A Speed-Independent Method for Stride Length Estimation in Running Using Foot-Mounted Inertial Sensors

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Summary

Stride length is a crucial metric for assessing running performance that can be accurately estimated in-the-field through foot-mounted inertial sensors. However, the performances of inertial-based methods are affected by running speed changes. This study aimed at providing an automatic inertial-based method for the stride length estimation that is robust to speed changes. The proposed method, validated on 20 runners at 8-14 km/h, achieved stride length errors of ~3% despite the speed.

Introduction

Stride length (SL) is a key running parameter influencing injury risk and recovery. Existing methods to estimate SL in-the-field are largely based on magneto-inertial measurement units (MIMUs), which can provide foot contact time and displacement through accurate but speed-dependent approaches [1]. This poses a challenge for analyzing sports with unpredictable speeds, as they require different parameter settings to account for the actual stride velocity. This study aimed to evaluate the importance of a proper parameter setting in inertial-based methods varying speed and to propose an automatic method for the speed-independent SL estimation between 8 and 14 km/h.

Methods

A total of 20 runners were enrolled: *A*) 10 runners ran both on treadmill and track at 8 and 10 km/h for about 400 m for 4 trials per speed, and *B*) 10 runners performed eight 6-min trials at 14 km/h on treadmill. A MIMU was attached to the instep of each foot (fs=100 Hz for dataset *A* and 200 Hz for *B*). The following methods were implemented to estimate SL: 1) foot contact identification through a template-based approach with dynamic time warping [1]; 2) zero-velocity instants identification within the foot contact phase, using a threshold-free zero-velocity update detector [2]; 3) foot orientation estimation to remove the gravity contribution [3]; 4) stride-by-stride double integration of foot accelerations between two consecutive zero-velocity instants to calculate SL. All the methods did not require to set any numerical parameters, except for the orientation estimation which relied on the fine-tuning of Madgwick's filter main parameter (β) to select a suitable trade-off value across speeds. Mean SL errors were computed using the total displacement for dataset *A*, and using concurrent stereo-photogrammetric data for dataset *B*. A one-way ANOVA was performed on SL error distributions to assess the effect of varying β values at a specific speed and across different speeds with a constant β.

Results and Discussion

More than 55,000 strides were analyzed. As expected, SL errors were significantly affected by changes in β parameter at each speed ($p < 0.05$): choosing an unsuitable β value resulted in errors of up to ~7% (Fig. 1). Errors computed using the implemented automatic methods, with a trade-off β within 0.29-0.36 rad/s across speeds, were not significantly affected by speed ($p > 0.05$) and were always equal or below 3.2% (Fig. 1).

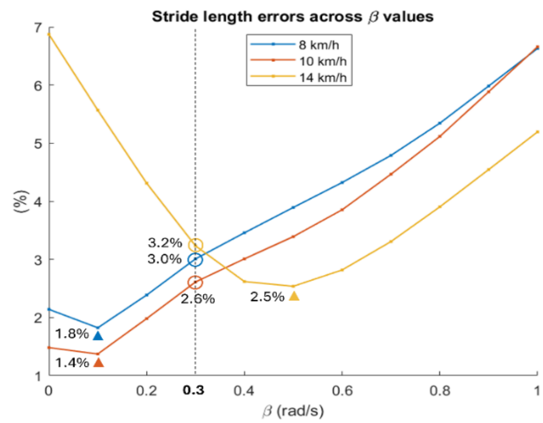

Figure 1: SL errors varying β at different speeds, highlighting min values (triangles) and trade-off β across speeds (dashed line).

Conclusions

This study automated the inertial-based SL estimation during running at different speeds and highlighted the importance of proper fine-tuning in non-automatic methods. A template-based identification of foot contacts, combined with a threshold-free zero velocity update and Madgwick's filter with a tuned fixed β, provided speed-independent performances from 8 to 14 km/h and SL errors of ~3% despite the speed. Future work will focus on extending the analysis to encompass sprinting speeds.

Acknowledgments

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