TOWARD A METHOD FOR SCALING HUMAN BODY MODELS IN AN IMU-BASED WORKFLOW

E. K. Marecki[1,2], F. N. Matari[3], K. H. Lostroscio[1], F. Stefanovic[2]

[1]NASA Johnson Space Center, 2101 E NASA Parkway, Houston, TX 77058

[2]SUNY University at Buffalo, 12 Capen Hall, Buffalo, NY, 14260

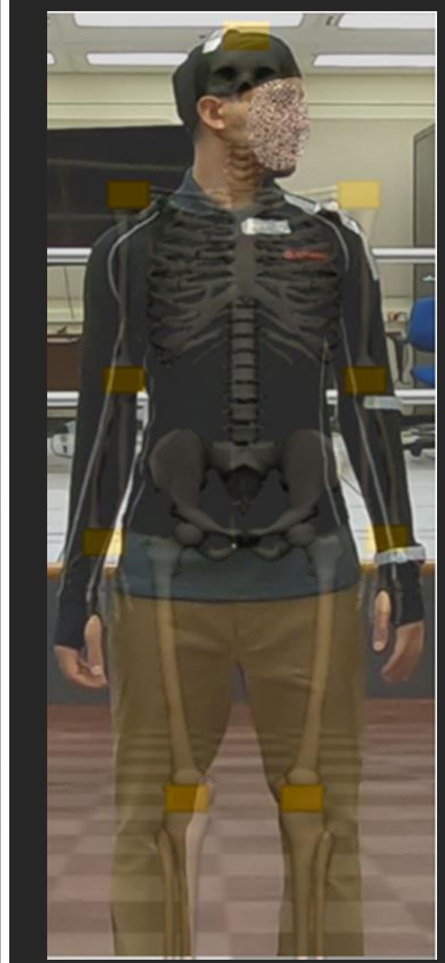
[3]CACI Inc., 2100 Space Park Dr., Houston, TX 77058

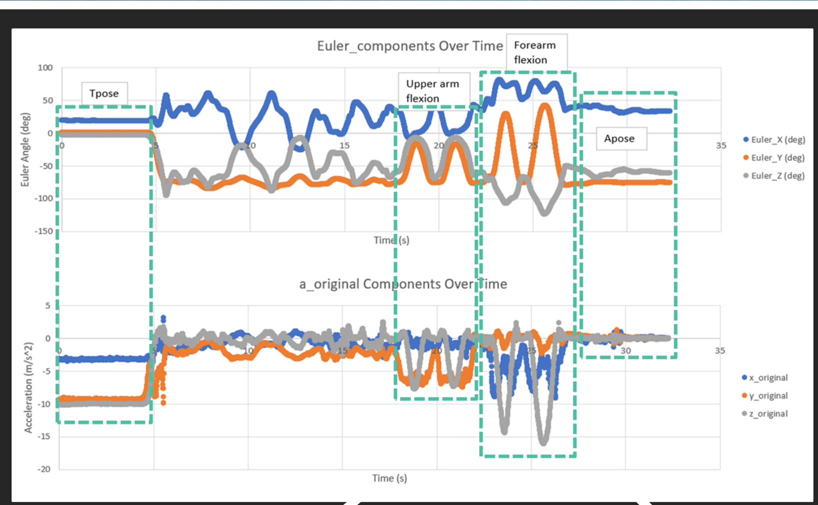
Introduction

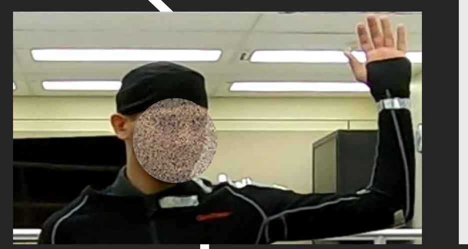
- Scaled biomechanical models can more accurately inform crew health decisions when tailored to the wide range of astronaut sizes. One component to improve scaling of existing models to better represent each unique astronaut's size is the individual length scaling of limbs. Traditionally, limb lengths are determined by motion capture or manual measurement.
- A new method is herein proposed for length scaling which can be done by measuring linear and angular accelerations at a desired point during isolated motion around a point of rotation, then calculating the distance between the desired point and point of rotation.
- When an Inertial Measurement Unit (IMU) device is placed at the distal point of a limb, the isolated motion is about that limb's proximal joint. This method of scaling limb segments can be used for any limb that has an easily defined proximal joint for the limb to rotate around including hands, arms, legs, feet.
- Calculated limb lengths are then used to scale models to each unique astronaut's size, thereby improving the applicability of the model.
- This method was investigated as a possible away to obtain scaling information in data collections where IMUs are worn, but optical motion capture may not always be available, such as inside spacesuits or during crew exercise on the International Space Station.

Segment	IMU Placement	Isolated Motion
Head/Neck	Head Vertex	Bend forward & back
Torso	Lumbar-1	Lateral Bend
Humerus	Elbow Joint Axis	Shoulder abduction/adduction
Forearm	Wrist Joint Axis	Elbow flexion/extension
Hand	Fingertips	Wrist flexion/extension
Femur	Knee Joint Axis	Hip flexion/extension
Shank	Ankle Joint Axis	Knee flexion/extension
Foot	Toes	Ankle flexion/extension

Methodology



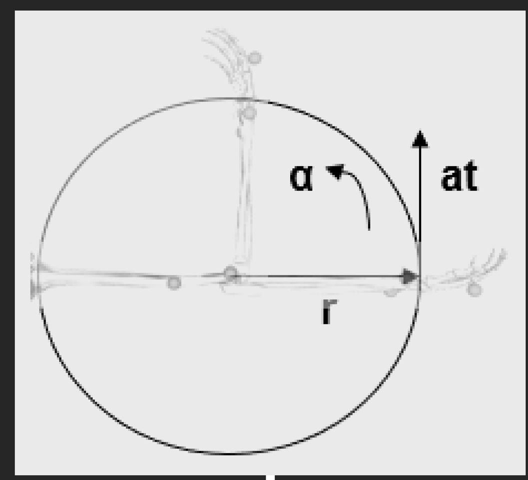




- a_t is acquired directly from IMU
- α derived from α = dω/dt, where ω is directly obtained from IMU

Xsens DOT ®

(Movella, USA)

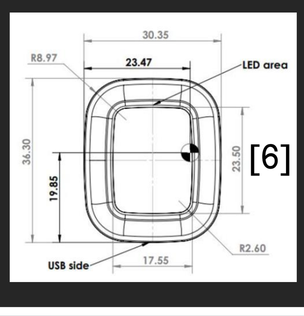


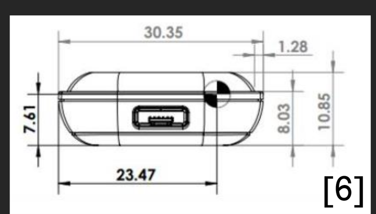
Place sensors securely, aligned with joint centers → Stand in calibration pose (used for OpenSense purposes) → Perform isolated motions → Calculate length from IMU data ($r = a_t/\alpha$) → Calculate scaling factors by computing ratio of calculated length to original model length

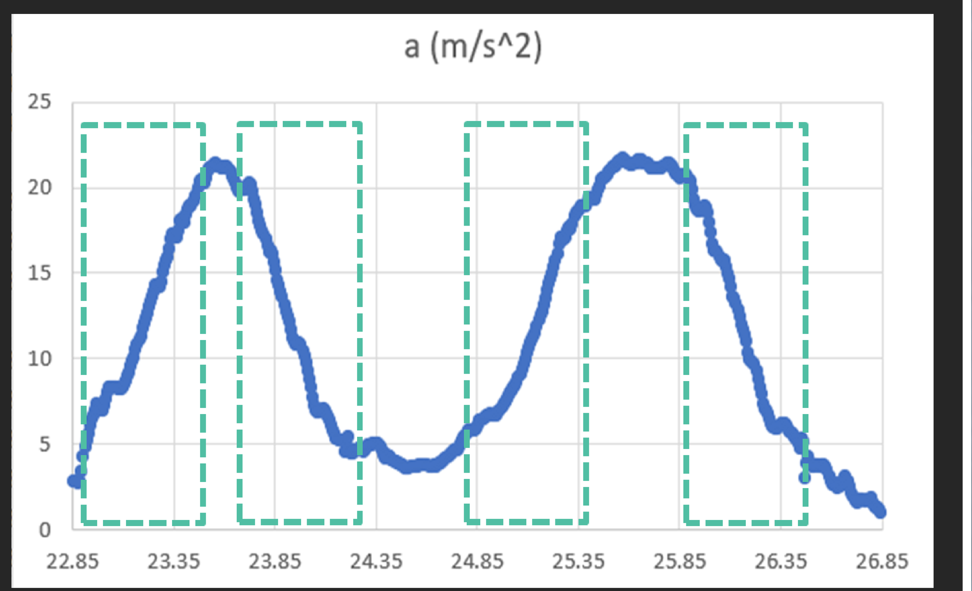
- An upper body data collection was performed with 5 Xsens DOT IMUs on a single subject. IMUs consist of an accelerometer, a gyroscope, and a magnetometer which collect linear acceleration, angular velocity, and magnetic fluctuations, respectively.
- Approximate removal of gravitational acceleration was performed by subtracting baseline data. The distances (radii) calculated at every time interval were filtered (bandpass filter keeping 5th-90th percentile data) to eliminate outliers and spurious data that occur when the isolated motion was stopped or nearly stopped (but no smoothing filters). The remaining distances were averaged, resulting in the calculated limb length.
- Scale factors are plugged into the Scale Tool in OpenSim [1,2] to apply the scaling to the Modified OpenSim Full Body Rajagopal Model [3,4]. OpenSense processing follows for kinematic results based on IMU data.
- The Anthropometric Survey of US Army Personnel (ANSUR II) [5] was also used as a third source of reference for limb length measurements.

Data Manipulations

- IMU data collections generated during motion (inside the green dashed boxes) as baseline equation fails when motion is stopped or nearly stopped (i.e., when linear acceleration is maximal and minimal)
- IMU base axis also adjusted to account for its origin not being centered on the device changed the calculated r







Future Work

- Introduce mass scaling estimation.
- Create a method for whole-body scaling estimation.
- Develop a method to remove gravitational component as this leads to some amount of overestimation.
- Generate a better method to remove data when motion is stopped or near stopped.
- Continued pursuit of these techniques is expected to enable acquiring anthropometric information using only IMUs in real-time.

Acknowledgements

- The work described here was performed entirely within the Simulation and Graphics Branch of the Software, Robotics, and Simulation Division of the NASA JSC Engineering Directorate by the Digital Astronaut Simulation (DAS) team.

Results

Segment	Measured	Calculated	%Difference
Ruler	10 in	12.9 in	29%
Forearm	29.5 cm	37.6 cm	28%
Humerus	36.3 cm	47.8 cm	31%

Conclusions

- Ruler bench test and human body trial results agree on overestimation confirming test method; filter and averaging optimization will yield more accurate results.
- Sources of error:
  - Attachment not very secure
  - Unrefined filter techniques
  - Arbitrary removal of stopped or near stopped data
  - Lack of method for fully removing gravitational acceleration and accounting for change in IMU orientation during movement.
  - Imperfect isolated motion (method currently expects that motion should be perfectly circular in a 2D plane)

References

[1] Delp, S.L., et al., "OpenSim: Open-source Software to Create and Analyze Dynamic Simulations of Movement", IEEE Transactions on Biomedical Engineering, (2007).

[2] Seth, A., Hicks J.L., Uchida, T.K., Habib, A., Dembia, C.L., Dunne, J.J., Ong, C.F., DeMers, M.S., Rajagopal, A., Millard, M., Hamner, S.R., Arnold, E.M., Yong, J.R., Lakshmikanth, S.K., Sherman, M.A., Delp, S.L. OpenSim: Simulating musculoskeletal dynamics and neuromuscular control to study human and animal movement. Plos Computational Biology, 14(7). (2018)

[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)

[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 HRP IWS. (2019).

[5] Gordon C.C., "Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics", US Army Natick Soldier RD&E Center. (2012).

[6] XSENS, Xsens DOT User Manual. Document XD0502P Revision F. (2022).