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Camera-Based Gait Analysis Using a Machine Learning Approach to Improve Patient Care

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Abstract

Gait analysis plays a vital role in clinical diagnostics and rehabilitation, providing insights into locomotor function, musculoskeletal disorders, and neurological impairments. Traditional gait analysis systems rely on high-cost, multi-camera motion capture setups, which, while accurate, are often inaccessible due to their complexity, immobility, and financial constraints. To address these challenges, this research presents a low-cost, camera-based gait analysis system utilizing an NVIDIA Jetson Nano platform integrated with an IMX519 ArduCam and a pre-trained pose estimation model. The objective is to develop a machine learning–driven approach capable of estimating human joint positions in real time and extracting kinematic data that support clinical evaluation and patient monitoring. The proposed system was designed using a modular and portable setup. The Jetson Nano Developer Kit, running JetPack 4.6.1 with L4T 32.7.1, served as the primary computation unit. A lightweight Docker container environment was implemented to ensure reproducibility and portability across multiple systems. Within this container, libraries such as PyTorch and TorchVision were integrated, and JupyterLab was employed as an interactive development platform. The IMX519 ArduCam, connected via the CSI interface, captured continuous video streams of a walking subject on a treadmill. The data acquisition process involved detecting and tracking key body joints, including knees, ankles, and hips, to measure positional variations over time. To enhance data reliability, the Multiplicative Extended Kalman Filter (MEKF) was applied to filter noisy joint angle signals and predict potential gait trajectories. The filtered outputs provided stable representations of knee and ankle motion dynamics, serving as a foundation for identifying gait abnormalities. Preliminary testing demonstrated that the system could accurately capture walking patterns and generate interpretable visualizations of lower-limb movements. Compared to conventional 3D motion capture technologies, this implementation achieved comparable motion trend recognition while maintaining significantly lower hardware and operational costs. This study highlights several key advantages of the proposed approach. First, its affordability enables deployment in resource-limited healthcare settings, expanding access to gait analysis beyond specialized laboratories. Second, the modular software environment facilitates rapid setup and remote replication, allowing researchers and clinicians to share and run the same containerized models across different machines. Third, the system's real-time data acquisition and visualization capabilities provide immediate feedback for both practitioners and patients, potentially improving rehabilitation efficiency. Finally, future work will focus on integrating the system with cloud-based monitoring tools and expanding its machine learning model to support predictive analytics for early detection of mobility impairments. In summary, this research demonstrates a cost-effective, accessible, and scalable solution for clinical gait analysis using computer vision and machine learning. The combination of an embedded AI platform, open-source software, and advanced signal processing offers a promising pathway toward democratizing gait monitoring technologies. By bridging the gap between affordability and accuracy, this camera-based system could significantly enhance patient care and data-driven physical therapy practices.

Keywords
Gait Analysis, Machine Learning, Pose Estimation, Jetson Nano, Kalman Filter