Development and Validation of a Deep Learning Markerless System for the Osteoarthritis Population

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Summary

This study developed a four-camera markerless system using data from 150 osteoarthritis patients to improve lower-limb kinematics measurement accuracy. The system showed a mean root mean square error (RMSE) of 13.0 mm and intraclass correlation coefficient (ICC) of 0.94 for keypoint prediction, with joint angle RMSE of 3.59° and ICCs of 0.92, 0.54, and 0.40 in sagittal, frontal, and transverse planes. It outperforms commercial systems, offering a cost-effective tool for clinical biomechanical research.

Introduction

With the advancement of deep learning technology, markerless systems have emerged as a cost-effective and user-friendly alternative to marker-based systems. However, most existing markerless systems are developed using datasets from healthy individuals [1,2], which limits their generalizability to patient populations. Therefore, this study developed a four-camera markerless system using a dataset of patients with osteoarthritis and validated its measurement accuracy in lower-limb kinematics.

Methods

A total of 150 patients with hip or knee osteoarthritis were allocated to a training set (n=120) and a testing set (n=30). Kinematic data were synchronously collected at a frequency of 150 Hz as participants walked at a self-selected speed, using both a markerless system (comprising four Blackfly S USB3 cameras) and a marker-based system (comprising ten Vicon Vero 2.2 cameras). A markerless system incorporating four cameras was developed on the training set, including data preprocessing, a 2D pose estimator, and a 3D pose estimator (Figure 1). On the testing set, the differences between the markerless and marker-based systems in terms of keypoints and joint angles were evaluated using root mean square error (RMSE) and intraclass correlation coefficients (ICC).

Results and Discussion

The grand mean RMSE and ICC for the keypoints predicted by the markerless system were 13.0 mm and 0.94, respectively. Additionally, the mean RMSE for all joint angles was 3.59°. The ICC for the joint angle waveforms between the markerless and marker-based systems in the sagittal, frontal, and transverse planes were 0.92, 0.54, and 0.40, respectively.

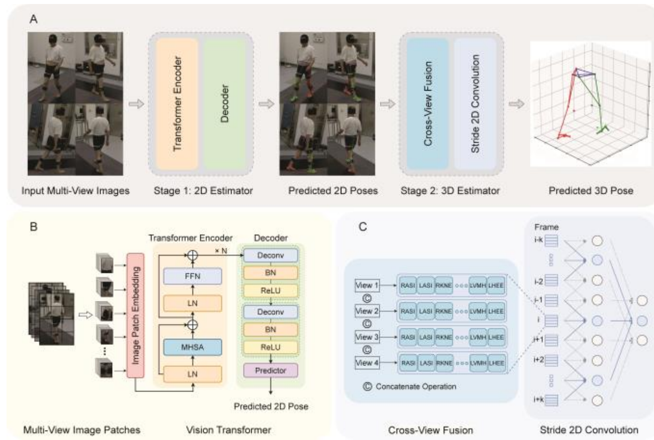

Figure 1: The workflow of the markerless system. B: The 2D Pose Estimator, LN: Layer Normalization; MHSA: Multi-Head Self-Attention; FFN: Feed-Forward Network; Deconv: Deconvolution; BN: Batch Normalization; ReLU: Rectified Linear Unit. C: The 3D Pose Estimator.

Conclusions

Our four-camera markerless system, developed using data from patient populations, shows high accuracy in lower-limb keypoints and joint angles prediction, outperforming current commercial markerless systems. This indicates that our markerless system is suitable for clinical populations and offers a cost-effective and convenient tool for disease-related biomechanical research.

References

[1] Lin TY et al. (2014). *European Conference on Computer Vision*, 740-755.
[2] Andriluka M et al. (2014). *2014 IEEE Conference on Computer Vision and Pattern Recognition*, 3686-3693.

Table 1: Joint angle error metrics, presented as mean (standard deviation).

	Hip			Knee			Ankle		
	Sagittal	Frontal	Transverse	Sagittal	Frontal	Transverse	Sagittal	Frontal	Transverse
RMSE (◦)	4.63 (1.77)	4.63 (2.21)	5.10 (1.72)	3.31 (1.14)	3.42 (1.07)	4.85 (1.30)	2.93 (0.91)	1.64 (0.42)	1.79 (0.42)
ΔRoM (◦)	-2.04 (1.73)	-1.24 (2.21)	0.99 (2.52)	2.61 (1.71)	2.18 (2.30)	3.63 (2.77)	1.28 (1.98)	0.49 (0.93)	0.80 (1.08)
ICC	0.90 (0.09)	0.66 (0.23)	0.29 (0.17)	0.97 (0.06)	0.31 (0.29)	0.29 (0.19)	0.90 (0.06)	0.61 (0.17)	0.63 (0.16)

RMSE: root mean square error; ΔRoM: range of motion difference; ICC: interclass correlation coefficient.