A Tightly Coupled IMU-based Motion Capture Approach To Estimate Upper Extremity Kinematics and Dynamics

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Summary

Upper extremity motion capture is a critical tool for diagnosing and treating patients with mobility disorders. We present a generic approach that integrates sensor measurements with musculoskeletal models, incorporating multibody system kinematics and dynamics to enhance estimation accuracy. The proposed framework is adaptable for fusing various sensor types; however, this study specifically demonstrates its capability to estimate model kinematics and dynamics using only Inertial Measurement Units (IMUs). The algorithm estimates key motion metrics such as joint angles, velocities, torques and power which provide quantitative insights about human movement quality and performance.

Introduction

The growing number of individuals with mobility disorders in Europe increases the need to measure human movement consistently for effective treatment. Optical marker-based motion capture systems provide accurate data but are limited to lab environments [1]. IMUs are portable, and their measurements can be used to compute orientations, which are usually used to determine joint angles using inverse kinematics. These orientations can either rely on magnetometers, making them vulnerable to magnetic disturbances, or be independent of magnetometers, in which case they are subjected to drift error accumulation. Particularly, if they do not account for musculoskeletal system dynamics. As a result, these inaccuracies propagate to the inverse dynamics calculations [2][3].

Methods

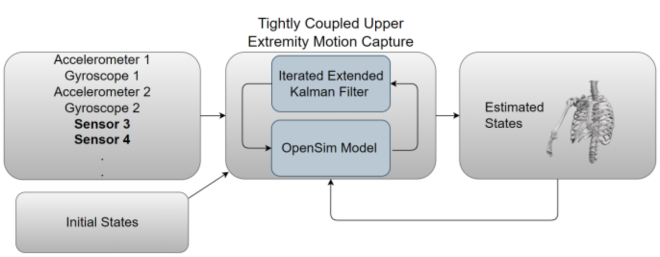

Figure 1: Motion capture algorithm using initial states and IMU measurements to estimate angles, velocities, and forces, extendable to include different sensors represented as sensors 3 and 4.

Our approach integrates IMU sensor measurements with musculoskeletal models in a unified framework, unlike traditional methods that estimate kinematics and dynamics separately. This approach does not rely on magnetometer readings and provides clinicians with generalized angles, velocities, torques and power for more effective assessment and treatment. The approach couples between the sensors measurements and the musculoskeletal dynamics using an Iterative Extended Kalman filter (Figure 1).

Results and Discussion

To verify our approach, we tested several upper extremity movements. Figure 2 presents an IMU-based capture of a grab and drink motion, demonstrating our method's ability to provide quantitative movement analysis. Joint angles, angular velocities and torques offer insights into range of motion, smoothness, and speed. Power analysis may enhance clinical interpretation by quantifying workload and differentiating between active and passive movements. These metrics aid in assessing volitional movements, strength, and compensatory strategies, making them valuable for rehabilitation and performance monitoring.

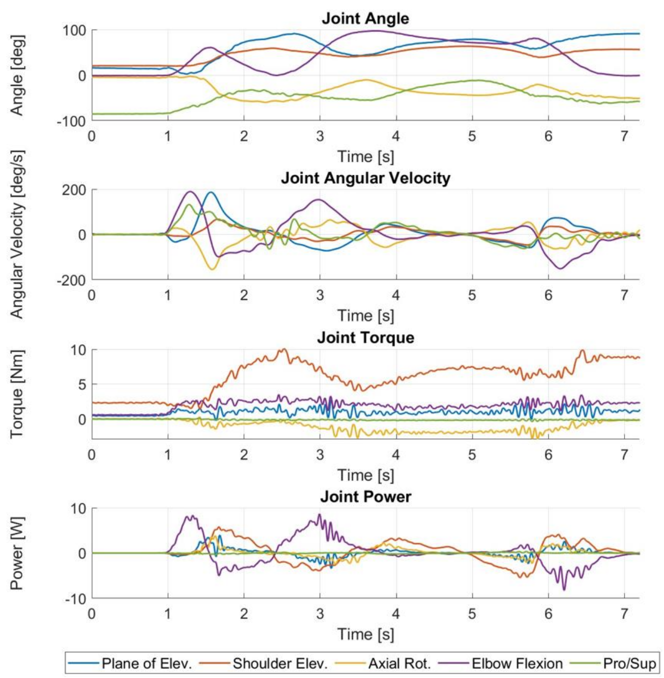

Figure 2: Kinematic and dynamic analysis of a grab and drink movement

Conclusions

We demonstrate a tightly coupled IMU-based motion capture framework for upper extremity analysis to simultaneously estimate kinematics and dynamics (torque and power). These portable measurements can provide insights into volitional control, strength, and compensatory strategies, supporting clinical assessments of workload, movement characteristics, rehabilitation, and performance monitoring.

References

[1] Bach JP et al. (2011). Mov Disord, 26: 2286-2290.
[2] Ahmed K et al. (2024). J NeuroEng Rehabil, 21: 128.
[3] Lee JK, Jeon TH. (2019). Sensors (MDPI), 19: 5522.