Photographic Realignment of Inertial-sensors for Motion Evaluation (PRIME): Application for Elbow Kinematics

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Summary

Inertial measurement units (IMU) are widely used for motion capture due to their portability and ability to track movement in real-world settings. Establishing sensor-to-segment alignment (SSA) is vital to obtain repeatable joint kinematics. Standard SSA methods, such as manual alignment, static pose and functional calibration, introduce variability due to dependence on operator precision or subject performance of certain pre-defined motions. This study aimed to test a frugal, easily-applicable landmark-based photographic augmentation calibration method (PRIME) as a viable alternative to reported SSA methods for tracking elbow kinematics. PRIME outperformed traditional SSA methods during elbow flexion-extension and reach-and-grab activity for larger misalignments, thereby showing potential for reliable and robust realignment of kinematic data captured using IMUs.

Introduction

Inertial measurement units (IMU) are used to capture human motion outside laboratory settings. To interpret joint kinematics accurately, it is vital to align the coordinate frame of reference of the IMU with that of the body segment [1]. Of the several commonly used sensor-to-segment alignment (SSA) techniques [1], manual alignment lacks additional computational steps, but relies on operator expertise, while the rather convenient static pose assumes precise alignment of the segment with the gravitational vector. Functional calibration limits the cross-talk effect between axes of motion, but is difficult to implement due to the need for repetitive, predefined motions. Augmented calibration approaches involve determining the segment axes by identifying palpable anatomical landmarks using additional devices, such as an optoelectronic system [2]. To reduce uncertainties and simplify implementation of SSA, this study aimed to test an augmented calibration approach involving photographic realignment of inertial-sensors for motion evaluation (PRIME).

Methods

Following institute ethics approval, two IMUs (Blue Trident, Vicon, UK) were placed each on the upper arm and forearm of 10 healthy participants (age = 21±2 years, six male) by a single operator. One of the two IMUs on each segment was secured using the proprietary IMU band (IMU_B), whereas the other was placed first visually-aligned to the long axis of the segment (IMU_A), followed by a deliberate misalignment (IMU_M) by the operator. While the IMU_B were calibrated using manual alignment, both IMU_A and IMU_M were calibrated through the static pose SSA method. Subjects performed pure elbow flexion-extension (FE) and a reach-and-grab (RaG) motion in triplicate. Elbow kinematics from IMUs, calculated following ISB recommendation [3], were compared to those obtained from a video camera-based benchmark (VID; Kinovea), which tracked contrast markers placed on palpable anatomical landmarks of the upper arm and the forearm [3].

PRIME was implemented using a frontal plane photograph of the body segment in the supine position, with the IMUs and contrast markers on landmarks clearly visible. This photo was used to define the landmark-based coordinate reference frame of the body segment [3], along with the reference frame of the IMU, thereby registering the IMU with respect to the body segment. The transformation thus obtained was used to realign the visually aligned and misaligned IMUs, thereby correcting elbow kinematics obtained from these sensors (IMU_A' and IMU_M').

Mean absolute differences between kinematics obtained from various IMUs and the benchmark VID throughout the range of motion were calculated as a percentage of the range of elbow motion during FE and RaG motions. The Friedman test was used to compare differences across IMUs, with post-hoc pairwise comparisons for significant results performed using the Wilcoxon signed-rank test ($p < 0.05$).

Results and Discussion

For both FE and RaG motions, differences in elbow kinematics obtained from misaligned IMUs with respect to VID were reduced after applying PRIME (IMU_M' vs. IMU_M); however, differences in visually-aligned IMUs were similar before and after applying PRIME (IMU_A and IMU_A') (Figure 1). PRIME effectively corrected IMU misalignments, with no statistically significant differences between IMU_A' and IMU_M', confirming its robustness. PRIME also showed a statistically significant improvement over the IMU_B, indicating its edge over manual alignment.

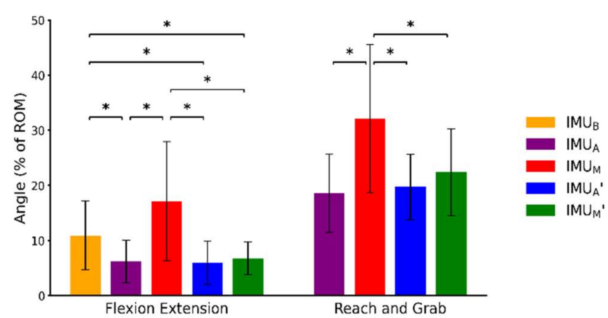

Figure 1: Absolute differences in elbow flexion-extension with respect to VID across subjects (significance: p<0.05)

These results demonstrated the reliability and ease of use of PRIME for elbow motions with a single degree of freedom; further assessment will be directed towards its applicability for joint motions with multiple degrees of freedom.

Conclusions

Improved elbow kinematics displayed the ability of PRIME to outperform traditional calibration methods for larger misalignments, indicating its potential for reliable and cost-effective correction of IMU sensor alignment.

References

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