High Precision Markerless 3D Gait Analysis Using Customizable Volumetric and Reprojection-Based Deep Learning

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Fully instrumented gait analysis provides clinicians with critical metrics for surgical planning and rehabilitation. It is the gold standard, combining infrared motion capture and force plates to quantify human motion, but remains limited by cost, complexity, and specialized laboratory access. Markerless systems like OpenCap show promise but are trained on typical gait and demonstrate reduced accuracy on atypical gait populations. Customizable frameworks can be retrained on any population but face inherent barriers: DeepLabCut, a 2D pose estimation framework, requires time-intensive manual labeling that introduces human error, while DANNCE, a 3D volumetric framework, is computationally intensive and designed for rodent-scale volumes. This study reengineers DeepLabCut and DANNCE as accurate and customizable 3D human gait analysis pipelines. For DeepLabCut, manual annotation was eliminated by implementing a novel auto-labeling pipeline that reprojected 3D ground truth to pixel-accurate 2D training labels. For DANNCE, architectural modifications to voxelization, including anisometric grids, model segmentation, and regions of interest refinement, enabled human-scale analysis. Both pipelines were validated on the BioCV dataset and benchmarked against a pretrained Pose2Sim/OpenCap-LSTM. DeepLabCut and DANNCE achieved mean per-joint position errors of 21.1mm and 29.1mm (33.9mm for Pose2Sim/OpenCap-LSTM, $p<0.001$), with mean joint angle errors across complete gait cycles of 1.79° and 3.30° (3.75° for Pose2Sim/OpenCap-LSTM, $p<0.001$), below the 5° clinical threshold for most angles. This demonstrates customizable frameworks can achieve near clinical-grade accuracy without priors, allowing for future retraining on atypical gait populations.

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