Markerless Gait Analysis Using a 3D Skinned Multi-person linear Model and a single RGB-Depth Camera in Children with Cerebral Palsy and Clubfoot

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Summary

Advancements in depth sensing and machine learning have paved the way for markerless (MS) gait analysis for clinical applications. However, single-camera MS methods rely on 2D analysis, failing to reconstruct out-of-plane movements. Recently, 3D statistical human models have been developed for gaming purposes, however their clinical use is underexplored. This study introduced an MS protocol combining a single RGB-Depth camera with a 3D model to estimate sagittal lower limb joint kinematics. Data from four children with cerebral palsy and six with clubfeet were collected using an RGB-D Azure Kinect camera. Validation against a marker-based system resulted in a strong reliability (ICC>0.75), demonstrating the clinical potential of the proposed 3D MS approach.

Introduction

Markerless (MS) gait analysis has shown increasing potential for clinical applications, however single-camera methods often rely on the manual identification of 2D anatomical landmarks and performance can decrease for out-of-plane movements [1]. Recent advancements in computer vision have led to the development of 3D statistical models, such as Skinned Multi-Person Linear model (SMPL) [2], capable of estimating a variety of human shapes and poses. However, their application in clinical gait analysis remains limited. This study proposed a MS protocol using a single RGB-Depth camera leveraging a 3D SMPL to improve sagittal kinematic accuracy.

Methods

Four participants with cerebral palsy (age: 14.7 ± 6.9 y.o.) and six with clubfeet (age: 12.2 ± 4.2 y.o.) were evaluated in a gait analysis laboratory using an Azure Kinect (30 fps) positioned laterally to the walkway. A SMPL consisting in foot, shank, thigh, and pelvis interconnected by ankle, knee, and hip joints, was calibrated to each participant's static posture (frontal, posterior, sagittal) to create a subject-specific model ($SMPL_{ss}$) (Figure 1a-b). Each participant completed three self-paced gait trials for both sides. 3D coordinates of hip, knee, and ankle centers were extracted by aligning $SMPL_{ss}$ to each dynamic point cloud (Figure 1c) using the articulated iterative closest point algorithm [3]. Validation was performed against a Qualisys system (100 Hz). To prevent interference between the IR sensors of the two systems, trials were recorded separately under the assumption of movement repeatability. Seven clinical gait features (Figure 1d) were extracted, and reliability was assessed using intraclass correlation (ICC).

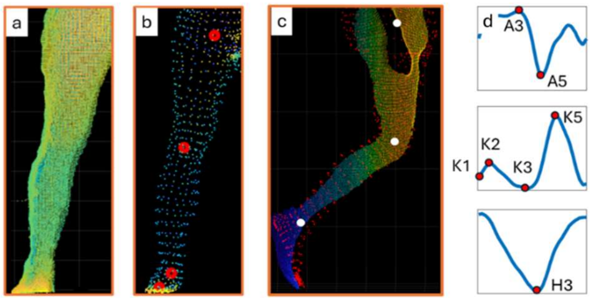

Figure 1: a) Frontal, sagittal, and posterior views b) $SMPL_{ss}$ c) Alignment between $SMPL_{ss}$ and a dynamic point cloud, d) gait features from sagittal lower-limb kinematics.

Results and Discussion

As shown in Table 1, the proposed MS method demonstrated good reliability (ICC>0.75) for every gait feature. Residual errors in estimating A5 were due to technological limitations, as the depth sensor failed to reconstruct values during the swing phase (highest velocity).

Conclusions

In conclusion, the proposed protocol, benefiting from a 3D model, can directly reconstruct 3D lower-limb joint centers, making the estimates more robust to out-of-plane movements than 2D MS analysis [1].

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References

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Table 1: ICC values for each gait feature for MS and MB protocols.

ICC	A3	A5	K1	K2	K3	K5	H3
MS vs MB	0.83 / 0.83	0.75 / 0.95	0.85 / 0.93	0.88 / 0.85	0.82 / 0.85	0.89 / 0.89	0.85 / 0.70