In-field temporal phase analysis of running: performance analysis of 18 algorithms based on inertial sensors measurements

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Summary

Wearable inertial measurement units (IMUs) are widely used in running analysis for in-field estimation of temporal parameters linked to performance. Various IMU-based algorithms have been proposed for detecting gait events, differing in sensors placement and computational approach. However, a complete comparison of these methods is needed to guide the selection of the proper algorithm. This study compares the performance of 18 IMU-based algorithms in the estimation of the stance, stride and flight phase duration. Ten amateur runners with IMUs placed on foot, shank, and lower back performed sprinting at three different speeds. Performances were evaluated using photocells as gold standard. Foot-mounted sensors resulted the most accurate across all parameters (absolute median error <0.051s, 0.002s, and 0.052s for stance, stride and flight phases, respectively) and less sensitive to speed variation. These findings emphasize the importance of selecting the most appropriate IMU-based algorithm for accurate running evaluation based on the specific application.

Introduction

Accurate estimation of stance, stride, and flight phase duration is essential in running analysis. While gold standard instruments provide precise measurements, their use is limited to laboratories and to a small number of steps [1]. Wearable sensors are, on the other hand, easy to use and offer continuous recording in real-world conditions, enhancing ecological usability during training. Several methods have been proposed, which exploit different sensors' locations and different computational approach for event detection, yet a direct comparison is lacking but still necessary to guide practitioners toward an effective choice. While some studies have analyzed sensor placement on the sacrum and pelvis [2] or foot [3], no comprehensive study has included all different placements. This study evaluates 18 algorithms identified from a literature review for estimating temporal parameters, using photocells as ground truth reference. The analyzed methods exploited acceleration (13), angular velocity (2), or both signals (3) from the foot (7), shank (6) or sacrum (5) sensor, implementing peak detection algorithms (17) or thresholding (1).

Methods

Ten amateur runners (9M1F, age: 26±4 years) performed sprints at 15, 20 and 25 km/h. Six IMUs (OPAL, ADPM wearable technologies, ±200g, ±2000deg/s, 800Hz) were attached on the dorsum of each foot, the 5th metatarsal head, the heel (laterally), the right shank, and the lower back (L5). Sensors were secured with adhesive tape and cohesive bands, with an additional belt for the lower back sensor. OptoJump Next (MicroGATE Srl, 1000Hz, 10 meters) served as the reference system. A total of 1034 strides were collected and analyzed separately for each speed to compare performance in terms of median error and interquartile range (75th percentile-25th percentile).

Results and Discussion

Foot-mounted sensors provided the most accurate and consistent estimations across all parameters, with less error variability across speeds (Figure 1). Stride time was less critical than stance and flight time for all sensor placements. Peak detection outperformed thresholding, which resulted in higher errors. No substantial differences were observed between accelerometer- and gyroscope-based methods and among different speeds.

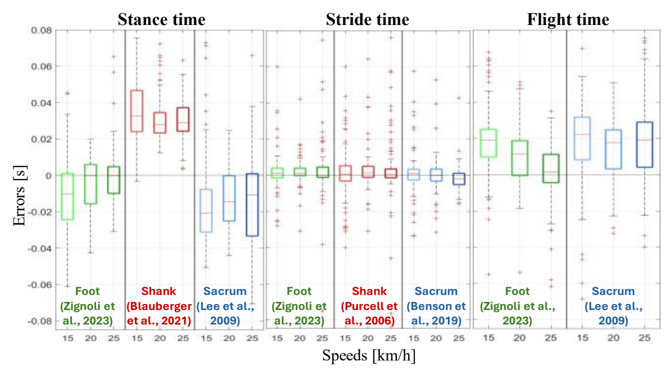

Figure 1: Estimation errors of the best-performing algorithms for each sensor position during sprints at 15-20-25 km/h.

Conclusions

This study highlights the influence of sensor placement and algorithm selection on the accuracy of IMU-based estimation of temporal parameters in running. Foot-mounted sensors are recommended for the best accuracy and repeatability. Peak detection should be preferred over thresholding as it yields lower errors. Performance differences between algorithms remained consistent across speeds.

References

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