IMU-Based Real-Time Hip Motion Tracking System

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CLINICAL CHALLENGE

Traditional clinical hip assessment relies on visual observation and basic goniometry, missing critical biomechanical details essential for conditions like femoroacetabular impingement. While gold standard optical systems provide high accuracy, they require expensive laboratory facilities and restrict assessment to artificial environments [1,2].

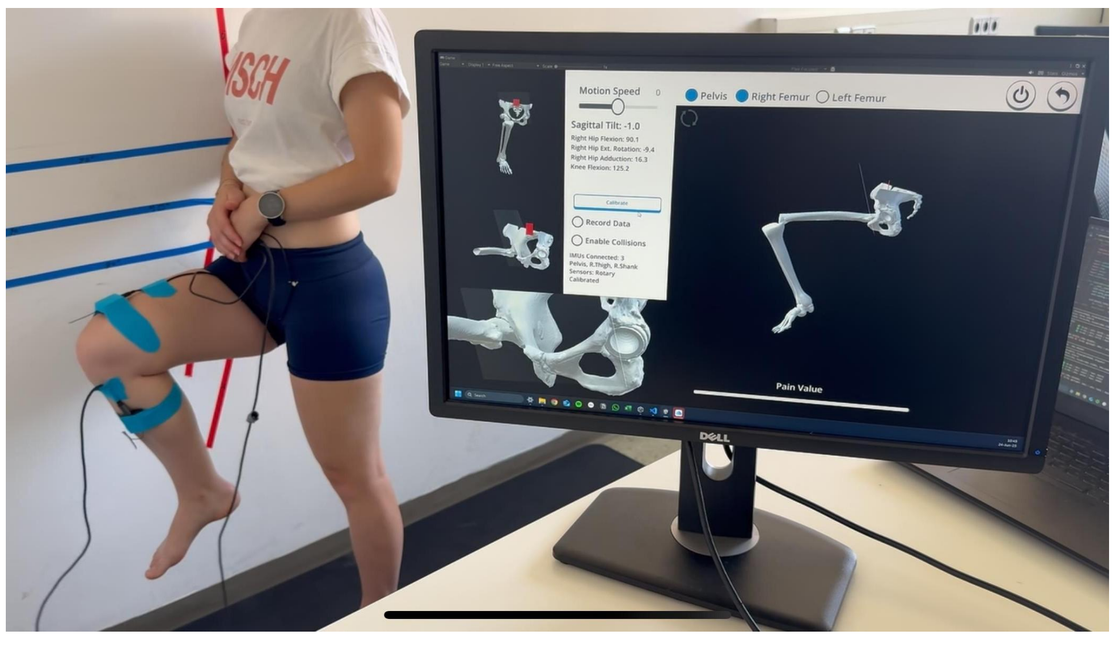

Fig. 1: System Overview

INTEGRATED SYSTEM SOLUTION

The developed system integrates four BNO086 9-DOF IMU sensors with ESP32 wireless modules, force-sensitive pain reporting device, and Unity-based AR visualization platform. The system employs custom 3D-printed sensor housings with anatomically-optimized placement, Python bridge server architecture for cross-platform deployment, and real-time quaternion processing for precise joint angle calculation. De-identified CT-based 3D skeletal models enable intuitive visualization while synchronized pain feedback captures movement-symptom relationships during dynamic activities.

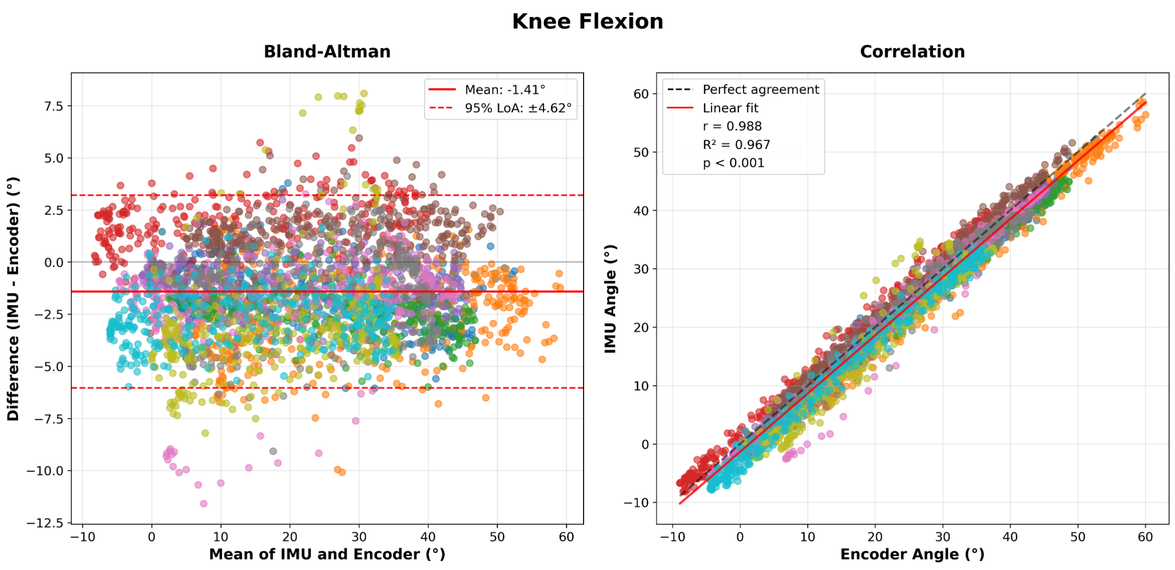

Fig. 2: Knee Flexion Bland-Altmann and Correlation of all Participants

VALIDATION & PERFORMANCE

System accuracy was validated against precision rotary encoder reference measurements through standardized protocols involving 10 healthy participants performing 690 movement sequences across six movement types. The system maintained stable 50Hz IMU data acquisition with 100% sensor connectivity throughout 105-minute average sessions. Custom 3D-printed validation assemblies provided continuous angular reference measurements, enabling comprehensive Bland-Altman analysis and correlation assessment against established clinical standards [3].

Table 1: System Validation/Performance Results

Movement	RMSE (°)	MAE (°)	Bias (°)	95% LoA (°)	r	R^2
Hip Ab/Adduction	2.81	2.14	-1.04	±5.11	0.944	0.867
Hip External Rotation	6.50	5.24	-4.92	±8.35	0.838	0.165
Hip Flexion Validation	12.26	9.88	5.11	±21.86	0.963	0.906
Hip Internal Rotation	5.20	4.28	1.15	±9.94	0.949	0.761
Knee Flexion	2.75	2.24	-1.41	±4.62	0.988	0.967
Pain Assessment	8.51	6.97	-2.78	±15.76	0.979	0.943
Sagittal Tilt	4.52	3.29	0.67	±8.77	0.936	0.873

RESULTS

Validation demonstrated excellent accuracy for knee flexion (RMSE: 2.75°, r = 0.988) and hip abduction (RMSE: 2.81°, r = 0.944) with more challenging hip rotations (Table 1). The pain assessment system detected all expected events with precise synchronization. Proof-of-concept polynomial correction algorithms demonstrated on one individual participant achieve substantial RMSE improvements for systematic measurement challenges (Figure 3). This system achieves large cost reduction compared to traditional optical motion capture ($450), democratizing precision motion analysis for hip impingement assessment and real-time movement quality evaluation [1,2,4].

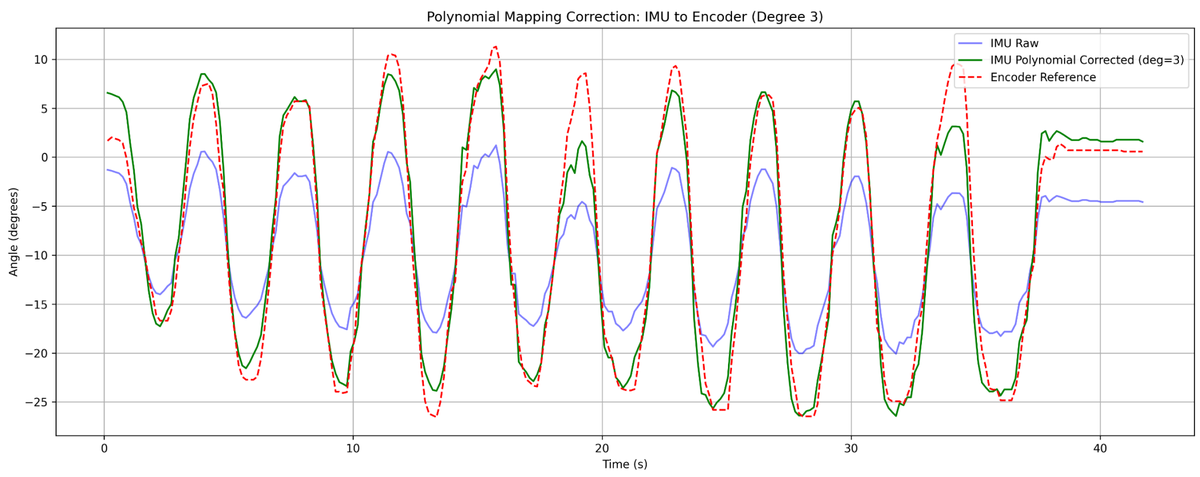

Fig. 3: Hip internal rotation tracking comparison. Blue: raw IMU data, red dashed: encoder reference, green: polynomial-corrected IMU data.

COOPERATION PARTNER

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References:
[1] Wang et al. (2025). Validity of an inertial measurement system to measure lower-limb kinematics in patients with hip and knee pathology. Journal of Biomechanics.
[2] Ghattas et al. (2021). Validity and reliability of wearable inertial measurement units for clinical assessment... [systematic review]
[3] Eslam Pour, A. (2024). De-identified CT scan datasets for research purposes. Yale University School of Medicine. [Personal communication/collaboration]
[4] McGrath & Stirling (2022). Body-Worn IMU-Based Human Hip and Knee Kinematics Estimation during Treadmill Walking. Sensors.