluctuated by ±0.1° irrespective of the time over which data was collected and since no filtering was done on the raw Vicon marker data, there was a constant jittering in the angles of ±0.5° for the second system.

Figure 6 shows the Course and Roll angles traced out by Vicon and MyoMotion during dynamic trials. Vicon tracked the angles 20ms faster when compared to MyoMotion, during both 100Hz and 200Hz sampling frequencies. Cross Correlation analysis revealed the lag was more in the course direction. Since MyoMotion displays the results in real time, pre-processing of the IMU output was done, which accounts for the delay. Vicon output on the other hand, was processed in MATLAB, without any pre-processing. Since Noraxon's IMUs are designed for Human Motion capture, a delay 20ms may not be significant. It may be an issue when IMUs are used in robotics or as part of electronic feedback.

The MSE for MyoMotion, when compared to Vicon was found to be 0.4° and the correlation coefficient was 0.99.

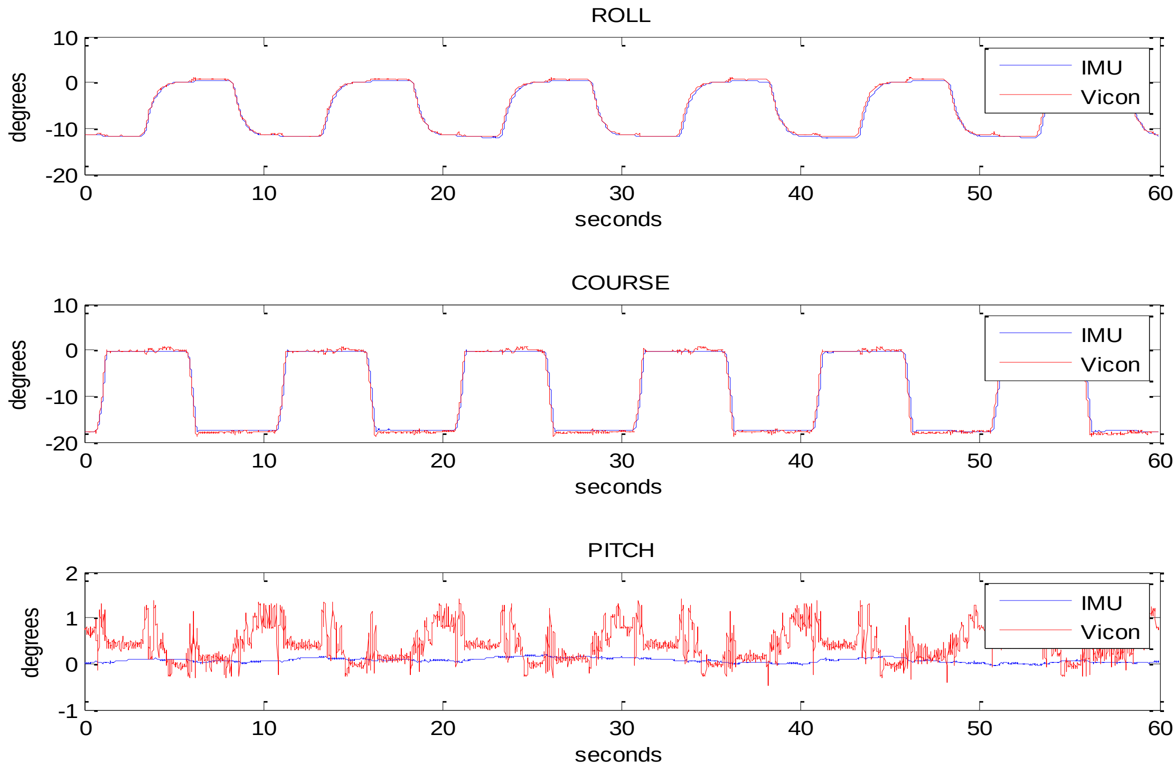

Fig 6: Dynamic Trials: Roll, Pitch and Course angles: Sensor placed upright and defined as head.

Figure 7 shows the box trace obtained from the roll and pitch angles, when compared to the actual angles set. When asked to move between two positions the robot would pass the set position in the corners of the box traced by up to 0.3 º , or overshoot. The capturing of that overshoot by each system required the fastest sample rates to be used.

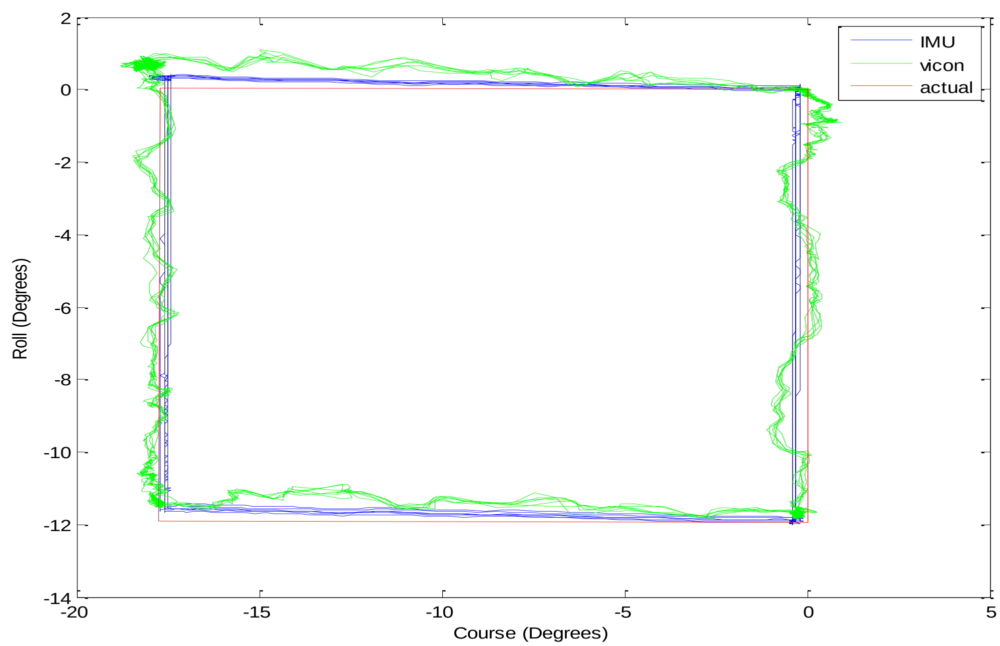

Fig 7: Roll versus Course outputs of MyoMotion and Vicon over a period of 60 seconds

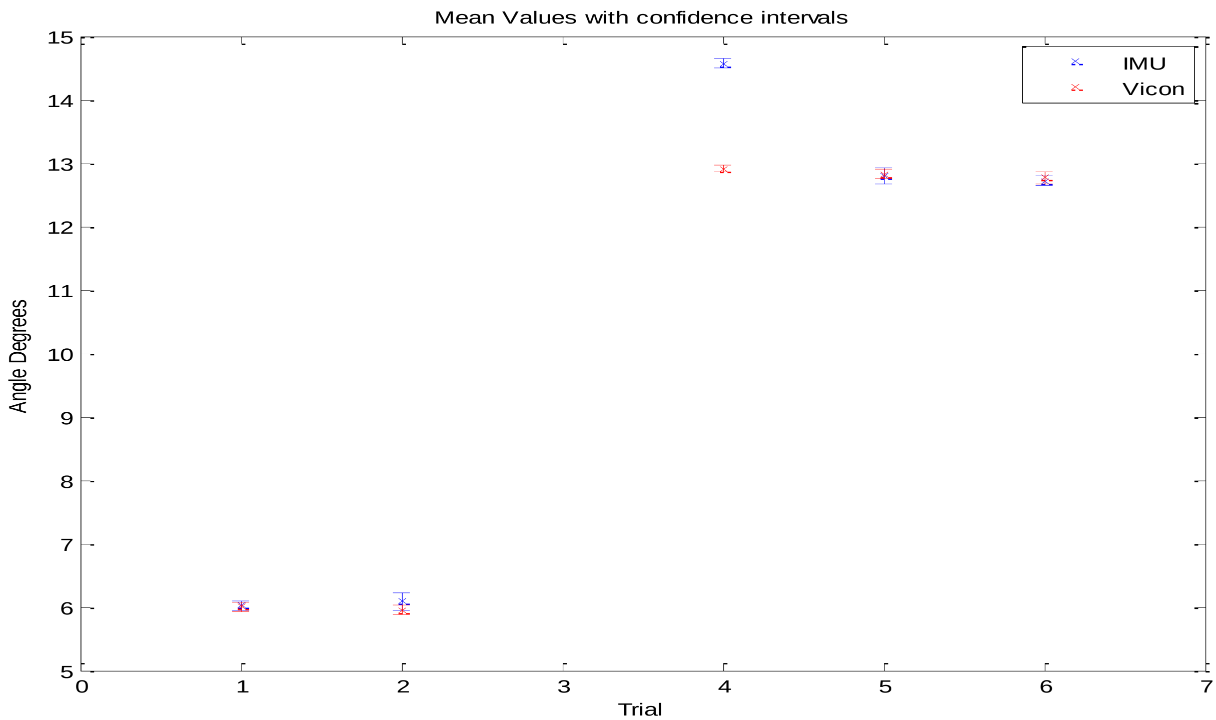

Fig 8: Mean values of pitch across trials: IMUs held static and tilted in alternation

Conclusion:

During static trials, the MSE when compared to the actual values using the robot was 0.2^o for IMUs and 0.3^o for Vicon. During Dynamic trials, the MSE obtained when MyoMotion compared with Vicon directly was 0.4^o.

VALIDATION USING METAL-FREE ENVIRONMENT (WOODEN BLOCK SETUP)

Method:

The setup consists of a wooden platform resting on a wooden base. Various wooden blocks were placed between the platform and base to position the platform at static angles. This apparatus was chosen to verify previous results in an environment free of large magnetic fields, as were present using the robot.

MyoMotion angles were measured using the IMU in two different orientations, when the sensor was held vertically and laying on its largest flat surface (tilted by 90^o), in alternation.

The same setup was used to measure angles with two sensors, one placed static on a nearby wooden structure and the other on the previously used wooden platform.

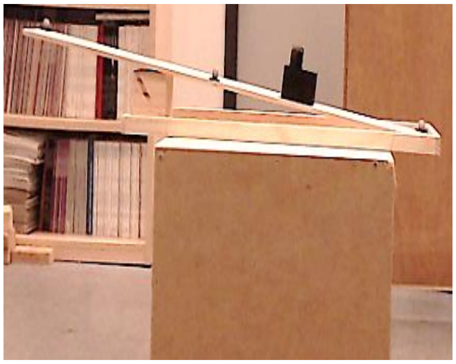

Fig 9: Wooden Block Setup

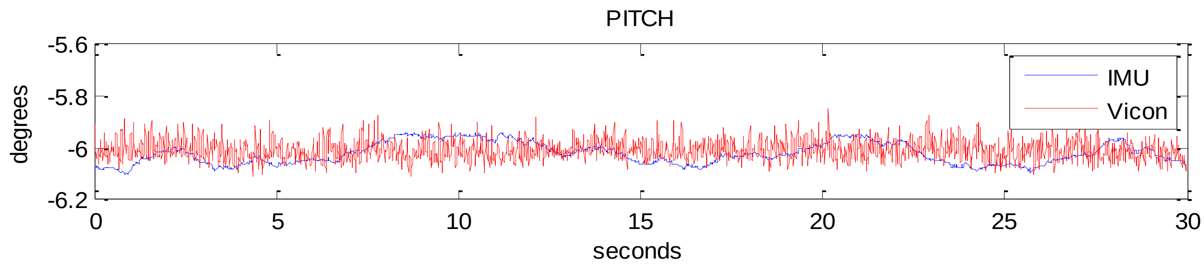

Fig 10: Pitch angle when IMU was placed static and straight in the wooden setup, IMU defined as head.

Results:

Figure 8 shows the mean values obtained when IMUs were placed static and tilted by 90º in alternation. The difference in the angles measured during straight and bent trials was less than 0.03º. Thus, for the same calibration, the angles measured across consecutive trials differed only by 0.03º.

Figure 10 shows the pitch angle obtained using both IMU and Vicon for a period of 30 seconds.

The results look similar to the results obtained using the robot setup. MSE between MyoMotion Vicon was 0.5º.

When two sensors were used to compare the anatomical angles provided by Vicon and MyoMotion, the error between Vicon and MyoMotion was 0.5º, similar to the static sensor trials, although Vicon appears to be fluctuating more than the IMUs. The sensors were defined as Head and Upper Thoracic in MyoMotion (Figure 11).

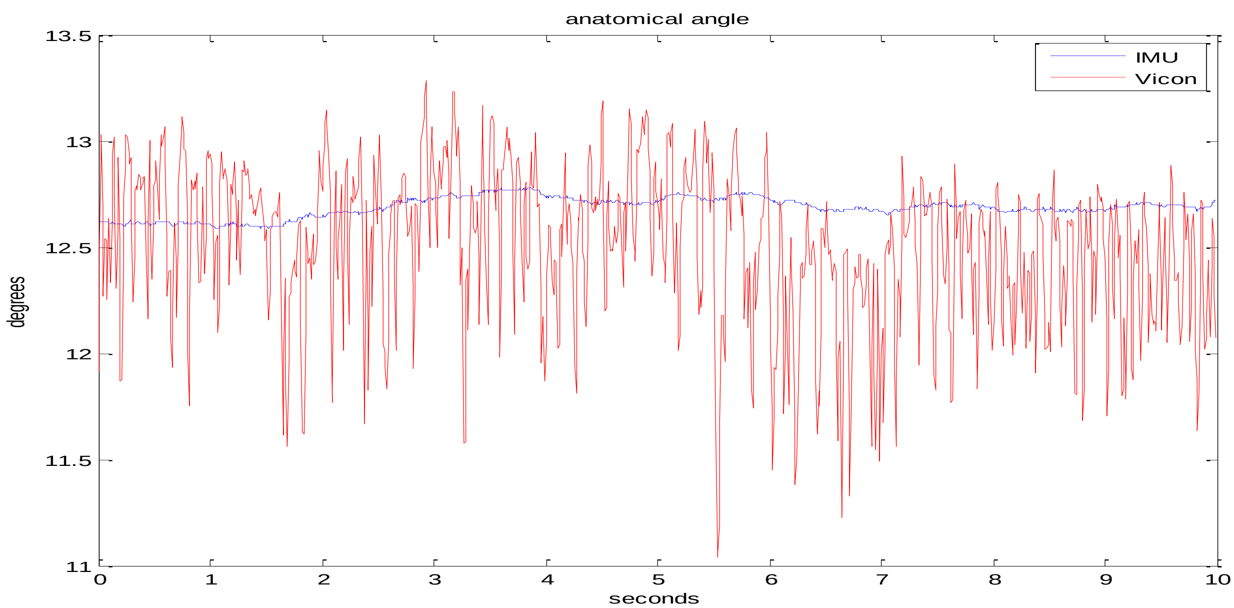

Fig 11: Anatomical angles with 2 sensors: Cervical Flexion

Conclusion:

The results reconfirmed the results obtained previously. The MSE when MyoMotion was compared with Vicon was 0.5^o for both single and two sensor setups. The angles measured by MyoMotion were repeatable and stable across several trials, with a negligible error of 0.03^o

HUMAN JOINT ANGLE ESTIMATION

Method:

Three reflective markers and one IMU were placed on each segment, the thigh and the shank. The subject was asked to perform repeated knee flexion/extension. Synchronization was performed similar to the goniometer study, using the sync light.

The maximum-minimum range was calculated for each knee flexion-extension using both systems. The results of Vicon and MyoMotion were then compared based on this measured range.

Results:

Vicon angles were measured from the raw marker data without considering knee offset angle or the Knee as a hinge joint. The mean error between Vicon and IMU results was 1.27 ±1.3 degrees. Unlike the previous studies where mechanical segments were used, the variability in the angles measured is higher in this experiment, due to movement of the muscle masses.

Conclusion:

When comparing anatomical angles between Vicon and MyoMotion the mean error obtained was found to be 1.27^o ±1.3^o. Angles measured for both systems were affected by the chosen sensor and marker placement. The Vicon system required adorning the markers on the side of the leg to stay within the camera's field of view. When placed on the side of the leg the MyoMotion system measured the angles produced from the muscle bodies whereas placement on the front of the leg measured angles created between the femur and tibia.

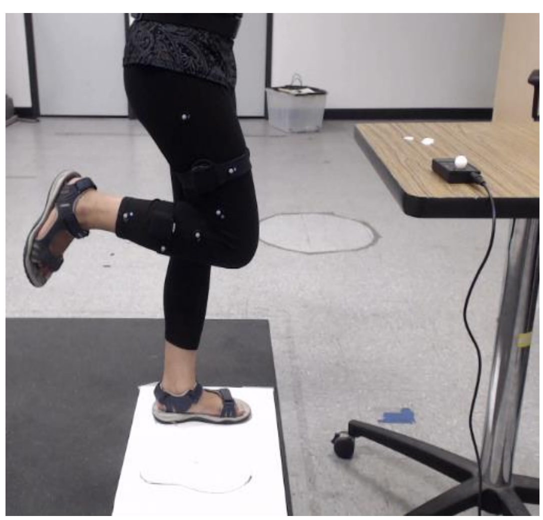

Fig 12: Knee Flexion trial

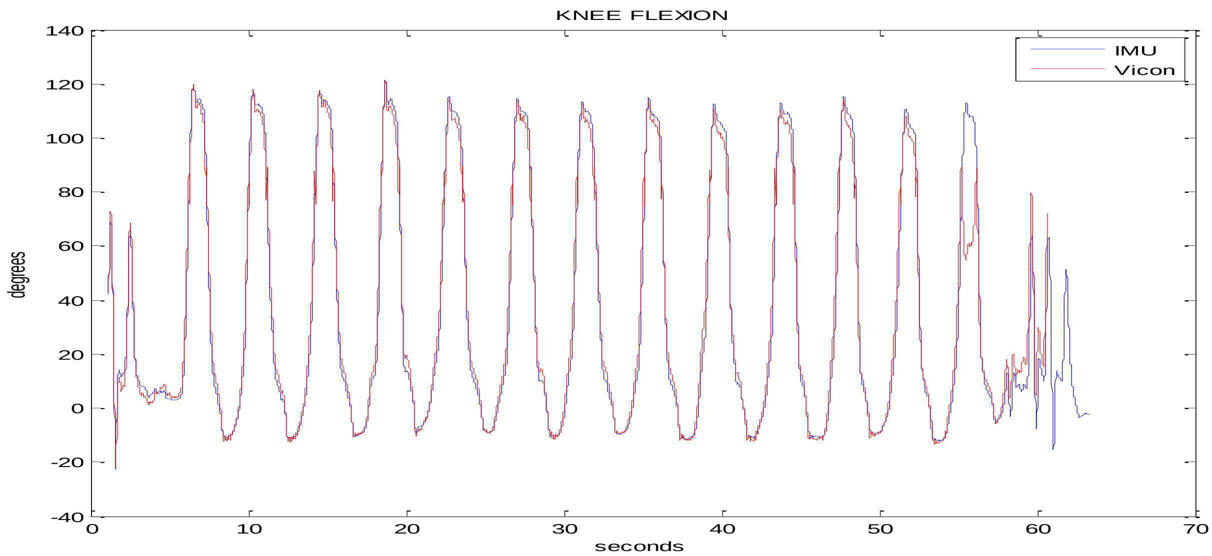

Fig 13: Knee flexion angle after correcting Vicon output for Gimbal lock

DISCUSSION

Noraxon's Inertial Measurement Units can be considered as an alternate to the Vicon motion capture system for movement analysis. The root mean squared error obtained with Noraxon's IMUs during static measurements was found to be a maximum of 0.2^0, for both the clinical and research IMUs. The RMSE for Vicon was found to be 0.3^0. The RMSE for the IMUs, considering Vicon as gold standard was found to be a maximum of 0.3^0. During dynamic trials, the MSE for MyoMotion when compared against Vicon was 0.5^0. The correlation coefficient between Vicon and MyoMotion for dynamic trials was 0.99.

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