DEVELOPMENT AND VALIDATION OF A SIMPLIFIED SYSTEM FOR UPPER LIMB MOTION ANALYSIS AND REHABILITATION BIOFEEDBACK

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Introduction

In recent years, there has been a noticeable increase in the use of various information technologies in rehabilitation. Gamification of physical rehabilitation by engaging in purposeful and functional movements, strengthening muscles, and improving flexibility [1]. Disorders affecting an individual's motor functions due to various pathologies negatively impact their quality of life. Motion therapy can significantly enhance both the precise and general movements of the upper limb, and during the therapeutic process, providing feedback on performance characteristics through external reversible responses can boost rehabilitation effectiveness [2-4]. Additionally, providing feedback about performance characteristics during therapy improves rehabilitation outcomes [5-6]. To address the need for accessible, accurate, and efficient motion analysis tools for clinical settings, this study aimed to develop a simplified system for evaluating upper extremity joint range of motion (ROM) during rehabilitation exercises. The goal was to design a user-friendly, real-time bio-feedback system to guide patients during exercises, track progress, and provide quantitative data for clinicians.

Methods

This study employed three motion capture systems for data collection: an optical motion capture system (BTS), two web cameras equipped with pose estimation and range of motion (ROM) calculation algorithms [7], and a depth-sensing Intel RealSense D435 camera. Movements involved upper extremity rehabilitation exercises focused on shoulder flexion, extension, abduction, adduction, internal and external rotation, elbow flexion, and pronation/supination. The motion capture data was processed using inverse kinematics in musculoskeletal BoB [8] to obtain precise joint ROM values, which served as the reference for system validation. Integrating the Intel RealSense D435 depth camera with AI-based pose estimation, image processing algorithms (OpenCV), and the pyrealsense2 library for capturing spatial data enabled real-time biofeedback. The processed data visualized patients' joint movements in 3D, providing real-time guidance during rehabilitation exercises.

Results

Figure 1 presents the shoulder flexion ROM estimation results from a depth camera, two web cameras, and a motion capture system. The Root Mean Square Errors (RMSE) for shoulder joint angles were as follows: alpha RMSE = 0.3897° with extraction RMSE = 0.0632°, beta RMSE = 0.3005° with extraction RMSE = 0.2437°, and gamma RMSE = 0.2081° with extraction RMSE = 0.1412°.

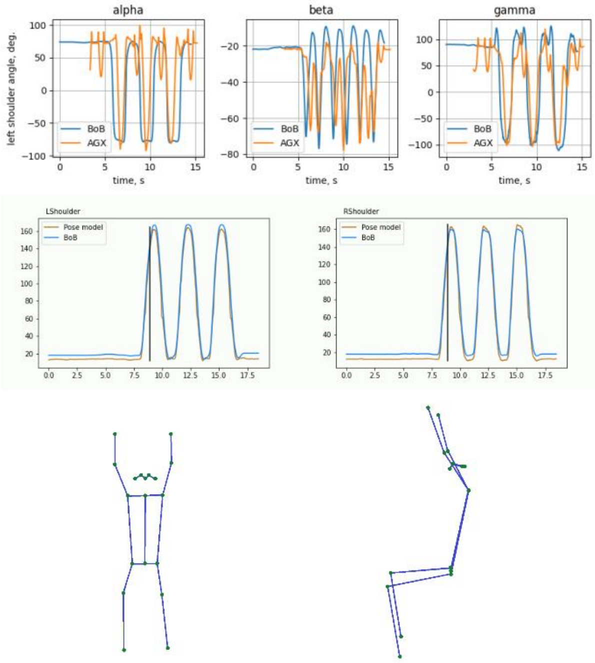

Figure 1: Shoulder flexion angle comparison – motion capture (BoB) vs AI-based posed estimation (AGX). Alpha, beta, and gamma represent the X, Y, and Z Euler angles, Pose model – web camera-based pose estimation.

Discussion

This simplified system demonstrated its potential for delivering accessible, user-friendly rehabilitation tools in clinical and remote settings. Future research will enhance the system's adaptability to different rehabilitation scenarios and patient-specific needs.

References

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