A Novel Inertial Measurement Units-based Method for Shoulder Kinematics Assessment

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Summary

Traditional clinical methods for assessing shoulder range of motion are sometimes unreliable and limited. This study presents a standardized inertial measurement unit (IMU)-based method for accurate shoulder kinematics assessment. Using a landmark registration technique to align sensors with the underlying bones, the proposed method reduces orientation errors compared to automatic alignment. It provides precise segment orientations and joint angles compared to 3D markers, offering a meaningful and accurate framework for upper limb kinematic analysis in both research and clinical settings.

Introduction

Traditional clinical methods for assessing active range of motion, such as the universal goniometer or visual estimation, lack reliability and are limited to measuring the thoracohumeral shoulder angle. IMUs offer a promising alternative, providing objective, real-time feedback on shoulder joint kinematics. However, extracting accurate, anatomically relevant angles from sensors placed on the skin remains challenging. The main issues are related to the alignment of the sensors with the underlying bone and the ability to account for skin movement artefacts [1]. This study proposes a new IMU-based protocol to obtain clinically meaningful shoulder angles. Specifically, this study aims to evaluate and compare the accuracy of two methods for aligning sensor orientations with actual bone orientations. The first proposed method uses bony landmarks combined with a scapular interpolation technique to account soft tissue artifacts, while the second employs an automatic sensor-to-segment alignment approach.

Methods

Twenty participants with normal shoulder function (age (mean (SD)) 29 (6.2) years, height 1.69 (0.09) m, weight 67 (13.8) kg, 17 males, 3 females) performed three repetitions of clinical range of motion (e.g., humerothoracic abduction and flexion, shoulder girdle elevation and depression and functional movements (e.g., jogging, lifting a box). Shoulder kinematics were simultaneously recorded using 3D motion capture (Vicon) and IMUs to track the thorax, scapula, and humerus following ISB recommendation for the definitions of joint coordinate systems. IMU orientation was estimated using two alignment methods: 1) automatic alignment of the IMU axes to anatomical landmarks with static posture calibration, and 2) landmark registration using a caliper and scapula locator to estimate orientation between palpable anatomical landmarks for the shoulder segments.

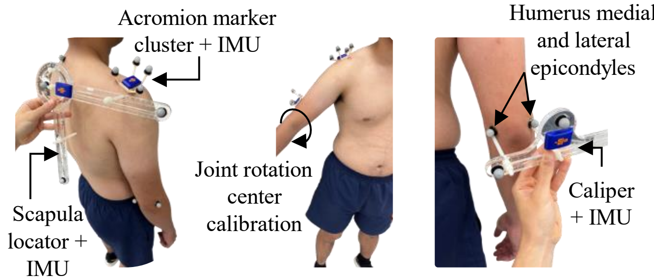

Figure 1: Segment-to-sensor alignment process using a scapula locator and caliper to register axes between anatomical landmarks and a joint rotation center calibration.

A gradient descent-based algorithm estimated IMU orientations [2] and the error quaternion between 3D motion capture and IMU data was computed as $q\_error = q\_3dMoCap * conj(q\_IMUs)$. The root mean square error was averaged over time for each ZYX Cardan sequence across all movement and rotation axes.

Results and Discussion

The segments orientation and joint angle root mean square errors between the reference system and the IMUs were calculated for both alignment methods. For segment orientation, the automatic alignment method showed errors of 12.1° (11.4°) for the thorax, 23.9° (20.9°) for the scapula, and 11.8° (10.1°) for the humerus, while the proposed method showed improved accuracy with errors of 4.4° (5.0°), 3.1° (4.6°), and 5.3° (7.1°), respectively. For joint angles, the automatic alignment method resulted in errors of 3.8° (12.9°) for the scapulothoracic joint, 18.5° (34.5°) for the humerothoracic joint, and 12.8° (26.2°) for the glenohumeral joint. The proposed method demonstrated reduced errors of 3.1° (12.8°), 8.6° (14.3°), and 5.7° (12.0°), respectively.

Conclusions

These findings study demonstrates the superior accuracy of a novel IMU-based protocol for assessing shoulder kinematics compared to an automatic alignment method, in both clinical and functional tasks. By integrating bony landmark registration and scapular interpolation, the proposed method reduces orientation and joint angle errors. This approach addresses the limitations of traditional clinical tools and offers an anatomically meaningful approach for shoulder kinematic analysis in clinical and research settings.

References

[1] Z. Fang et al. (2023). *Sensors*, **23**.
[2] R. Riddick et al. (2023). *J. Biomech.*, **157**, 111726.
[3] R. W. Simovitch et al. (2024). *JSES*, **33**, 492-506.