Algorithms to detect Foot Contact in High-Dynamic Movements using Inertial Measurement Units: A Systematic Review

Margherita Mendicino[1], Stefano Di Paolo[1], José Miguel Santos[2], Stefano Zaffagnini[1]
[1]2nd Orthopaedic and Traumatological Clinic, IRCCS Rizzoli Orthopaedic Institute, Bologna, Italy
[2]University of Porto, Porto, Portugal
Email: margherita.mendicino@ior.it

Summary

Inertial Measurement Units (IMUs) offer promising alternatives to traditional motion capture systems, especially in real-world sports scenarios. Accurate foot contact detection (FCD) is crucial for biomechanical analysis, and IMU-based FCD algorithms have been extensively investigated. However, sports activities leading to musculoskeletal injuries (e.g., anterior cruciate ligament injury) are multidirectional and high-dynamics in nature, potentially worsening FCD algorithm performance. This systematic review analysed FCD algorithms in high-dynamics movements through IMUs. According to PRISMA guidelines, 15 studies, evaluating 30 FCD algorithms, were included. Most papers focused on running, only two on cut manoeuvres. All studies involved healthy individuals only. Foot linear acceleration was the most inspected FCD metric. FCD algorithms demonstrated high accuracy, though speed impacted performance in 11/15 studies. This review highlights the lack of validated IMU-based FCD algorithms for high-dynamic movements and emphasizes the need for improved methods to advance sports-specific biomechanics in both healthy and injured athletes.

Introduction

Inertial Measurement Units (IMUs) are promising alternatives to laboratory-based motion capture systems, returning more trustful results with real-world, sport-specific data [1]. To inspect relevant biomechanics, proper foot contact detection (FCD) is mandatory, and since on-the-field force plates are unsuitable, IMU-based algorithms are required [2]. However, FCD algorithms have mostly been studied in gait analysis, leaving a gap in knowledge regarding their reliability in high-dynamic movements, which are more common in sports and likely to cause musculoskeletal injuries, such as anterior cruciate ligament rupture [3]. This review aims to explore different FCD algorithms through IMUs in high-dynamic movements. The goal was to identify each algorithm's strengths and limitations and provide insights into methodological improvements and future implementations.

Methods

A systematic review was conducted on PubMed (Figure 1). Inclusion criteria were articles using IMUs, algorithms with a method for FCD, articles analysing high-dynamic movements, articles focusing on FCD. Two independent reviewers inspected the retrieved papers, solving conflicts with a third reviewer. Review articles were excluded from the analysis. Studies were inspected according to the movement type, the cohort, FCD metrics adopted, IMU placement and the ground truth used for validation. A specific focus on the algorithm steps (where available) was reported.

Results and Discussion

Overall, 106 articles were identified, out of which 15 were included in the final analysis. A total of 30 FCD algorithms were adopted across the 15 articles. 12/15 articles were restricted to running, one to sprinting and two to change of direction tasks. All studies analysed healthy individuals only. The foot was chosen for IMU placement in 10/15 articles. 18/30 algorithms used linear acceleration as the feature inspected. Among these, 12/18 used foot linear acceleration, 4/18 pelvis linear acceleration, 1/18 upper back linear acceleration, and 1/18 shank linear acceleration. As a ground-truth data source, 7/30 algorithms utilised a force sensing system, while the remaining adopted less reliable sources (e.g., high-speed and consumer-grade camera systems, infrared cameras, and photoelectric bars). According to each study threshold, the algorithms' accuracy and consistency were overall high. An effect of movement task speed over algorithmic accuracy was reported in 11/15 articles.

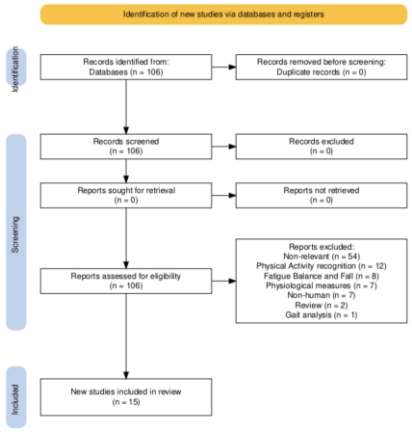

Figure 1: PRISMA flow diagram of the screening process.

Conclusions

This systematic review highlighted lack of IMU-based FCD algorithms on high-dynamic movements. Only 15 articles were identified, mostly related to running in healthy athletes. Foot linear acceleration was the most widely adopted feature. Validated FCD algorithms on high-dynamics movement are mandatory to promote the on-field use of IMUs in sports-specific biomechanics testing of healthy and injured athletes.

References

[1] Prasanth H et al. (2021) *Sensors*, **21(8)**, 2727.
[2] Niswander W and Kontson K (2021). *Sensors*, **21(12)**, 3989.
[3] Rodriguez-Merchan EC and Encinas-Ullan CA (2022). *ABJS*, **10(11)**, 951–958.