Fusing Multi-Azure Kinect Skeleton Data for Industrial Applications: a Comparison with OpenCap using Bland-Altman Analysis

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Summary

The MIROSCIC project leverages a MirrorWorld paradigm to improve safety and efficiency in smart factories by creating a virtual representation of human and non-human entities. Real-time data from wearable sensors and vision systems enable operator tracking for occupational medicine analysis. As part of the broader MirrorWorld concept, one focus of the project is human pose estimation, achieved by integrating data from RGB and RGBD cameras using a Bayesian approach.

Introduction

In occupational medicine, evaluating shoulder joint angles is essential for assessing ergonomic risks and preventing musculoskeletal disorders in the workplace since prolonged or repetitive arm elevation, especially above shoulder height, can lead to overuse injuries. In this work, we aim to develop a non-invasive and reliable method for body tracking to accurately assess shoulder joint angles, providing an accessible solution for ergonomic risk evaluation and injury prevention.

Methods

Tests were conducted in a workplace-simulated environment where participants carried objects or moved within a room. During the trials, cameras were deliberately occluded at random intervals to simulate real-world challenges. The setup included four Azure Kinect cameras, hardware-synchronized via AUX connections, and four iPhones running the OpenCap framework. Calibration of the Azure Kinect cameras was performed using an ArUco marker placed at the room's center. Sensor data fusion was implemented using Bayes' theorem, with temporal smoothing achieved by incorporating the previous fused position updated by a velocity term scaled by the time step as the prior distribution.

For each 3D point **z** a multivariate normal distribution has been assumed (1), and the covariance matrix associated to it has been evaluated as explained in [1].

$$P(\boldsymbol{z}|\boldsymbol{x}) = \frac{1}{(2\pi)^{\frac{3}{2}}|\Sigma|^{-\frac{1}{2}}} \exp\left(-\frac{1}{2}(\boldsymbol{z}-\boldsymbol{x})^T \Sigma^{-1}(\boldsymbol{z}-\boldsymbol{x})\right) \quad (1)$$

After evaluating the normalization factor, the final 3D position (2) and the corresponding covariance matrix (3) are evaluated:

$$z_{fused} = \Sigma_{fused}\left(z_1\Sigma_1^{-1} + z_n\Sigma_n^{-1} + z_{prior}\Sigma_{prior}^{-1}\right) \quad (2)$$

$$\Sigma_{fused} = \left(\Sigma_1^{-1} + \Sigma_n^{-1} + \Sigma_{prior}^{-1}\right)^{-1} \quad (3)$$

After the fusion of keypoints, their trajectories were applied to a modified Rajagopal musculoskeletal model [2] in OpenSim to compute inverse kinematics and derive joint angles. These results were compared to OpenCap-derived angles using the Bland-Altman method to evaluate trajectory agreement.

Results and Discussion

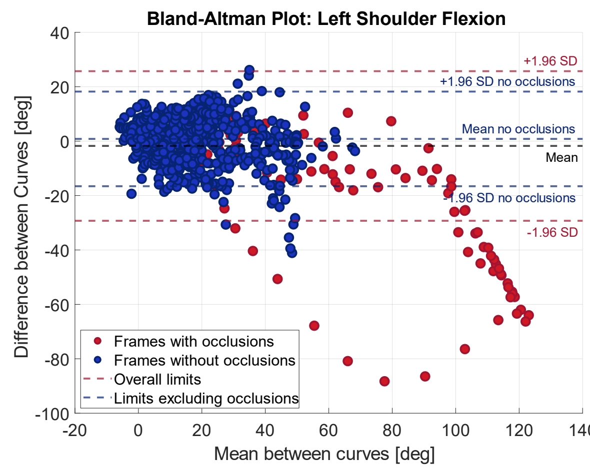

Figure 1: Bland-Altman comparison between Azure Kinect and OpenCap for the left shoulder flexion.

The Bland-Altman analysis frame by frame for the relevant shoulder angles in occupational medicine has been conducted. Figure 1 shows the left shoulder flexion, and the red points refer to the part of the video when occlusions occurred. It is visible how for most of the points the two measurement systems are compatible between them (blue points): the mean of the difference between the two curves stands near zero and the blue points remain inside the confidence region.

Conclusions

The present work managed to develop a marker-less vision system that is compatible with one of the already existing and validated one. This system may provide insights to the occupational medicine doctor while analysing video for ergonomics risk assessment. The advantage of this system is that it can be used in real-time providing instantaneous feedback to the workers through AR glasses, for example to advise them of risk movements.

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