

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

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BACKGROUND

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, these 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. For example, to measure forearm length, an IMU is placed at the wrist, the point of rotation is at the elbow, and the isolated motion is forearm flexion and extension. These calculated lengths are then used to scale models to each unique astronaut's size, thereby improving the applicability of the model. 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. Utilizing IMUs for data collection also provides the synergistic ability to record data without a dedicated space in a room with many cameras, therefore reducing the data collection footprint, or record data where optical motion capture is not possible, such as inside a spacesuit.

METHODS AND RESULTS

To test this method, 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. Before any ground-based laboratory collection, the magnetic fluctuations are used to correct the heading of the IMU in space relative to the Earth's magnetic field. The direct measurement of angular velocity is integrated to calculate angular acceleration. Then the linear acceleration (a) and angular acceleration (α) are solved using $r = at/\alpha$ to calculate the radius, which in this case is the distance between the IMU and the point of rotation (i.e., segment length). The IMU must be placed at the most distal point of the limb being measured (i.e., ankle if measuring lower leg length) and the test plan must consist of an isolated motion about that limb's proximal joint (i.e., knee flexion and extension if measuring lower leg length). 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. The remaining distances were averaged, resulting in the calculated limb length. Scaling factors were then computed by dividing the calculated limb length by the unscaled model's length. These scale factors are plugged into the Scale Tool in OpenSim [1,2] to apply the scaling to the OpenSim Full Body Rajagopal Model [3,4]. Manual measurements of limb lengths were taken before data collection started and used for comparing against the calculated lengths. The Anthropometric Survey of US Army Personnel (ANSUR II) [5] was also used as a third source of reference for limb length measurements. The following measurements were retrieved from the subject before data collection: 34.5 cm from L1 to C7 (thorax), 25.7 cm from C7 Joint Center (JC) to head vertex (neck and head), 36.3 cm from shoulder JC to elbow JC (humerus), 29.5 cm from elbow JC to wrist JC (forearm), and 16.2 cm from clavicle to acromion (clavicle).

Of those five, forearm and humerus lengths were calculated using this proposed method to obtain preliminary results. The forearm length after filtering and averaging was calculated to be 37.6 cm. This is a 28% overestimation from the measured forearm length (29.5 cm). The humerus length after filtering and averaging was calculated to be 47.8 cm. This is a 31% difference from the measured subject length (36.3 cm). Sources of error include imperfect isolated motion (method currently expects that motion should be perfectly circular in a 2D plane, include no rotation of the IMU, and be relatively smooth; a more secure IMU attachment method will help), unrefined filter techniques (removed highest and lowest values with 20% high and low pass filters and no smoothing filters), arbitrary removal of stopped or near stopped data (kept data for only a short range before and after the angular velocity peaking), and a more representative method for removing gravitational acceleration is needed (current method is to zero all accelerations against a baseline taken just before the isolated motion which does not account for the gravitational acceleration changed due to IMU rotation during movement). Addressing these error sources will improve the accuracy of the limb length calculation. Next steps include creating a method for whole-body scaling estimation using individual limb scale factors. Continued pursuit of these techniques is expected to enable acquiring anthropometric information using only IMUs in real-time.

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