IMU-based Estimation of Walking Kinematics for 3-body Lower-limb Model

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Introduction

- Inertial measurement units (IMUs) offer opportunities to measure human kinematics outside traditional laboratories
- Spatial estimates require estimation methods to reduce integration drift errors (e.g. zero-velocity foot updates)

Primary Goal:

Develop method to accurately estimate joint angles and stride parameters for human lower-body from array of IMUs

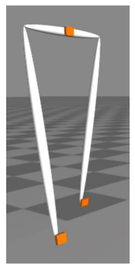
As first step, focus on simplified 3-body model of human lower-limbs

Filter Framework

- Error-state Kalman filter (ESKF) [1] used to estimate pose (position and orientation) of each segment (i.e., legs and pelvis)

$$x = \begin{bmatrix} q_{Rleg} & P_{Rleg} & V_{Rleg} & q_{Pelvis} & \dots \end{bmatrix}^{\intercal}$$

- Process model: Segment poses estimated by integrating IMU data
- Measurement model: known kinematic constraints and states used to correct drift errors

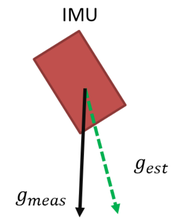


[2]

Drift Corrections

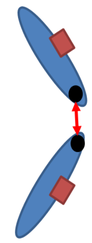
Kinematic States

- Zero-velocity foot condition
- Gravitational direction when segment is still



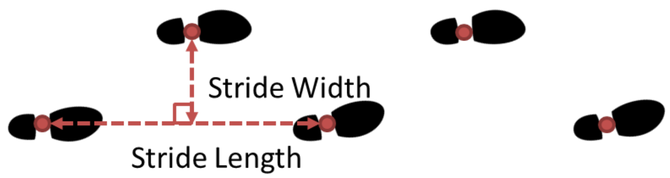
Kinematic constraints

- Position of joint center [3]
- Direction of joint axes [4]



Study Design

- 3-body model of the human lower-limbs consisting of pelvis and two legs.
- Evaluate accuracy of stride length (SL) and stride width (SW) estimates



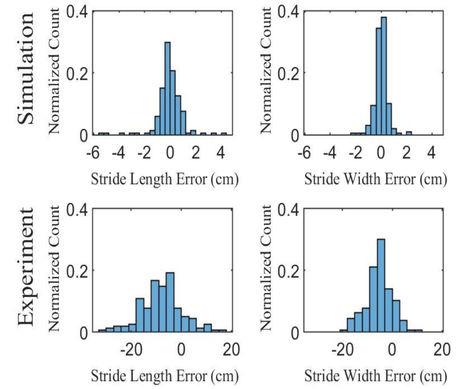
Simulation:

- Generate IMU data from prescribed human-like walking gait [5] for 200 strides
- Hip joint in pure flexion/extension

Experiment

- Subject walks with stiff knees and ankles down 90 meter hallway
- Markers on floor for known SW and SL

Results



Simulation:

- Mean errors in stride length and stride width both less than 2%

Experiment:

- Mean errors in stride length and stride width less than 7% and 17% respectively

References

[1] J. Sola, "Quaternion kinematics for the error-state Kalman fitler", *arXiv* 2017.

[2] S. Delp, et al., "OpenSim…" *IEEE Trans. Biomed. Eng.*, 2007.

[3] W. Teufl, et al., "Validity, test-retest reliability …", *Sensors*, 2018.

[4] R. Vitali, et al., "Method for estimating Three-D…", *Sensors,* 2017.

[5] Garcia, et al., "The simplest walking model…", *J. Biomech. Eng.*, 1998.

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