Short Communication
Volume 12:01, 2025

Journal of Biomedical Systems & Emerging Technologies

ISSN: 2952-8526

Open Access

Real-time Gait Analysis Using Embedded Systems and Edge AI Technology

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Introduction

Gait analysis the study of human locomotion is a vital tool in clinical diagnostics, rehabilitation monitoring, sports science, and eldercare. Traditional gait analysis methods often rely on expensive motion capture systems and laboratory-based assessments that require specialized equipment and trained personnel. However, with recent advancements in embedded systems and Edge AI (Artificial Intelligence), real-time gait analysis has become more accessible, portable, and affordable. This paradigm shift is crucial for continuous health monitoring, fall risk prediction, post-surgery mobility assessments, and performance optimization in athletes. Embedded systems, such as microcontrollers and system-on-chip (SoC) devices, are now equipped with onboard sensors (e.g., IMUs Inertial Measurement Units, accelerometers, gyroscopes) and processing units that can run AI models locally. Edge AI brings computational intelligence closer to the data source, reducing latency, enhancing privacy, and minimizing reliance on cloud connectivity. By integrating wearable sensor technology with edge computing, real-time gait analysis becomes a viable solution for remote, ambulatory, and personalized healthcare [1].

Description

Embedded systems form the physical backbone of modern gait analysis systems. These compact computing platforms integrate various sensors that capture biomechanical parameters like stride length, cadence, walking speed, joint angles, and symmetry. Wearable devices such as smart insoles, ankle bands, and thigh straps incorporate these systems and are positioned at strategic locations on the body to gather multidimensional motion data. The collected data is processed locally using microprocessors (e.g., ARM Cortex-M series) or AI accelerators (e.g., Google Coral, NVIDIA Jetson Nano), which run lightweight machine learning models trained to detect and interpret walking patterns. These models can classify different gait phases heel strike, mid-stance, toe-off and detect anomalies such as limping, dragging, or shuffling. The embedded systems are optimized for energy efficiency, real-time signal processing, and wireless communication (Bluetooth, Zigbee) to transmit the results to user interfaces or medical servers when necessary.

Edge AI technology transforms raw sensor data into actionable insights in real-time. Unlike cloud-based AI, which requires transmitting large volumes of data over networks, edge AI allows instant inference at the source, enabling immediate feedback and decision-making. For example, in elderly individuals, the system can identify subtle changes in gait that precede falls such as reduced step regularity or increased double support time and trigger alerts to caregivers or clinicians. This real-time feedback loop enables preventive interventions, such as suggesting rest, medication, or changes in walking aids. Moreover, edge AI can support adaptive systems that personalize gait recommendations based on the user's history, environment, and condition. Deep learning models such as Convolutional Neural Networks (CNNs) or Recurrent Neural Networks (RNNs) can be optimized and compressed (via quantization or pruning) to run efficiently on edge devices, making them suitable for prolonged use in wearable form factors [2].

The clinical and rehabilitation applications of real-time gait analysis are extensive. Patients recovering from stroke, hip replacement, or orthopedic injuries often undergo physiotherapy to restore normal gait function. Traditional methods rely on periodic assessments, which may miss critical changes that occur between clinic visits. A real-time embedded system enables continuous monitoring, allowing therapists to track progress and adapt treatment plans dynamically. Similarly, patients with Parkinson's disease or multiple sclerosis experience episodic gait disturbances that can now be detected and quantified outside the clinic, offering a more comprehensive picture of disease progression. The portability of these systems facilitates in-home rehabilitation, improving patient adherence and reducing healthcare costs. In sports, athletes benefit from real-time gait feedback to enhance running form, reduce injury risk, and optimize performance through biomechanical adjustments.

Conclusion

Real-time gait analysis using embedded systems and Edge AI represents a transformative advancement in the intersection of healthcare and technology. By enabling portable, efficient, and intelligent monitoring of human locomotion, these systems empower clinicians, patients, and athletes with immediate insights that enhance diagnosis, recovery, and performance. The convergence of wearable sensors, on-device computing, and adaptive AI models offers a scalable and personalized solution to mobility-related healthcare challenges. As innovations in sensor miniaturization, energy harvesting, and machine learning algorithms continue to evolve, real-time gait analysis will become increasingly accurate, affordable, and widely adopted. Addressing current limitations related to accuracy, power efficiency, and user experience will be crucial for mainstream integration. Ultimately, this technology has the potential to redefine gait assessment from a sporadic clinical task to a continuous, accessible, and life-enhancing tool for millions worldwide.

Acknowledgement

None.

Conflict of Interest

None.

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Received: 02 January, 2025, Manuscript No. bset-25-168438; **Editor Assigned:** 04 January, 2025, PreQC No. P-168438; **Reviewed:** 18 January, 2025, QC No. Q-168438; **Revised:** 23 January, 2025, Manuscript No. R-168438; **Published:** 30 January, 2025, DOI: 10.37421/2952-8526.2025.12.242

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How to cite this article: Andersson, Sofia. "Real-time Gait Analysis Using Embedded Systems and Edge AI Technology." *J Biomed Syst Emerg Technol* 12(2025): 242.