Enhancing Pulmonary Rehabilitation Exercises Analysis with Acoustics and Pose Estimation

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I. Introduction

Pulmonary diseases, including Chronic Obstructive Pulmonary Disease (COPD) and Asthma, rank as the third leading cause of mortality globally [1]. Pulmonary rehabilitation (PR), emphasized by the Global Initiative for Chronic Obstructive Lung Disease (GOLD), significantly enhances breathing capabilities and quality of life for patients [1]. However, there is a notable gap in the feedback mechanism for pulmonary rehabilitation exercises performed at home, limiting clinicians' ability to monitor and adjust patient exercises effectively. This gap, combined with the escalating healthcare costs, which have reached approximately $3 trillion annually in countries like the United States, underscores the urgent need for innovative solutions like remote rehabilitation.

Our method leveraging acoustics (Figure 1) achieved a mean absolute error (MAE) of 1.7 cm across 22 subjects, outperforming previous reported studies such as GoPose (4.7 cm, 10 subjects, WiFi) [2], BodyTrak (6.9 cm, 12 subjects, RGB) [3], and Shibata et al. (2.8 cm, 8 subjects, Audio) [4]. This demonstrates our method's higher accuracy, scalability, and cost-effectiveness in pose estimation and exercise analysis.

II. EchoMotion System

To address the aforementioned challenges, we introduced EchoMotion (Figure 2), an innovative, non-invasive, acoustic-based smart speaker system designed for analyzing cardio rehabilitation exercises. EchoMotion utilizes deep learning to transform acoustic signals into precise human pose estimations, offering a novel method for analyzing exercise performance in remote rehabilitation sessions. This system significantly advances the integration of technology within healthcare, particularly in analyzing critical aspects of pulmonary rehabilitation exercises, such as form, repetitions, sets, and duration, in a privacy-preserving manner.

A. System Development and Data Collection EchoMotion was developed to analyze reflections of active acoustic signals from the human body in motion, converting these signals into a detailed human pose estimation skeleton. We collected a comprehensive acoustic dataset from 22 individuals performing five cardiovascular exercises. This dataset, comprising around 11 hours, 880,000 frames, and 67,800 repetitions of exercises, was synchronized with ground truth data from the Azure Kinect DK sensor. The exercises were conducted in two environments (home and lab) under various conditions to test the system's robustness.

B. Performance and Impact EchoMotion demonstrated a low average Mean Absolute Error (MAE) of 1.7 cm, significantly outperforming the state-of-the-art performance in human pose estimation, which ranges from 2.8 cm to 6.9 cm MAE. Additionally, our system showed remarkable adaptability to various environments and conditions, maintaining high accuracy across different distances, noise levels, and participant factors. The ability to accurately analyze the duration, sets, and repetitions of exercises enables effective management of exercise intensity and form, which is crucial for preventing injuries during rehabilitation.

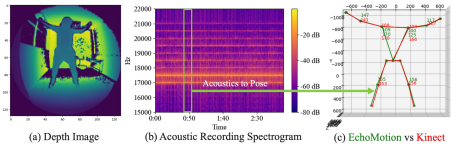

Fig. 1: EchoMotion: One frame of Jumping Jacks exercise

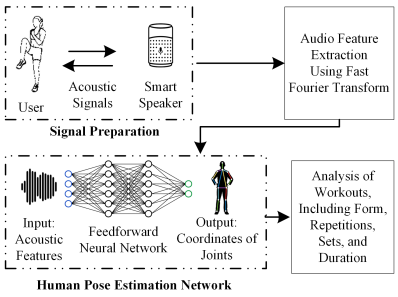

Fig. 2: Flowchart representing the audio signal analysis and processing pipeline for our method

III. Conclusion

EchoMotion introduces a groundbreaking approach to home-based pulmonary rehabilitation by leveraging acoustic signals for non-invasive human pose estimation. Its superior performance, coupled with its ability to analyze exercise forms and repetitions accurately, makes it a potent tool for enhancing the efficacy of pulmonary rehabilitation programs. EchoMotion represents a significant leap forward in integrating technology with healthcare, offering a cost-effective, accessible, and privacy-preserving solution for patients and clinicians alike.

References

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