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A Cost-Effective Multi-Camera Calibration System for 3D Reconstruction in Real-World Biomechanical Gait Analyis

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Introduction

Computer-vision based evaluation of movement kinematics is a promising candidate for affordable biomechanical gait analysis outside clinical or laboratory environments. In this context, accurate 3D reconstruction of anatomical key points and their dynamics is essential. Conventional approaches rely on marker-based systems that are expensive and limited in scalability. Alternative 2D pose estimation methods cannot capture movements outside the recording plane. Recent advances in estimating multi-view geometry and the availability of open-source tools have enabled cost-effective 3D reconstruction using multiple consumer grade cameras. However, there is limited guidance regarding optimal camera placement and calibration for an accurate setup. To address this, we developed and tested a structured calibration pipeline for an affordable 3D pose estimation framework in a real-world environment.

Methods

We placed eight DJI Osmo Action 5 Pro cameras around a 6-meter walkway to ensure comprehensive coverage of a large volume that allows capturing performance of unconstricted whole-body movements. We tested multiple ChArUco boards of different dimensions for intrinsic and extrinsic calibration in Caliscope (https://mprib.github.io/caliscope/) to estimate camera parameters and reconstruct their 3D spatial configuration. To assess accuracy, we calculated the relative error between the reconstructed and real-world camera positions for all inter-camera distances and recorded movement from 20 volunteers.

Results

The estimated camera positions demonstrated strong agreement with ground truth measurements, indicating reliable calibration and spatial alignment across all viewpoints (mean and standard deviation of relative error over inter-camera distances = 3.58% ± 3.43%). The framework also enabled real-world data collection, consistently reconstructing movement from 20 subjects.

Conclusion

We present a practical and cost-effective framework for multi-camera calibration tailored towards 3D movement analysis in real-world settings. The system captures a large area, allowing to investigate unconstrained whole-body movements. We thus established a strong foundation for 3D motion analysis in low-cost environments.

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