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

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***Abstract*—Methods for accurately measuring lower-limb kinematics outside traditional laboratory environments are critical to advancing our understanding of human locomotion in natural environments. We propose a novel method utilizing an error-state Kalman filter for estimating the lower-limb kinematics from an array of body-worn IMUs. We develop this method for a simplified 3-body model of the lower limbs and evaluate our approach through simulation and experiment. We demonstrate mean errors $<$1 cm for both stride length and stride width using simulated IMU data over 100 strides. Utilizing this simple model on a human subject walking with stiff knees and ankles resulted in mean stride length and stride width errors of -8 cm and -5 cm respectively over 75 strides.**

***Index Terms*—IMU, kinematics, gait, error-state Kalman filter**

I. Introduction

The ability to accurately measure lower-limb kinematics outside of traditional laboratory environments offers many opportunities to advance the study of locomotion in more natural settings. Miniature inertial measurement units (IMUs) are a promising option for accomplishing this goal due to their portability, small mass, simple setup, and relatively low cost. However, accurate estimation of relevant parameters (e.g., stride parameters, joint angles) requires estimation methods that reduce integration drift errors. We propose a method for estimating lower-limb kinematics from an array of body-worn IMUs (one on each major segment). As a first step, this abstract reports results for a simplified 3-body model of the lower limbs, which we evaluate via simulation and experiment.

II. Methods

We utilize an error-state Kalman filter [1] to estimate the poses (positions and orientations) of lower-limb segments and use these to derive relevant kinematic features (e.g., stride parameters). Our approach takes advantage of known kinematic states (e.g., zero-velocity updates) and kinematic constraints within the 3-body model to reduce integration drift errors and to obtain accurate pose estimates [2]. We first evaluate this method using simulated IMU data for a simplified 3-body lower-limb model with a human-like walking gait. We then test this model through an experiment on a human subject walking with stiff knees and ankles.

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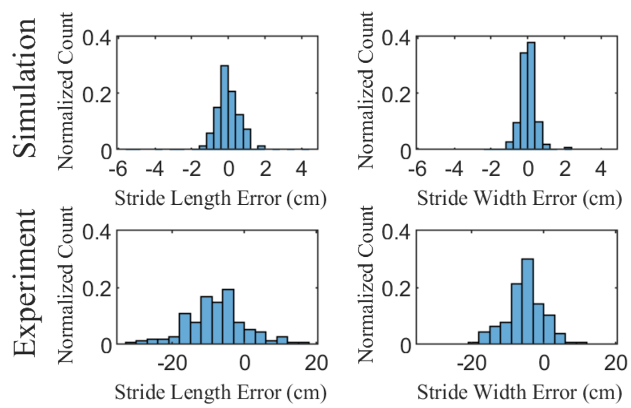

Fig. 1. Histograms of stride length and stride width errors for simulation (top) and experiment (bottom). Note difference in scale of errors for simulation versus experiment.

III. Results and Discussion

The distributions of errors in stride length and stride width are shown in Fig. 1. Simulation results demonstrate excellent agreement between estimated stride parameters and ground truth with low errors in estimated stride length (mean = 0 cm, SD = 1 cm) and stride width (mean = 0 cm, SD = 0.5 cm). Experimental results with human stiff-legged walking also demonstrate good agreement with ground truth with modest errors in estimated stride length (mean = -8 cm, SD = 8cm) and stride width (mean = -5 cm, SD = 5 cm). These promising results support the future goal of estimating the kinematics of all (seven) major lower-body segments by extending this approach.

References

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