National Aeronautics and Space Administration
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Lunar Surface Operations Modeling Using Digital Astronaut Simulation

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Technology Taxonomy Area (TX): 13.2.4 Verification and Validation of Ground, Test, and Surface Systems; 11.2.3 Human-System Performance Modeling; 11.3.4 Simulation-Based Training and Decision Support Systems

TRL: start 4 / current 5

FY21 IRAD PROJECT OVERVIEW

During Apollo, crew members experienced falls and near-falls while engaging in extravehicular activity. The Digital Astronaut Simulation (DAS) expanded human biomechanics modeling tools to begin investigating this prospective mission safety and success challenge for the Artemis program.

INNOVATION

This technology integrates motion capture and human-system mass properties with an expanded OpenSim based biomechanics tool set to observe dynamic feasibility of motion in a given gravitational environment. The capability enables observation of whether tasks performed in 1g can be performed the same way in lunar gravity or if they require modifications. To accomplish, the technology calculates Center of Pressure (COP) relative to the Base of Support (BOS) of the astronaut.

OUTCOMES

- COP Investigation: Across a range of unit test, pick up, and exercise motions, accuracy of calculated COP was characterized via comparison to force plate measurements. Current results achieve an average difference **< 5 mm**, with a maximum difference encountered of 10.8 cm.
- COP Improvement: Adjustments in modeling methods, including use of additional motion capture markers in scaling and inverse kinematics (IK) processes and modified joint axes and limits, reduced maximum difference from an original > 5 m error (due to IK artifacts). Strategies for filtering in the workflow further improved final COP results.
- Suit Aspects Incorporation: To accommodate space suit mass property data in OpenSim modeling, placeholders for xEMU data were added to designated body segments. This implementation enables adding suit mass properties to an existing human model to investigate effects on system CG, COP, and dynamic feasibility outcomes or other biomechanics applications.
- Theoretical Scaling: In order to represent a theoretical subject, such as a 50th percentile male which has been used as a reference in space suit data, a tool was developed to generate body segment geometry, mass properties and joint locations using the ANSUR II database [1] and scaling factors derived from the unscaled OpenSim model.

INFUSION SPACE / EARTH

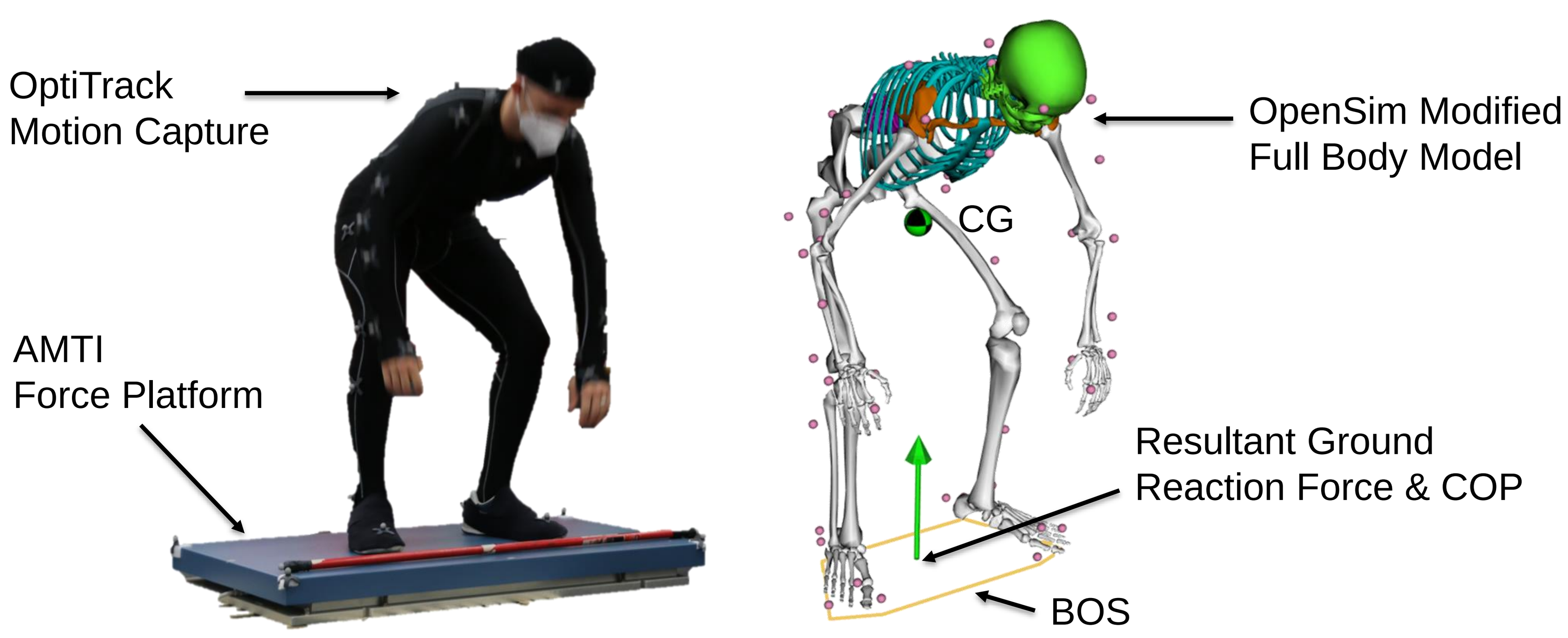

Fig. 1. Human-In-The-Loop Collection in the Prototype Immersive Technology (PIT) Laboratory Driving Model and Simulation in OpenSim [2-4]

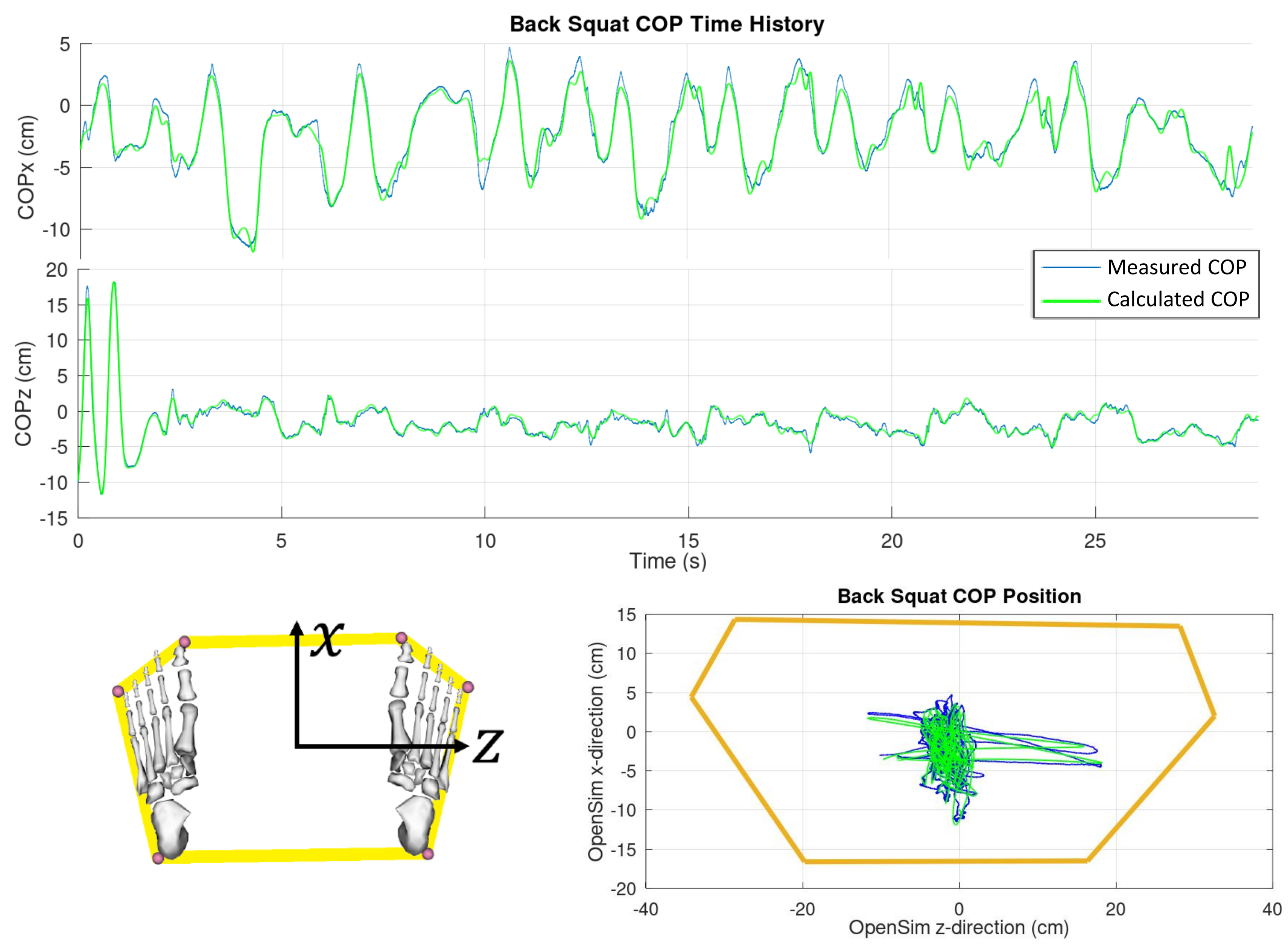

Fig. 2. 1g Comparison of Force Plate Measured vs Motion Capture/OpenSim Calculated COP for a Back Squat Motion

INFUSION SPACE / EARTH

- This technology can be applied toward inspecting the representativeness of our ground-based testing and training, such as lunar offloading in the Active Response Gravity Offload System (ARGOS) or the Neutral Buoyancy Laboratory (NBL).
- Other applications could include investigating the feasibility of proposed lunar task motions completed during testing and crew training, where effects of property changes in space suits, tools, or other systems could be explored.
- The capability is now being applied in stability analyses to address long standing needs for exercise Vibration Isolation & Stabilization (VIS) system development.

PARTNERSHIPS / COLLABORATIONS

The Center for Assistive, Rehabilitation, and Robotics Technology (CARRT) at the University of South Florida created a 1g Lunar Task Database of motion capture and force plate data to enable testing of new and future modeling techniques for incorporation of EVA tools, different user stances/motions, and a broader test subject population.

The Anthropometry & Biomechanics Facility (ABF/SK3), John DeWitt (KBRwyle), and Beth LeWandowski (GRC) provided subject matter expertise related to stability criteria, previous lunar studies, and ongoing developments in related biomechanics fields.

FUTURE WORK

Testing in an ARGOS shirtsleeve configuration will enable initial demonstration in an operational setting, providing applicable analyses and a progression toward suited evaluations. Verification and validation efforts for the current implementation of adding suit mass properties are needed. Exploration EVA applications may drive additional development and tailoring of the technology described herein.

[1] Gordon C.C., 2012 "Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics", US Army Natick Soldier RD&E Center.
[2] S. L. Delp, F. C. Anderson, A. S. Arnold, P. Loan, A. Habib, C. T. John, E. Guendelman, and D. G. Thelen, "OpenSim: open-source software to create and analyze dynamic simulations of movement," IEEE Trans Biomed Eng, vol. 54, no. 11, pp. 1940–1950, 2007 (2007)
[3] Rajagopal, Apoorva, et al. "Full-Body Musculoskeletal Model for Muscle-Driven Simulation of Human Gait." IEEE Transactions on Biomedical Engineering 63.10 (2016): 2068-2079. (2016) https://simtk.org/home/full_body/
[4] R. K. Huffman, W. K. Thompson, C. A. Gallo, L. J. Quiocho, "Improvement Of Scaling And Inverse Kinematic Results with Additional Upper Body Joints Added to Opensim Rajagopal Model", NASA Human Research Program Investigator's Workshop, (2019).

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