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A wearable device for movement analysis in outdoor walking and running: A sensor-fusion approach

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Summary

We developed a single body-mounted sensor that integrates a 3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer, barometer, and GPS. The sensor accurately computes speed, acceleration, location, angular velocity and angular orientation at 400 Hz. Steps are also segmented and metrics computed for each step (e.g. cadence, speed, step length and vertical oscillation). This device is a portable alternative to expensive and cumbersome existing methods. Here we present results of tests where biomechanical parameters were computed in walking and running on an outdoor track.

Introduction

Current biomechanical methods for the analysis of walking and running mechanics use a combination of high-speed video and ground reaction force measurements that can provide detailed gait information including forces, pressure distribution, joint angles, running velocity etc. However, these approaches are often limited by cost, portability, analysis time, and the need for trained personnel. In this study we present a novel wearable device that combines an inertial navigation system (INS) with GNSS (INS/GNSS) to perform continuous analysis of gait mechanics and technique during outdoor walking and running.

Methods

The measurement setup consists of a Raspberry Pi-3 model B running Linux OS, Vectornav VN-200 GPS-aided inertial navigation system (INS/GPS), GPS antenna and a power bank, all packaged in a 3D printed case. Data are stored on a memory card or via cloud storage, and sampled at 400Hz. The device is a small (150 x 75 x 48 mm), fully autonomous and self-contained data logger.

A total of 20 participants (28±4 yrs., 74±13 kg, 176±7 cm) walked (1.0-1.5m/s) and ran (2.2-3.3m/s) on an outdoor track with the device attached to the upper back between the shoulder blades. Custom-written algorithms were used to transform velocity and acceleration to the anatomical frame (by computing ground track), segment steps, and compute gait metrics. Acceleration was transformed to forward acceleration by computing the magnitude of horizontal acceleration components. Steps were segmented based on vertical velocity. The beginning of each step was defined as the instant when vertical velocity was zero and the CoM was in the highest position. Vertical displacement was computed for each step by numerical integration of vertical velocity.

Results and Discussion

The following accuracy levels are achieved with our device (with good GPS coverage): Velocity: ±0.05 m/s; True inertial heading: 0.3° RMS; Pitch/Roll: 0.1° RMS; Angular resolution: < 0.05°; Vertical displacement: ≤ 3mm [1].Data were excluded from 3 participants who did not complete the protocol. Group mean results (n=17) for a range of common metrics are shown in Table 1. The results are consistent with values in the literature obtained using lab-based methods such as motion analysis [e.g. 2].

Table 1. Group mean data across all speeds/conditions computed from a mean of 95 steps (range: 57-147).

Condition	Speed (m/s)	Cadence	Vertical displacement (cm)	Step Duration (s)	Step Length (m)
Walk 1.0	0.99	98	3.34	0.61	0.61
Walk 1.3	1.27	111	4.40	0.54	0.69
Walk 1.5	1.49	117	5.43	0.51	0.76
Run 2.2	2.28	156	9.28	0.38	0.85
Run 2.5	2.53	159	9.47	0.38	0.95
Run 2.8	2.86	161	9.55	0.37	1.06
Run 3.1	3.14	164	9.34	0.37	1.15
Run 3.3	3.40	167	9.18	0.36	1.22

Conclusions

We present a device and methodological approach that can be applied to biomechanics research and sports performance evaluation. Our approach uses a new generation of small, accurate sensors for movement analysis in natural environments. Gait segmentation provides results in a convenient format, with metrics computed for each step. Data can also be integrated with deep learning techniques for indirect estimation of other important parameters such as ground contact time and ground reaction forces [1]. New sensor technology combined with machine learning and artificial neural networks can lead to improvements in athletic performance, injury rehabilitation and motion disorder diagnostics.

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