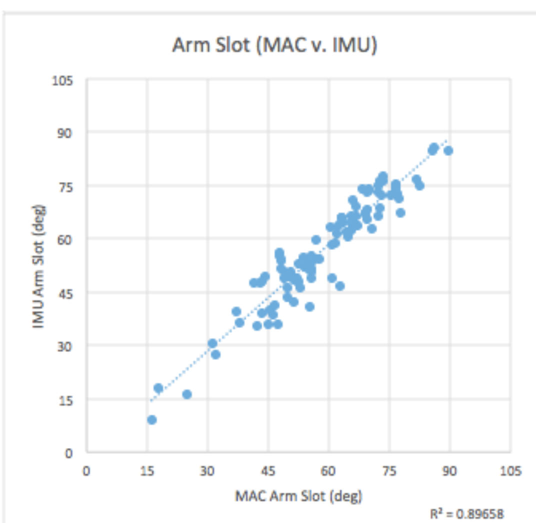
motusTHROW Wearable Data Summary
01032017-BH

Overview: This document serves as a technical summary of benchmarked data comparisons between traditional Motion Capture biomechanical data and simultaneously captured Inertial Measurement Unit biomechanical data.

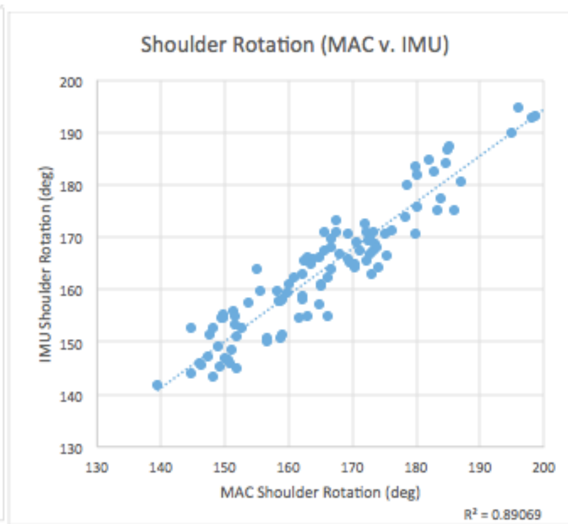
MotusTHROW Data- Motus Lab Comparison

Methods : The 35 subjects included in this dataset were of varying age and competition level. The average age of the subjects were 14.2 (+/-5.6) years. 1 of the subjects were Professional, 7 of the subjects were in college, 15 of the subjects were in high school (varsity), 7 of the subjects were in middle school, and 5 of the subjects were youth pitchers. Motion capture data were recorded at 480 Hz with 8 MAC Cameras in Cortex 5, filtered at 18 Hz, and run through .sky scripts & Motus' motion capture physics engine to compute kinetic measurements of the elbow. The filtered marker data was then run through the physics engine outlined in this report to produce comparable kinematics to that of the inertial measurement unit data. Inertial Measurement Unit data were sampled at 1000 Hz with a microcontroller (Cypress CYBL10563-68FNXIT) from a 3-axis gyroscope (Invensense- ITG-3701 @ +/- 4000 degrees/second Full Scale Range) and a 3-axis Accelerometer (STmicro-LIS331HH @ +/- 24 g's Full Scale Range).

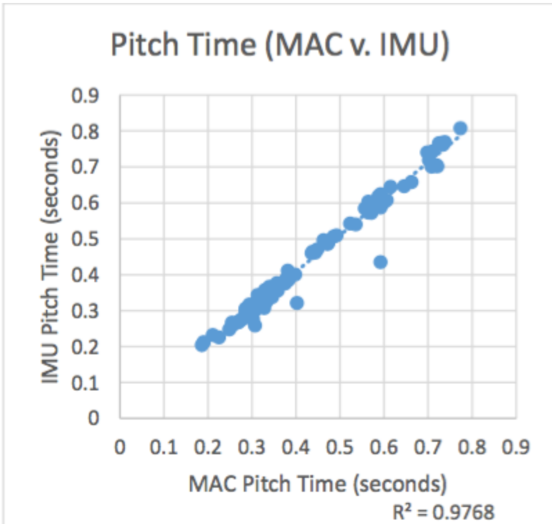
Data:

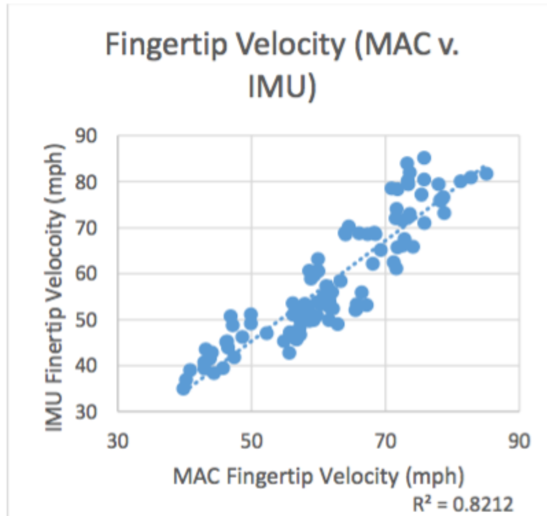


(a)

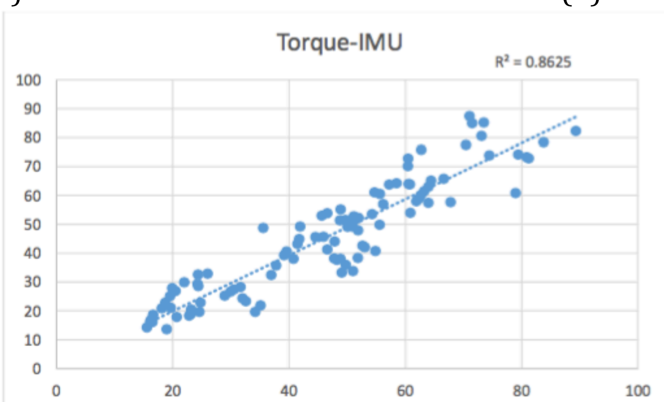


(b)





(c) (d)



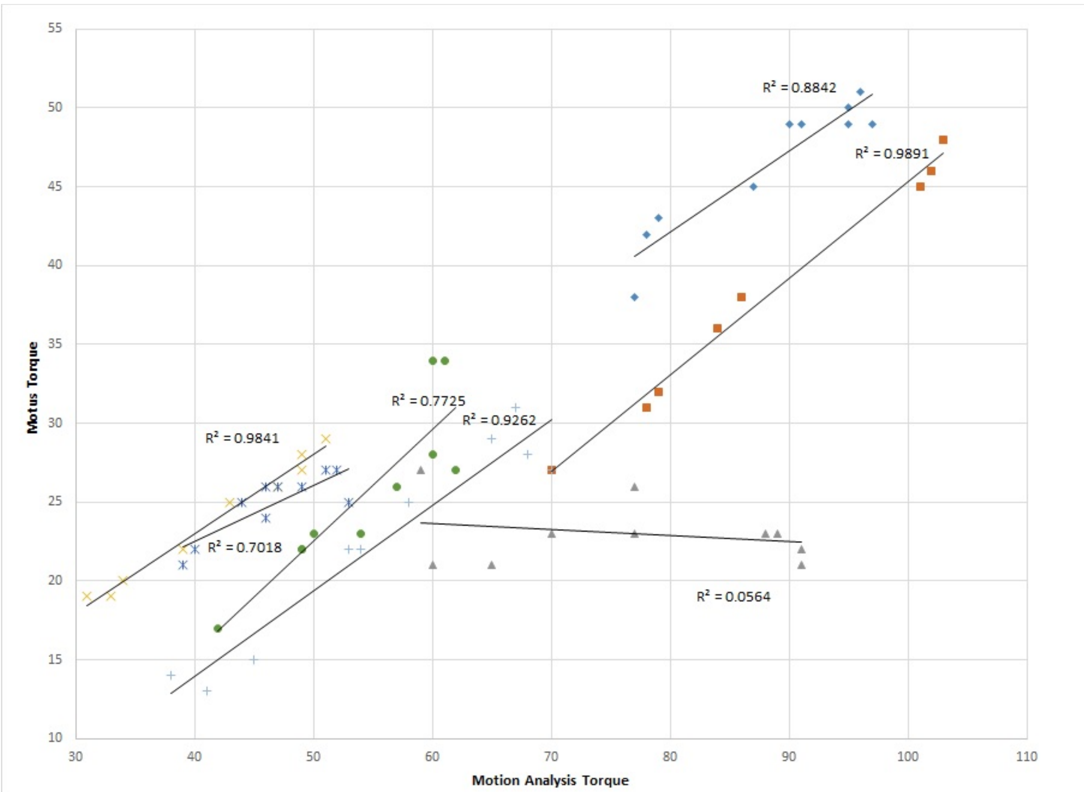
(e)

Figure 1 – Comparative dataset on 09/18/2015 for motusTHROW w/ Motus Lab

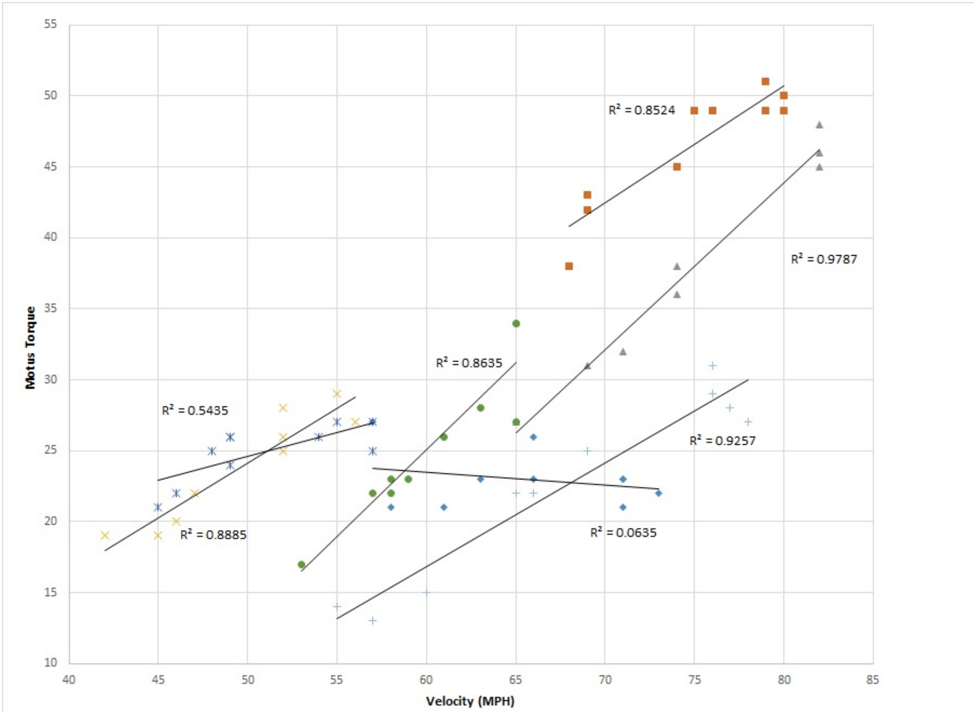
MotusTHROW Data- Independent Lab Study (ASMI)

Methods: Seven pitchers underwent simultaneous data capture utilizing twelve (12) MAC cameras, a Motus IMU Sensor, and a Stalker Radar gun. Motion Capture Data were recorded at 240 Hz in Cortex 5, filtered at 14 Hz. Pitchers threw 10 pitches of variable effort (from low effort to full effort). Filtered marker data were then run through ASMI's BioPitch physics engine. Inertial Measurement Unit data were sampled at 1000 Hz with a microcontroller (Cypress CYBL10563-68FNXIT) from a 3-axis gyroscope (Invensense- ITG-3701 @ +/- 4000 degrees/second Full Scale Range) and a 3-axis Accelerometer (STmicro- LIS331HH @ +/- 24 g's Full Scale Range).

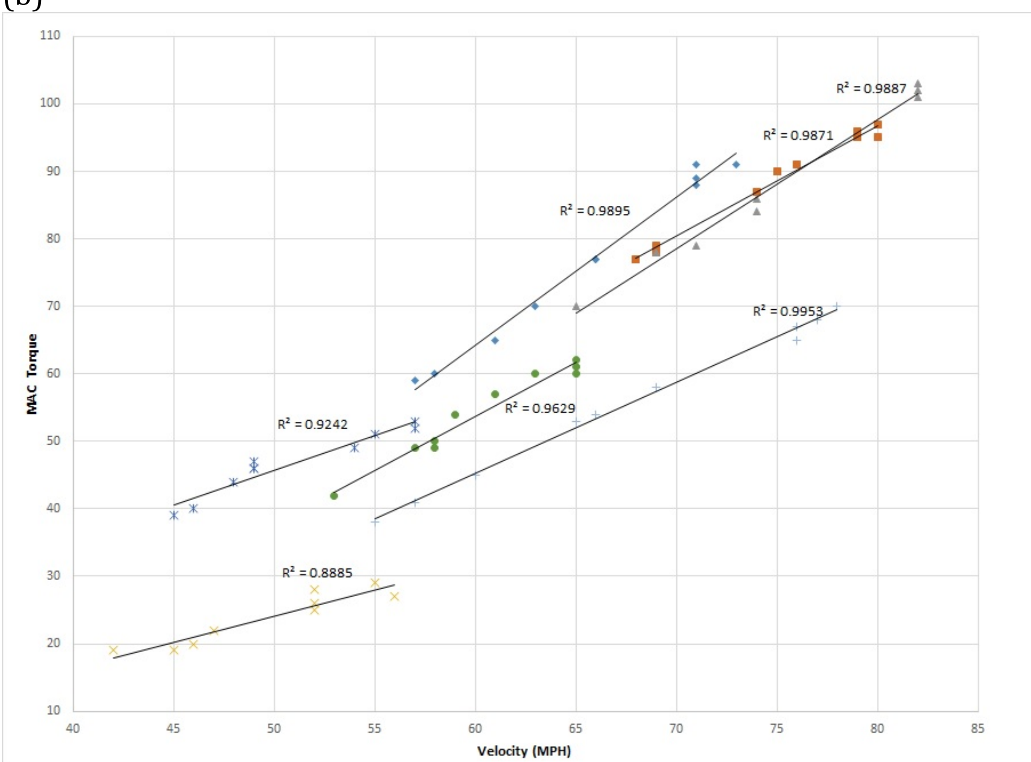
Data:



(a)



(b)



(c)

Figure 3- Comparative Dataset independently gathered from ASMI w/ BioPitch Physics Comparisons on 07/01/2016.

MotusPRO Overview: All Biomechanical Data from motusPRO was validated in similar fashions to the processes of motusTHROW and motusBATTING; however, the kinematic data seen at the trunk, pelvis, and foot move much slower than the extremities and did not require as much fine tuning as the dynamic bat and forearm. Quantifying the sensor fusion algorithms and network sync accuracies were therefore the focus of our efforts. To accomplish this, a network of motusPRO sensors were attached to a rigid body (a wooden Block) and put through a variety of movements. Sample output of time-series kinematic outputs, and impulse accelerations can be seen below.

Methods: One of the motusPRO network sensors was adhered to a block covered in double-sided tape, alongside five retro-reflective markers. A variety of movements were recorded to test the sensor's ability to fuse data into rotational matrices. Motion capture data were recorded at 480 Hz with 12 MAC Cameras in Cortex 5 and were processed with Motus' motion capture physics engine to compute rotational matrices. Data were upsampled to 1000 Hz and time-shifted to compare to Inertial Data. Inertial Measurement Unit data were sampled at 1000 Hz with a microcontroller (Cypress CYBL10563-68FNXIT) from a 3-axis gyroscope (Invensense- ITG-3701 @ +/- 4000 degrees/second Full Scale Range) and a 3-axis Accelerometer (STmicro- LIS331HH @ +/- 24 g's Full Scale Range).

Data:

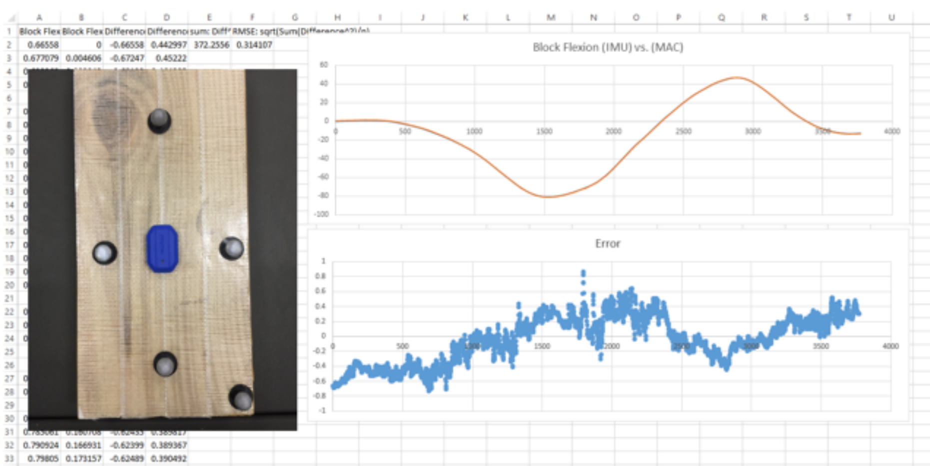


Figure 7- Sample output of time-series Sensor Rotation Output v. Motion Capture (RMSE: 0.3 Degrees)

Network Time Sync:

Methods: Four of the motusPRO network sensors were adhered to a block covered in double-sided tape, alongside five retro-reflective markers. The Master sensor was held in the hand to trigger an event. A Movement Impulse was given to the system in the form of a strong kick to the block in the resulting Y-Axis direction of the aligned sensors. Motion capture data were recorded at 480 Hz with 12 MAC Cameras in

Cortex 5 and were processed with Motus' motion capture physics engine to compute rotational matrices. Data were upsampled to 1000 Hz and time-shifted to compare to Inertial Data. Inertial Measurement Unit data were sampled at 1000 Hz with a microcontroller (Cypress CYBL10563-68FNXIT) from a 3-axis gyroscope (Invensense- ITG-3701 @ +/- 4000 degrees/second Full Scale Range) and a 3-axis Accelerometer (STmicro- LIS331HH @ +/- 24 g's Full Scale Range). Data were calibrated using manufacturer offset values, and known orientation of the digital sensors on the circuit board. Data were stored to flash memory and compressed using a down-sampling algorithm from 1000 Hz to a variable sampling rate, fulfilling the Nyquist Criteria. Data were transferred via BLE to an iOS application, upon which the data were stored to a file system and decompressed using a recovery algorithm.

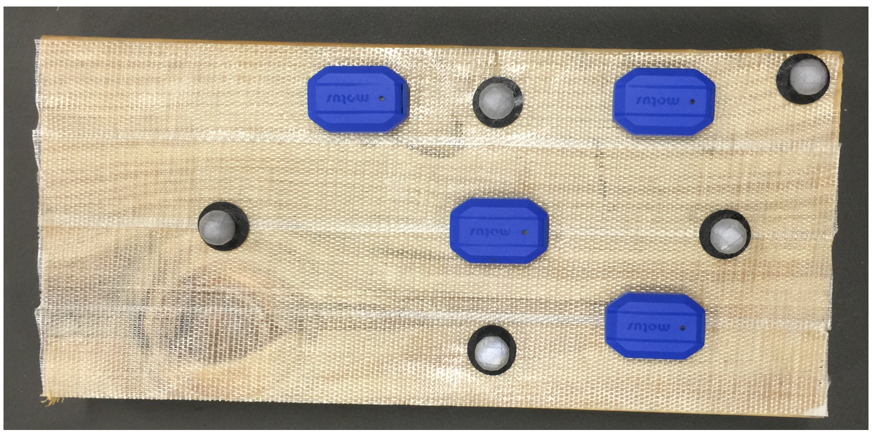


Figure 8- Experimental setup to evaluate network Sync accuracy.

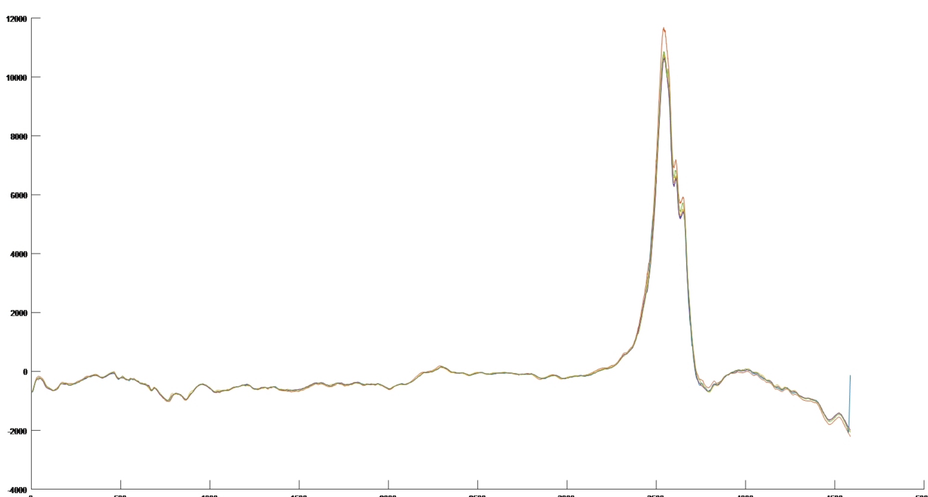


Figure 9- Overlaid Y-Axis Accelerometer output of all four slave sensors.

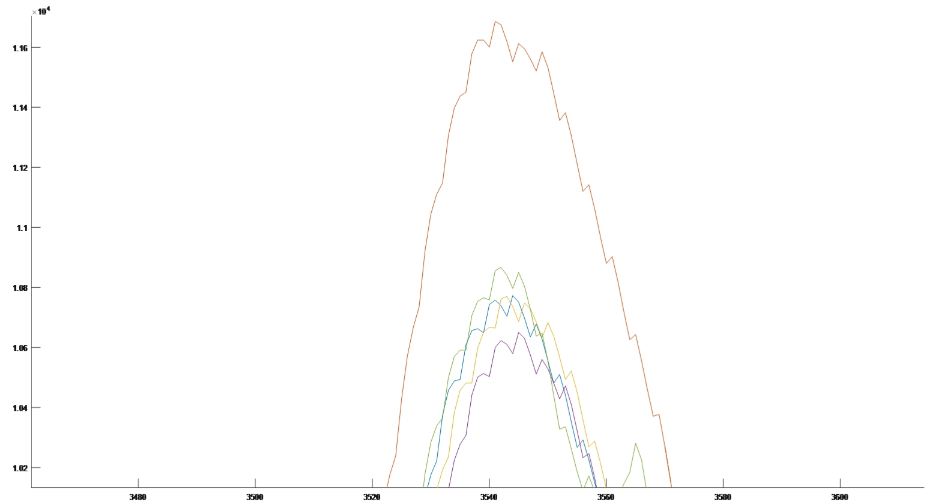


Figure 10- Zoomed in view of Figure 9 near the peaks of the acceleration impulse. The x-axis represents 1 sample of data (captured at 1000 hz), or 1 millisecond in time. The alignment of the peaks show that data are in sync within +/- 1 millisecond.