COMPARING REAL VS. SIMULATED LINEAR ACCELERATION IMU DATA DURING STEADY-STATE WALKING

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Introduction: Inertial measurement units (IMUs) provide valuable information about human kinematics and provide a portable method for data acquisition in comparison to typical motion capture software. The portable and wearable nature of these sensors has made them invaluable in wearable robotics, specifically in data-driven applications that require real-time biomechanical information about the user. Previous work has replicated physical IMUs that would be placed on the body (RealIMU) using post-hoc analyses on motion capture data to create simulated IMUs (SimIMU), where IMU data is generated as though the sensor was attached to a specific body segment. Therefore, SimIMU data is often considered *ideal*, exhibiting less noise from soft tissue artifact than RealIMU data because it is perfectly coupled to the skeleton. SimIMU data has been used to successfully train data-driven models to predict factors such as biological joint angles and moments for use in gait analysis [1] and robotic control applications [2]. They have advantages over RealIMUs because researchers can simulate any combination of locations and choose optimal placement for a given wearable design. While predictions from data-driven models have shown promise, errors between the raw RealIMU and SimIMU data are rarely shown in detail to determine if foot impact-induced soft tissue noise impacts the accuracy of SimIMU estimates throughout specific gait cycle regions. In this work, we sought to investigate the relationship between RealIMU and SimIMU data throughout different regions of the gait cycle in the anteroposterior direction (AP) during steady-state walking. We hypothesized that error would be highest for all sensors at ipsilateral heel contact, due to high impact forces and resultant soft tissue noise, and relatively minimal throughout the rest of the gait cycle.

Methods: We collected motion capture at 100 Hz (Vicon Motion Systems, UK) and IMU data at 200 Hz (Microstrain by HBK, USA) from one participant walking at 1.25 m/s on a CAREN treadmill (Motek Medical, The Netherlands). We placed full-body motion capture markers on the subject, who also wore a pair of pants with five IMUs integrated into the fabric and one IMU on the sternum. We placed markers on each IMU to measure their locations on each segment. We collected steady-state walking data from 150 gait cycles of a protocol approved by the Georgia Institute of Technology Institutional Review Board. We calculated the body kinematics of each segment using OpenSim and simulated IMU signals at each marker location that marked a physical IMU [3]. We identified gait events using a kinematic method, used these events to define single and double stance regions, and resampled all data to 0-100% of double and single stance phases [4]. We evaluated the mean absolute error (MAE) between SimIMU data and RealIMU data over each single and double stance phase with respect to the right leg.

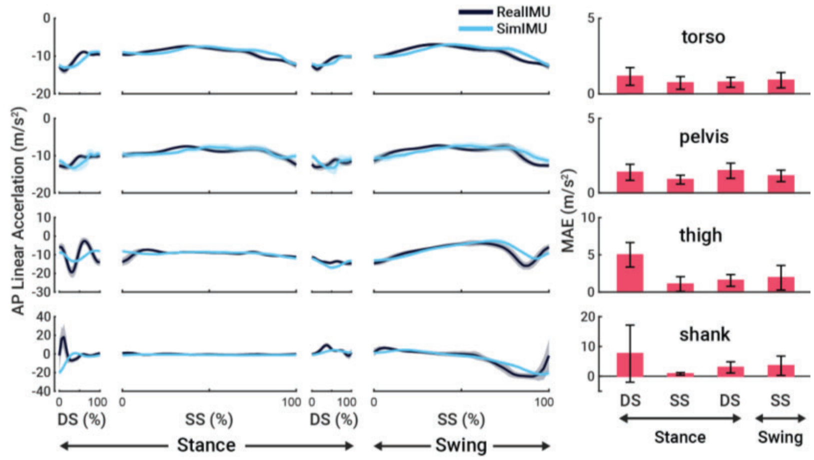

Figure 1: (Left) RealIMU and SimIMU linear acceleration in the anteroposterior (AP) direction during steady-state walking for the torso, pelvis, right thigh, and right shank across right stance/swing as percent double-support (DS) and single-support (SS). (Right) Corresponding RealIMU and SimIMU mean absolute error (MAE).

Results & Discussion: MAE between RealIMU and SimIMU is relatively low (<10 m/s) for the torso, pelvis, and thigh segments throughout all gait cycle regions. However, MAE increases during the transition from swing to stance phase – a period of ~10ms. The shank MAE exhibits high variability (7.57 ± 9.57 m/s^2) and reaches a peak of 33.34 m/s^2 at 7% of stance limb DS (Fig. 1). Overall SimIMUs appear smoothed, resulting in lower peak accelerations than RealIMUs at heel contact. These results partially support our hypothesis, showing higher error around heel contact and minimal error throughout the rest of the gait cycle for only the sensor on the shank. Proximal sensors produce lower errors during heel contact, rejecting our hypothesis and suggesting that high-acceleration signals are dissipated once they reach the upper thigh. This analysis proves that RealIMU data is vital to capturing distal lower-limb movement with high-fidelity, especially at heel contact. However, it is unclear if this disparity is due to soft tissue noise and sensor-user decoupling in RealIMUs or due to position-derived and filtered SimIMUs that are failing to capture transient, high-acceleration signals.

Significance: This analysis demonstrates that SimIMUs possess value as inputs to a data-driven model for proximal sensors. Researchers can take advantage of existing motion capture data, incorporate SimIMUs, and further extract compelling information about human physiological states *offline*, ranging from spatiotemporal gait parameters to ML-driven exoskeleton control. However, the translation of SimIMU to *real-time* monitoring is not perfect for distal segments. RealIMU is invaluable for capturing high-acceleration signals at distal locations – an important observation for those studying high-speed maneuvers such as perturbations.

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References: [1] Mundt et al. (2020), *Front. Bioeng. Biotechnol*. [2] Camargo et al. (2022), *J Biomech*. [3] Rajagopal et al. (2016), *IEEE TBME* [4] Zeni & Higginson (2008), *Gait Posture*