KINEMATIC SENSORS EVALUATION FOR SPACEFLIGHT EXERCISE DATA COLLECTIONS

S. Faragalla[1], K. H. Lostroscio[2], C. A. Bell[3], F. N. Matari[3], L. J. Quiocho[2]

[1] University of South Florida, 4202 E Fowler Ave, Tampa, FL 33620
[2]NASA Johnson Space Center (JSC), 2101 E NASA Pkwy, Houston, TX 77058
[3]CACI, Inc., 2100 Space Park Dr., Houston, TX 77058

Introduction

- On the International Space Station (ISS), exercise feedback from astronauts is very important to diagnose and mitigate any injuries and to ensure efficacious exercise prescriptions and systems. Going forward, exploration exercise efforts seek to gain further quantitative data of human and system performance, including through full body kinematic tracking.
- There are limited methods of collecting in-flight exercise data on the ISS, including marker-based motion capture where astronauts must wear reflective markers over their clothes which can be cumbersome to secure properly.
- **Objective:** To collect and compare marker-based, Inertial Measurement Unit (IMU)-based, and markerless video-based motion capture (MoCap) to evaluate kinematic accuracy and inform of feasible methods for exercise data collections on the ISS and future Gateway applications.

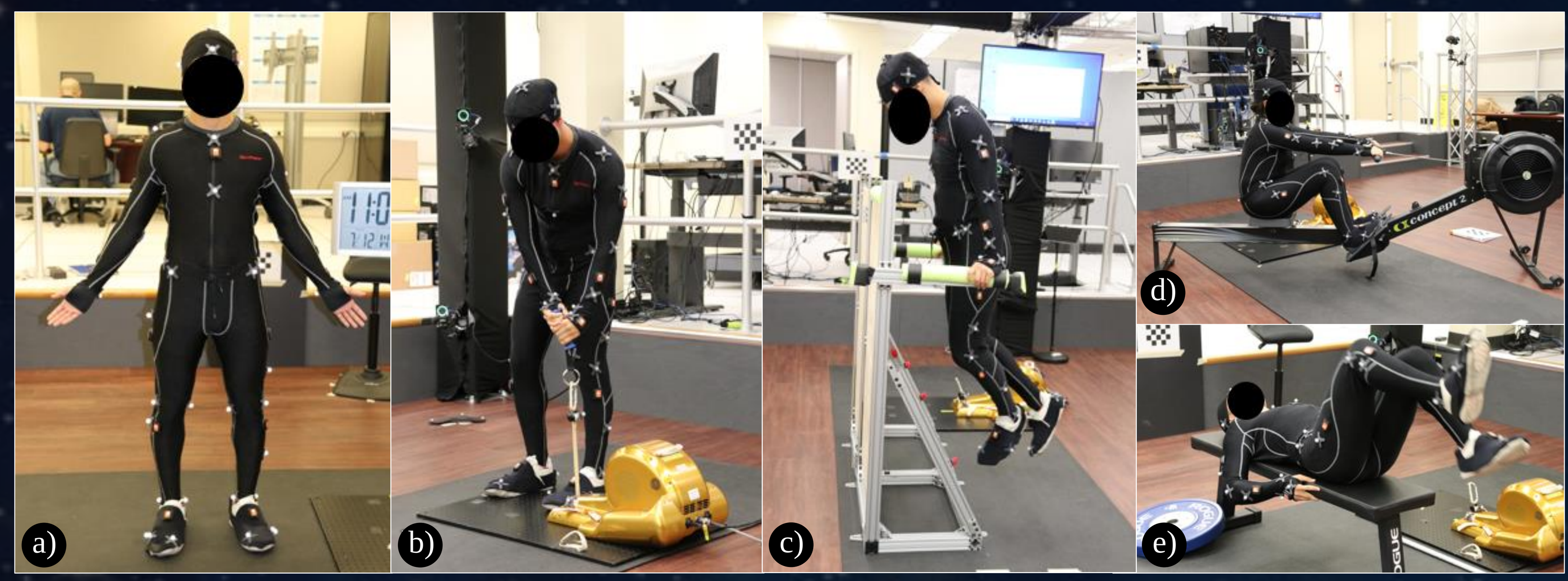

Figure 1. a) Subject fully suited standing in an A-pose for OpenSense model calibration; b) Subject performing a chop exercise with the MED-2; c) Subject performing dips on a custom structure; d) Subject performing a seated rowing exercise on the Concept 2 rowing ergometer; e) Subject performing a cycling motion while lying on a bench.

Methods

Figure 2. Data collection and testing methodology.

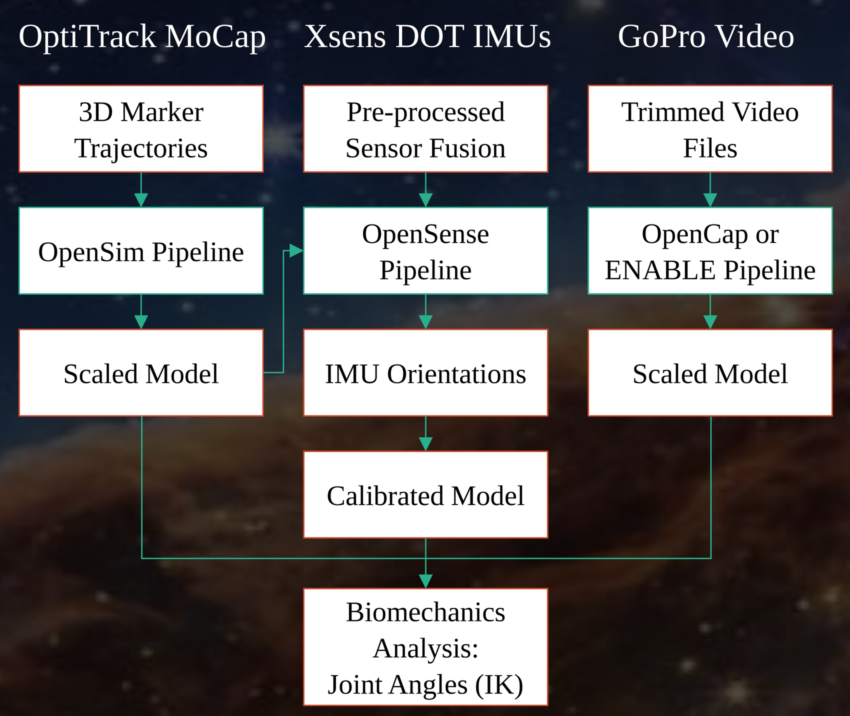

Figure 3. Data analysis and processing methodology.

- A marker-based OptiTrack MoCap system (16 cameras) in the Prototype Immersive Technology (PIT) lab at JSC tracked 46 markers using Motive software. Cleaned marker data was used to drive biomechanical models for kinematic analysis. This was regarded as the gold standard for result comparison.
  - Passive markers were affixed to each subject according to a modified full body Plug-in Gait marker set [1] with four modified head and two modified toe marker locations as well as one additional top of head, two medial elbow, two outer front hip, and two ball of foot markers added to the original 39 markers.
- The markerless video-based MoCap data was collected using two GoPro Hero7 cameras and one GoPro Hero11 camera.
- For the IMU data, a full body set of 17 Xsens DOTs were placed on the subject, including 10 upper body and 7 lower body IMUs. A custom Python script was used to sync all IMUs using multiple Bluetooth central devices (Raspberry Pi, Windows laptop), and two smart phones were used to start recording on the DOTs onboard storage.
- Three test subjects performed a variety of flight-like resistance and aerobic exercises using the Miniature Exercise Device (MED-2) [2], Concept-2 rowing ergometer, barbell mockup, bench (e.g., for bench press, hip thruster, and cycling), and a custom structure for dips. These were also intended to represent exercises which could be performed on the multi-modality European Enhanced Exploration Exercise Device (E4D) [3].
- Biomechanical modeling and evaluation was conducted through OpenSim [4] (marker-based), OpenSense [5] (IMU-based), OpenCap [6] (markerless video-based), ENABLE [7] (markerless video-based), and other modeling software.

Results & Discussion

Challenges/Lessons Learned:

- Markerless Video-based MoCap:
  - Clothing choice and background should contrast.
  - Personnel should not be in the background when possible.
  - Optimal camera placement and number should be refined and consider both human and calibration objects.
  - Results may improve when omitting video from cameras with less ideal placement (e.g., back view).
- IMU-based MoCap:
  - Sensors may have shifted during exercise.
  - Possible accidental deactivation if Xsens DOT is pressed (e.g., while laying on bench).
  - Ensuring synchronization for a large quantity of Xsens DOTs requires further data acquisition system development.
  - OpenSense model calibration and sensor orientations requires further iteration, especially for upper limb IMU motion.
  - Pelvis translation must subsequently be incorporated, since OpenSense only maintains segment orientations.

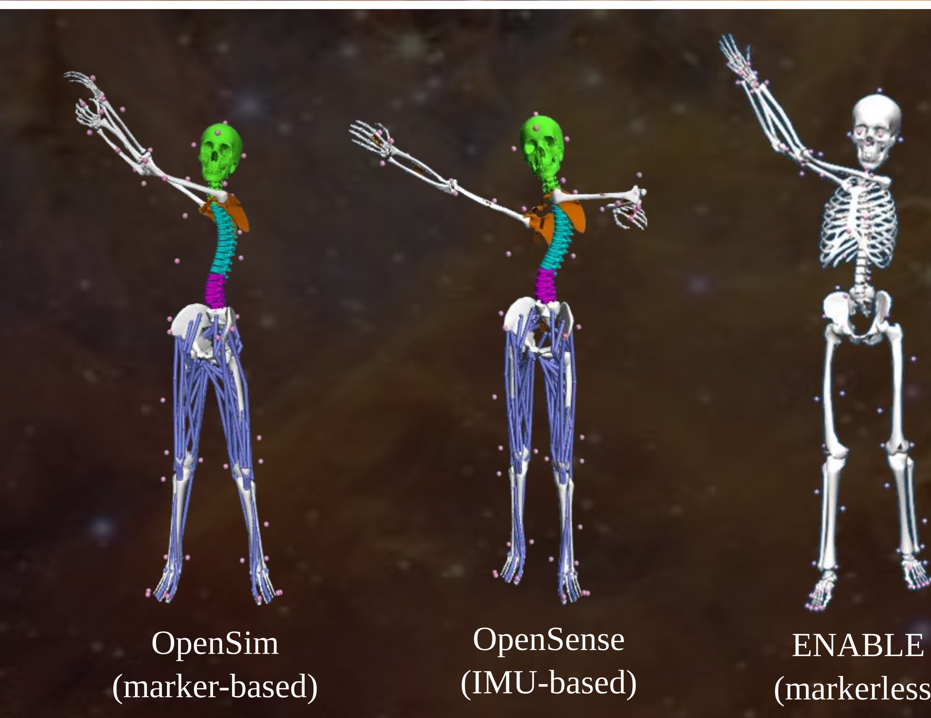

Figure 4. Kinematic results from marker-based, IMU-based, and markerless video-based pipelines for a subject performing a Chop exercise.

Note: OpenSense used the scaled model created in the OpenSim workflow, and ENABLE generated an OpenSim scaled model from 2-camera video data.

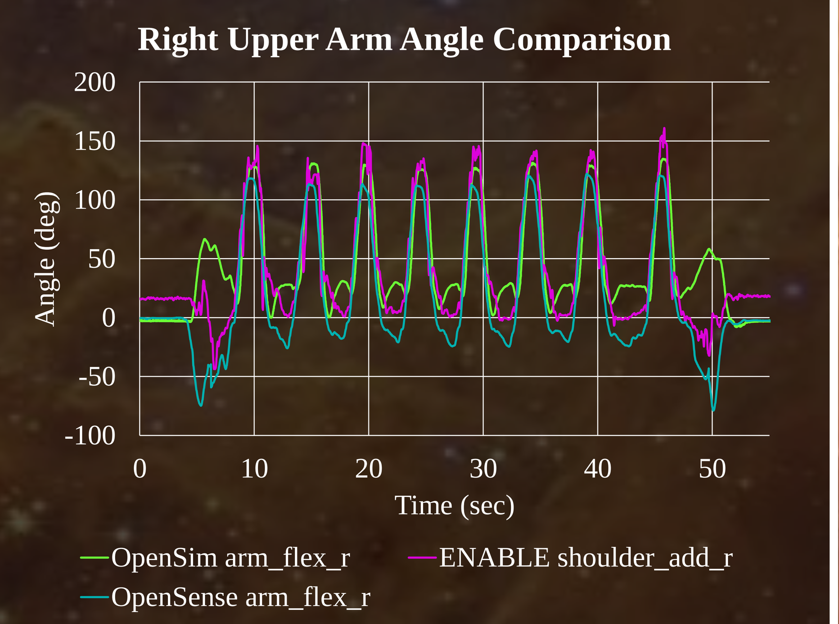

Figure 5. OpenSim (marker-based) vs. OpenSense (IMU-based) vs. ENABLE (markerless video-based) results for a subject's primary upper arm angle during a Chop exercise.

Forward Work

- For all issues encountered, there can be workarounds with further software development and reasonable adjustments to the data collection operations.
- Can compare marker-based MoCap with 3 cameras (or number equivalent to video cameras).

Conclusions/Recommendations

- While this work was mainly focused on ISS data collection, sensor data along with continued evaluation and development efforts will help to establish best methods for exercise data collection on Gateway, other parts of Artemis missions, and beyond.
- If flown today, the markerless video-based MoCap option is our recommended method of data collection and processing as it already addresses certain IMU shortcomings and is estimated to be least in equipment volume, upmass, and crew setup time (i.e., for cameras). Software-based solutions for video analysis continue to improve over time, so issues from data acquisition challenges can be overcome.

Acknowledgements

- This work was performed in collaboration with the HumanWorks team in the Software, Robotics, and Simulation Division (ER) of the NASA JSC Engineering Directorate.
- The NASA OSTEM internship with the Digital Astronaut Simulation (DAS) team was sponsored, in part, by the ISS Vibration Isolation and Stabilization (VIS) system project.
- A special thanks to the Southwest Research Institute (SwRI) ENABLE developers for a demo license, collaboration, and support to assess this example exercise data.
- While not used in this data collection, an IMU suit developed by Pratt Institute students was evaluated as an aid for crew IMU placement and mitigation of the shifting noted above.

References

[1] "Plug-In Gait Reference Guide." Vicon Motion Systems Limited. (2021, March 25)
[2] Miniature Exercise Device-2 (MED-2): Preliminary ISS Evaluation Results for a Compact Motorized Resistive and Aerobic Rowing Exercise Device. (2018, July 23). https://ntrs.nasa.gov/citations/20180006490
[3] New Danish space exercise machine completes testing at NASA. (2019, April 25). https://www.danishaerospace.com/en/news/new-danish-space-exercise-machine-completes-testing-at-nasa
[4] Seth, A., et al.,OpenSim: Simulating musculoskeletal dynamics and neuromuscular control to study human and animal movement. PLoS Computational Biology, 14(7). (2018)
[5] Al Borno, M., et al., "OpenSense: An open-source toolbox for inertial-measurement-unit-based measurement of lower extremity kinematics over long durations", Journal of NeuroEngineering and Rehabilitation, (2022).
[6] Musculoskeletal forces from smartphone videos. OpenCap. https://www.opencap.ai/
[7] Engine for automatic biomechanical evaluation (enableTM). Southwest Research Institute. (2023, August 4). https://www.swri.org/industry/biomechanics-human-performance/engine-automatic-biomechanical-evaluation-enable