The Development of a Robust Markerless Motion Capture System with Applications for Clinical Spine Assessments

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Summary

This study focuses on the development of a robust deep learning (DL) markerless motion capture system that measures spine kinematics using accessible red-green-blue-depth (RGB-D) cameras. This system utilizes a convolutional neural network (CNN) that segments the trunk and pelvis into three anatomical masks: upper spine, lower spine, and pelvis. Depth images are used to obtain 3D pixel positions of mask corners, enabling the development of local coordinate systems and the measurement of spine kinematics. The kinematics measured with the predicted and ground truth segmentations are highly correlated (≥0.98) with RMSE ≤3.4°. This work demonstrates the feasibility of using accessible and inexpensive technology to assess spine movement patterns.

Introduction

Clinically, visual movement assessments are used to evaluate function and disability in patients with spine deformities and dysfunctions [1]; however, these subjective assessments have poor reliability [2]. Gold-standard optical motion capture systems are impractical for clinical use, and portable, low-cost alternatives, such as inertial measurement units (IMUs) require comprehensive knowledge and expertise to acquire high-quality data [3]. Previously, we developed and validated an easy-to-use markerless motion capture system that uses DL and accessible RGB-D cameras to measure the lumbar kinematics of male participants during forward bending (FB) [4], as aberrant lumbar movement patterns are frequently seen in people with low back pain (LBP) [1]. However, with LBP and other spine conditions, functional limitations are also observed in the frontal and transverse planes [5]. Therefore, the purpose of this study was to increase model robustness, by expanding participant recruitment to include female participants, and the evaluation of multi-planar movements (i.e., FB, lateral bending (LB), and axial twisting (AT)).

Methods

All participants included in [4], and 9 new participants (6M,3F) were recruited from the University of Ottawa. All new participants were recorded with a Microsoft Azure (Microsoft, U.S.A) RGB-D camera, while performing cyclic FB, LB, and AT. A CNN was trained using infrared, colourized, and surface normal depth images to segment the trunk and pelvis into three anatomical masks: upper spine, lower spine, and pelvis (Figure 1). Using the corresponding depth images, a first-degree linear polynomial surface was fit to each mask, obtaining three-dimensional pixel positions of the mask corners. Local coordinate systems were defined for each mask, enabling the measurement of total, lumbar, and pelvis kinematics. Participants were divided into train and test datasets with an 80:20 split. 10% of the training dataset was further isolated for model validation and hyperparameter tuning. The test dataset remained independent from training to evaluate model performance and generalizability. Root means square error (RMSE) and correlations were measured between ground truth and predicted test data kinematics.

Results and Discussion

A segmentation accuracy ≥0.94 was achieved on the test dataset. When comparing kinematics measured from predicted and ground truth segmentations, RMSE in the primary movement axis were ≤3.4° with correlations ≥0.98. The inclusion of multiplanar movements in the training dataset also resulted in improved correlations during FB in the LB and AT movement axes compared to previously published results (LB ≥0.81; AT ≥0.78) [4].

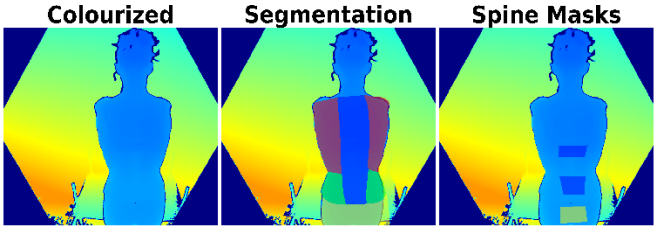

Figure 1: Predicted segmentations on a female participant.

Conclusions

The developed motion capture system can assess spine movement during FB, LB, and AT, demonstrating the feasibility of using this technology for clinical assessments. Data collection is ongoing to achieve a balanced male-to-female participant ratio, and to validate against a gold standard motion capture system for LB and AT.

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