
Developing an mHealth System for Rehabilitation Using Wearable Sensors and Machine Learning

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Abstract

Physical therapy rehabilitation is crucial for patients recovering from various musculoskeletal conditions, yet adherence to prescribed exercises remains a significant challenge. Non-compliance rates can range from 15% to 87% in back pain rehabilitation [1], and for osteoarthritis therapy, patients often struggle to integrate exercises into their daily routines [2]. Despite the widespread availability of smartwatches—with over 224 million users worldwide as of 2024 [3]—current mobile health (mHealth) interventions lack real-time targeted feedback on patients' movement quality, essential for effective rehabilitation. This project proposes a scalable solution leveraging inertial measurement units (IMUs) and machine learning (ML) techniques to provide meaningful metrics on a person's movement performance throughout the day. By developing an activity recognition model, we aim to offer continuous asynchronous feedback to patients and valuable insights to therapists. This system could enhance patient adherence, improve rehabilitation outcomes, and extend access to quality physical therapy, particularly in underserved areas.

Keywords: *Physical Therapy Rehabilitation, Machine Learning, IMU Sensors, Movement Quality Metrics, mHealth Solutions*

1. Introduction

Physical therapy rehabilitation is essential for patients recovering from injuries or managing chronic conditions. However, adherence to rehabilitation exercises is often low, with non-compliance rates ranging from 15% to 87% in back pain patients [1]. In osteoarthritis therapy, patients frequently struggle to incorporate exercises into their daily routines [2]. Despite the potential for recovery through consistent exercise, many patients receive insufficient guidance and support, leading to ineffective rehabilitation.

Mobile health (mHealth) technologies offer a promising avenue to address these challenges. The prevalence of smartwatches—224.31 million users worldwide as of 2024 [3]—provides an opportunity to leverage wearable devices for rehabilitation support. However, current mHealth solutions lack real-time, targeted feedback on movement quality, which is critical for effective physical therapy. Without actionable insights, patients may perform exercises incorrectly, risking injury or diminished progress.

Our project aims to develop a novel system that utilizes inertial measurement units (IMUs) and machine learning (ML) to monitor and assess movement quality during daily activities. By providing continuous feedback and personalized recommendations, we seek to enhance patient adherence, improve rehabilitation outcomes, and offer therapists valuable data to tailor interventions. Our key unique contribution is that this intervention only needs a watch and no camera compared to other products of the similar nature to monitor physical activity usage. The other consideration is that this will be a low cost solution to reach many people and that since our messages from the chatbot will be personalized, the nudges will lead to improved activity functions. We will also discuss the relevant ethical considerations that may affect this product's efficacy.

2. Methods

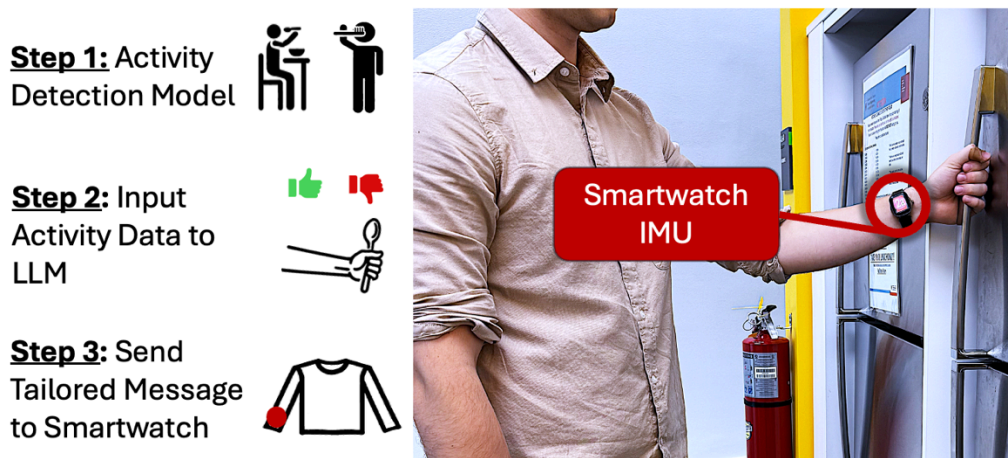


Figure 1 demonstrating the steps in our high level pipeline.

2.1 System Architecture

The proposed mHealth system comprises one IMU sensors one on the wrist (via a smartwatch). This sensors captures kinematic data during the patient's daily activities. Shown in FFigure 1, the system architecture includes three main components:

- **Activity Recognition Model**
- **Movement Quality Assessment**
- **Personalized Feedback Mechanism**

2.2 Activity Recognition

We will eventually use multivariate time-series transformers to process IMU signals and classify activities of daily living (ADLs), such as reaching, lifting, or bending. By estimating kinematic features like joint angles and velocities, the model contextualizes movements throughout the day. The current implementation due to restrictions in assets and data is an average of step count throughout the day.

2.3 Movement Quality Metrics

To determine if the number of steps have improved overtime, we perform a linear regression on the past seven days. If the actual steps improve more than the predicted value from the linear regression, then the model knows it has improved.

2.4 Personalized Feedback from the Data

We integrate algorithms to optimize the timing and content of feedback messages delivered to the patient via the smartwatch. The watch agent adapts to the patient's behavior, delivering personalized suggestions to improve adherence and movement quality. The architecture is demonstrated in the flowchart below Figure 2:

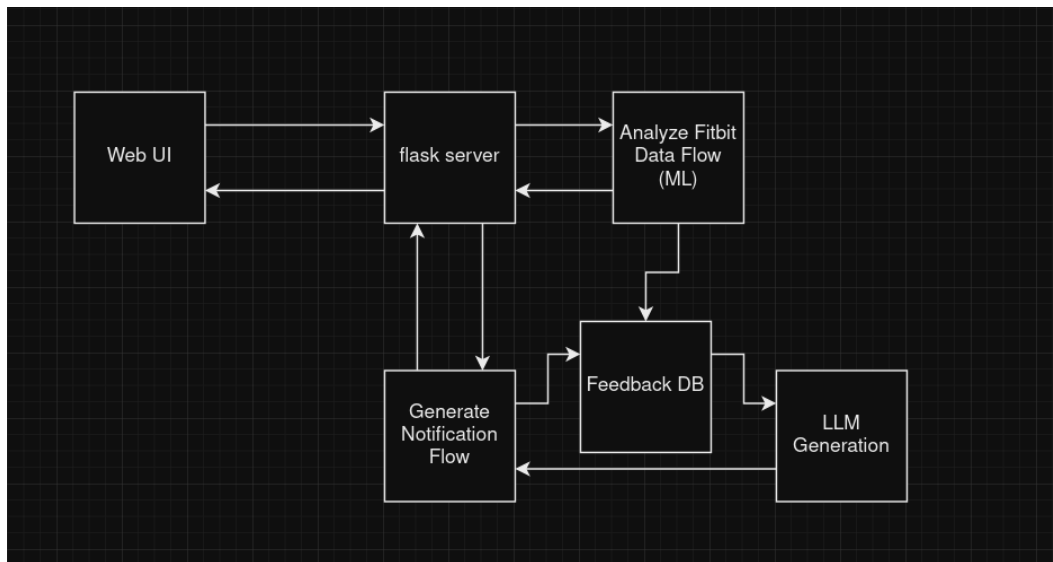


Figure 2 Demonstrating the flowchart for the implementation of the AI chatbot architectures.

2.5 Development Tools

- **Programming Languages:** Python for backend development.
- **Frameworks:** TensorFlow and PyTorch for ML models.
- **Wearable Integration:** Fitbit Wear OS for smartwatch application.
- **Data Processing:** Signal processing libraries for feature extraction.

3. Results



Figure 3 Shows the input website where CSVs of movements are inputted and an output is the example motivational speech

We developed a web-based platform to simulate the daily inputs of CSV data to the model shown in Figure 3. Patients' step data collected throughout the day are uploaded to the website, where the model processes the data and returns personalized feedback prompts.

3.1 Web Platform Development

The website serves as an interface for patients to interact with the system. Key features include:

- **Data Upload:** Patients can upload their daily IMU data in CSV format.
- **Real-Time Processing:** The backend model processes the data upon upload.
- **Feedback Delivery:** Personalized feedback is displayed to the patient, highlighting areas of improvement and reinforcing positive behaviors.

3.2 User Experience

The platform is designed to be user-friendly, ensuring ease of use for patients with varying levels of technical proficiency. The interface guides users through the data upload process and presents feedback in an accessible manner.

3.3 Physical Therapist Access

Physical Therapists can access the platform to review patients' movement data and feedback history. This allows for remote monitoring and adjustments to therapy plans based on the patients' performance.

This is a temporary demonstration and will be implemented on a smartwatch in the future.

4. Ethical Considerations

Data Concerns and Complying with HIPAA

- **Data Privacy:** Ensuring patient data confidentiality is paramount. Our system complies with HIPAA regulations by implementing secure data encryption and access controls.
- **Local Solution:** Data processing occurs locally on the patient's device whenever possible to minimize the transmission of sensitive information.

Accessible Product

- **User-Friendly Design:** The platform is designed to be accessible to users with varying technical abilities, promoting widespread adoption.
- **Cost-Effective:** Utilizing common devices like smartwatches makes the solution affordable and scalable.

AI Safety Concerns

- **Low-Function Tool:** The AI functions as an assistive tool, providing guidance without making critical medical decisions, thereby reducing the risk of unintended harm.
- **Transparency:** The system provides clear explanations for feedback to ensure users understand the suggestions and can act accordingly.

Developer Obligations

5. **Post-Deployment Performance Monitoring:** Ongoing monitoring of the system's performance is essential. We are committed to updating models and addressing any issues that arise to maintain efficacy and safety.
6. **Ethical Responsibility:** Developers have an obligation to ensure that the system operates ethically, safely, and in compliance with all relevant regulations.

7. Discussion and Conclusion

The integration of IMU sensors and ML algorithms presents a promising solution to enhance physical therapy rehabilitation. Our system addresses the critical challenge of patient adherence by providing real-time, personalized feedback, thus encouraging patients to perform exercises correctly and consistently.

The use of widely available smartwatches leverages the existing prevalence of wearable technology [4], facilitating scalability and accessibility. By focusing on movement quality, the system not only promotes adherence but also ensures that exercises are performed effectively, maximizing rehabilitation outcomes.

Challenges encountered include ensuring data privacy and managing varying levels of patient engagement. Future work will involve larger-scale studies to validate efficacy, exploring integration with additional wearable devices, and expanding to other rehabilitation areas.

Our project contributes to the mHealth field by offering a scalable, innovative solution that has the potential to transform physical therapy rehabilitation, improve patient outcomes, and reduce healthcare costs.

8. References

- [1] <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0276326>
- [2] <https://jech.bmj.com/content/55/2/132>
- [3] <https://www.demandsage.com/smartwatch-statistics/>