VALIDATION OF A MULTI-SENSOR IMU SYSTEM TO MEASURE ACTIVE RANGE OF MOTION AT THE TRUNK AND SHOULDER

Caitlin P. Owen, Brittany Dowling, Koby Close, Ben Hansen
Motus Global, Rockville Centre, NY, USA
Email: caitlin@motusglobal.com, web: www.motusglobal.com

INTRODUCTION

Functional movement screens are widely used to determine physical readiness in athletics, the workplace, and the military. These screens are also used in a clinical setting to determine if an individual can return to normal activity levels following a musculoskeletal injury. These screens are often subjective and unreliable, and the results are inconsistent. The ability to translate accurate, objective measurements in these screens is imperative in developing individualized performance and rehabilitation programs.

A fundamental portion of a comprehensive musculoskeletal exam involves evaluation of an individual's range of motion. Optical motion capture systems are considered the 'gold standard' in measuring human movement. However, these systems remain costly and generally require a laboratory to conduct evaluations. More conventional and affordable methods, such as goniometry, are often time consuming and have several limitations- yet remain the most versatile and commonly used measurement tool used today. In fact, Gajdosik et al. [1] suggested clinicians should be careful in the interpretation and reporting the results of goniometric findings. Recent advancements in technology have provided the ability to accurately measure body motions outside of the lab, providing a less obtrusive, portable method for obtaining functional information at a low cost.

Inertial measurement units (IMUs) allow for real-time feedback in all three planes of motion. Typically, IMUs contain a triaxial accelerometer and a tri-axial gyroscope; by the fusion of the information it is possible to estimate relative orientation of a rigid body in three-dimensional space. IMUs have shown to accurately measure ROM in the laboratory for the knee [2], cervical spine [3, 4], and shoulder [4, 5]. Multiple sensor IMUs have successfully been implemented in dynamic tasks such as gait analysis [6-8], countermovement jumps [9], and overhead throwing [10]. Moreover, IMUs have been proven successful in the measurements of upper limb movements [11-16].

The capabilities of IMUs have increased in recent years to where they have become an acceptable way to measure joint biomechanics. Recently, a six sensor IMU system has been introduced to the market that provides full body joint measurements. The motusONE integrates the six IMUs during a battery of movements to provide the user with real-time, objective joint-range-of-motion measures. The purpose of this study was to investigate the reliability and validity of this new IMU system to traditional motion capture.

METHODS

One adult male (age 32.3; 81.8 kg; and 183 cm), reported to the Motus Biomechanics Lab for testing. The subject was instrumented with 45 reflective markers on anatomical landmarks. The motusONE IMU system was adhered to the subject with sensors placed on the upper back (T4 vertebrae), pelvis (L5 vertebrae), and both biceps. The subject then performed a series of eight instructed moves designed to evaluate objective joint range of motion. The targeted areas of the motusONE screen include shoulder, spine, and cervical mobility. A list of tests included in this assessment are: shoulder internal/external rotation, shoulder abduction, shoulder extension, trunk rotation, trunk flexion/extension, and trunk lateral flexion.
Motion capture data were recorded at 480 Hz with 16 Motion Analysis Corporation (Santa Rosa, CA, USA) cameras in Cortex 5, filtered at 18 Hz, and run through a custom physics engine to compute kinetic measurements of the body. Inertial measurement unit data were sampled at 1000 Hz with a microcontroller (Cypress CYBL10563-68FNXIT) from a 3-axis gyroscope (Invensense- ITG-3701 @ +/- 4000 °/s Full Scale Range) and a 3-axis Accelerometer (STmicro- LIS331HH @ +/- 24 Gs Full Scale Range). Data from the Motus sensors were compressed alongside firmware 0.21.1047 in the motusTHROW app (version 5.4.2) with Advanced User enabled, under the manual trigger. The Manual Trigger was pressed one second after the user finished returning from his maximum excursion of movement. Compressed data were imported into Matlab, uncompressed, and up-sampled to 1600 Hz for analysis. Custom physics were drafted to compute time-series kinematics for each move. Data from both sources were time-synced and compared graphically with a Pearson correlation and RMSE measure.

RESULTS

A table of the RMSE values are shown in Table 1. Motion capture versus IMU data for each move collected are presented in Figures 1-8.

Table 1: RMSE for motusONE measurements

Movement	RMSE
Shoulder internal rotation	2.97
Shoulder external rotation	3.22
Shoulder abduction	1.30
Shoulder extension	4.98
Trunk rotation	3.98
Trunk flexion	6.59
Trunk extension	0.53
Trunk lateral flexion	2.83

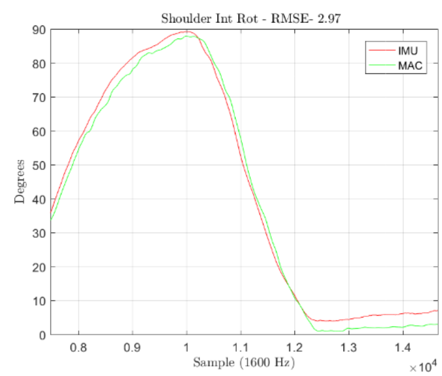

Figure 1: Shoulder internal rotation

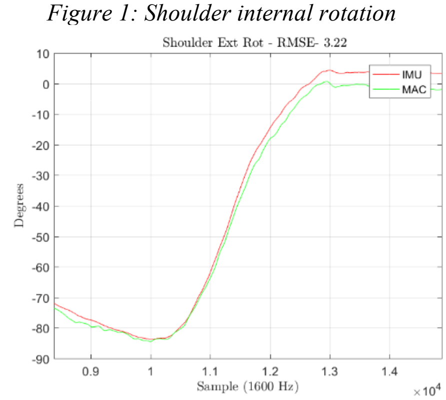

Figure 2: Shoulder external rotation

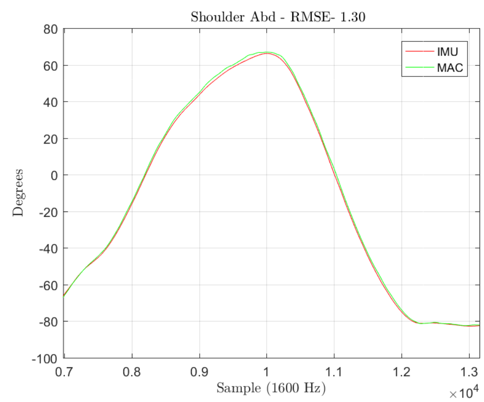

Figure 3: Shoulder abduction

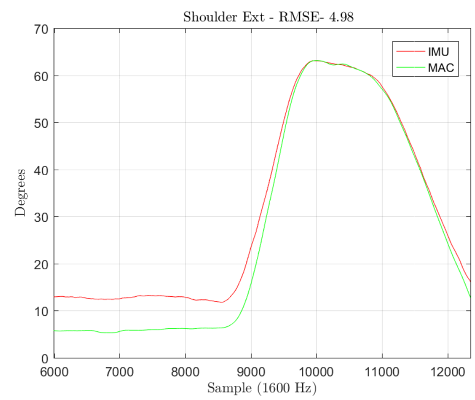

Figure 4: Shoulder extension

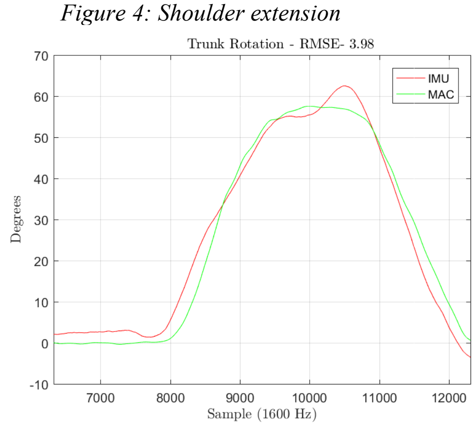

Figure 5: Trunk rotation

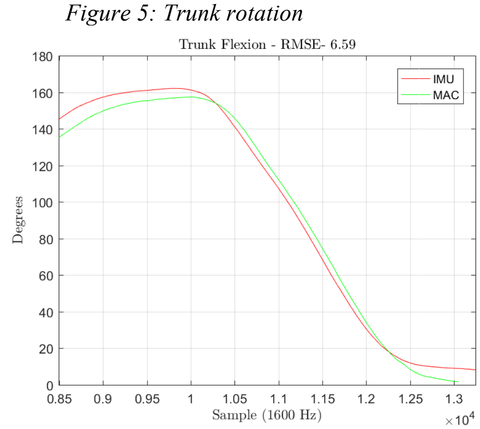

Figure 6: Trunk flexion

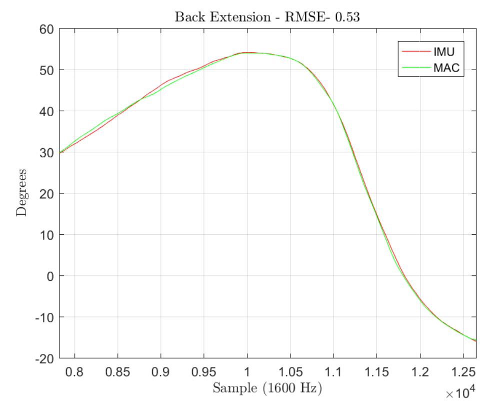

Figure 7: Trunk extension

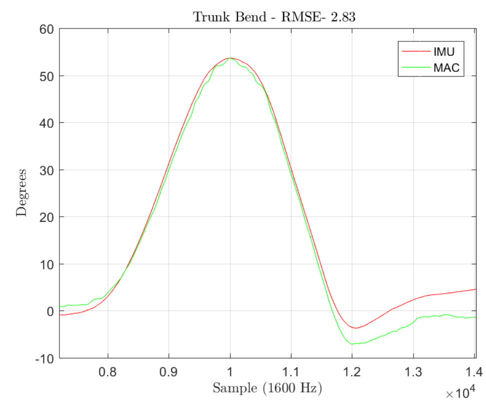

Figure 8: Trunk lateral flexion

CONCLUSION

The results of this study show the motusONE multi-sensor system is able to provide precise range-of-motion measures about the trunk and shoulder. The motusONE can provide functional movement data efficiently and accurately at a reduced cost and with minimum time constraints than that of traditional motion capture. Nonetheless, adopting this system would pose several advantages for therapists and trainers.

REFERENCES

1. Gajdosik, R.L. and R.W. Bohannon, *Clinical Measurement Range of Motion.* Physical Therapy, 1987. **67**(12): p. 1867-1872.
2. Favre, J., et al., *Ambulatory measurement of 3D knee joint angle.* J Biomech, 2008. **41**(5): p. 1029-35.
3. Theobald, P.S., M.D. Jones, and J.M. Williams, *Do inertial sensors represent a viable method to reliably measure cervical spine range of motion?* Man Ther, 2012. **17**(1): p. 92-6.
4. Jordan, K., et al., *The reliability of the three-dimensional FASTRAK measurement system in measuring cervical spine and shoulder range of motion in healthy subjects.* Rheumatology (Oxford), 2000. **39**(4): p. 382-8.
5. Parel, I., et al., *Ambulatory measurement of the scapulohumeral rhythm: intra- and inter-operator agreement of a protocol based on inertial and magnetic sensors.* Gait Posture, 2012. **35**(4): p. 636-40.
6. Leardini, A., et al., *Validation of the angular measurements of a new inertial-measurement-unit based rehabilitation system: comparison with state-of-the-art gait analysis.* J Neuroeng Rehabil, 2014. **11**: p. 136.
7. Bolink, S.A., et al., *Validity of an inertial measurement unit to assess pelvic orientation angles during gait, sit-stand transfers and step-up transfers: Comparison with an optoelectronic motion capture system.* Med Eng Phys, 2016. **38**(3): p. 225-31.
8. Cooper, G., et al., *Inertial sensor-based knee flexion/extension angle estimation.* J Biomech, 2009. **42**(16): p. 2678-85.
9. Picerno, P., V. Camomilla, and L. Capranica, *Countermovement jump performance assessment using a wearable 3D inertial measurement unit.* J Sports Sci, 2011. **29**(2): p. 139-46.
10. Grimpampi, E., et al., *Quantitative assessment of developmental levels in overarm throwing using wearable inertial sensing technology.* J Sports Sci, 2016. **34**(18): p. 1759-65.
11. Zhou, H., et al., *Use of multiple wearable inertial sensors in upper limb motion tracking.* Med Eng Phys, 2008. **30**(1): p. 123-33.
12. Zhou, H. and H. Hu, *Upper limb motion estimation from inertial measurements.* Int J Inf Technol, 2007. **13**(1): p. 1-14.
13. Zhou, H., H. Hu, and Y. Tao, *Inertial measurements of upper limb motion.* Med Biol Eng Comput, 2006. **44**(6): p. 479-87.
14. Roldan-Jimenez, C. and A.I. Cuesta-Vargas, *Studying upper-limb kinematics using inertial sensors: a cross-sectional study.* BMC Res Notes, 2015. **8**: p. 532.
15. Kirking, B., M. El-Gohary, and Y. Kwon, *The feasibility of shoulder motion tracking during activities of daily living using inertial measurement units.* Gait Posture, 2016. **49**: p. 47-53.
16. El-Gohary, M. and J. McNames, *Shoulder and elbow joint angle tracking with inertial sensors.* IEEE Trans Biomed Eng, 2012. **59**(9): p. 2635-41.