

WEARABLE ELBOW REHABILITATION DEVICE WITH REAL – TIME FEEDBACK

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ABSTRACT

In this paper, a wearable elbow rehabilitation monitoring system is proposed for real-time tracking and analysis of physiotherapy exercises. The system uses two MPU6050 sensors placed on the upper arm and forearm to capture joint motion and orientation data. An ESP32 is used for efficient data acquisition and processing, followed by wireless transmission to a user interface developed using PyQt5 in the Python environment. The elbow joint angle is calculated based on the relative orientation between the sensors, allowing accurate movement analysis. The system detects exercises such as flexion-extension and pronation-supination, and performs repetition counting using predefined threshold values to ensure correct execution. The developed interface provides real-time monitoring, graphical visualization, and automatic report generation. Experimental results show that the system is able to measure joint angles accurately, identify exercise patterns, and count repetitions reliably. The proposed system is low-cost, portable, and suitable for practical rehabilitation applications.

Keywords: Rehabilitation System, Wearable Device, ESP32, MPU6050, Inertial Measurement Unit (IMU), Physiotherapy Monitoring, Joint Angle Measurement, PyQt5, Real-Time Monitoring.

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I. INTRODUCTION

Rehabilitation plays a significant role in helping patients regain normal physical function after injuries, surgeries, or neurological conditions [1]. It focuses on improving muscle strength, coordination, and mobility. The elbow joint is particularly important for performing daily activities such as lifting, holding, and moving objects. Common rehabilitation exercises include flexion-extension and pronation-supination movements, which help restore joint functionality [2]. To ensure effective recovery, these exercises must be performed correctly and consistently under proper guidance.

However, traditional physiotherapy methods often require continuous clinical supervision, which can be time-

consuming, expensive, and sometimes inconvenient for patients [3]. In many cases, patients may not perform exercises correctly at home due to the lack of real-time feedback and monitoring. This can lead to improper recovery or delay the rehabilitation process. Therefore, there is a growing need for intelligent systems that can assist patients in performing exercises accurately outside clinical environments.

In recent years, wearable sensor-based rehabilitation systems have gained attention due to advancements in embedded systems and low-cost sensors [4]. Inertial Measurement Units (IMUs), such as the MPU6050, are widely used for motion tracking as they provide both acceleration and angular velocity data [5]. These sensors enable continuous monitoring of limb movement and joint

orientation, making them suitable for rehabilitation applications.

This paper proposes a smart wearable elbow rehabilitation monitoring system that integrates IMU sensors with an ESP32 for real-time data acquisition and processing. The system captures motion data from the upper arm and forearm, calculates joint angles, identifies exercise patterns, and provides feedback through a user interface developed using PyQt5. The proposed system aims to provide a low-cost, portable, and efficient solution for home-based physiotherapy.

This suggested system is designed with the intention of providing an affordable, mobile, and easy-to-use system for rehabilitation monitoring. By ensuring that exercise execution is monitored and tracked in real-time, the system enables users to execute their exercises correctly and consistently. The system also allows for session analysis and reporting, which may help doctors track their patients' progress.

II. LITERATURE SURVEY

Recent improvements in wearable technology have had a big impact on how rehabilitation monitoring systems are made. People have used Inertial Measurement Units (IMUs) like the MPU6050 a lot to keep track of how they move because they are small, cheap, and can give both acceleration and angular velocity data. These sensors are frequently utilized in physiotherapy to assess joint angles and evaluate movement patterns [3].

Madgwick proposed an efficient orientation estimation algorithm for inertial sensors by combining accelerometer and gyroscope data to improve motion tracking accuracy [4]. This algorithm is commonly used in IMU-based systems because of its computational efficiency and reliable performance.

R. Kumar, S. Prakash, and A. Verma introduced an elbow rehabilitation monitoring system using flex sensors to measure joint bending angles [7]. Their system provided feedback through visual indicators and demonstrated a simple and economical solution for continuous monitoring.

Chen and Zhang developed an IMU-based motion tracking system for physiotherapy monitoring, achieving accurate joint angle estimation under real-time conditions [3]. Their work highlighted the capability of inertial sensors in capturing human movement effectively.

Singh and Sharma presented a wearable physiotherapy monitoring framework for exercise tracking and remote supervision [8]. Their system showed effective rehabilitation monitoring performance but required additional communication infrastructure, increasing the complexity of the design.

Ahmed and Khan proposed an IoT-based rehabilitation monitoring system that enabled remote access to patient exercise data [6]. Although the system supported real-time monitoring, it depended heavily on network connectivity and cloud resources.

Arjun, Mohan, and Suresh described a machine learning-based rehabilitation system that analyzed patient movement patterns and provided personalized feedback [9]. Their approach improved monitoring accuracy but required higher computational resources.

Although these systems improved rehabilitation monitoring, several limitations remain, including higher system complexity, lack of portability, and dependence on network infrastructure. To address these issues, the proposed system integrates MPU6050 sensors with an ESP32 to provide a low-cost, portable, and real-time rehabilitation monitoring solution with accurate joint angle estimation and interactive feedback.

III. PROPOSED SYSTEM

The proposed system is a smart wearable elbow rehabilitation monitoring solution designed to assist patients in performing physiotherapy exercises accurately in real time. The system integrates inertial sensors, an embedded processing unit, and a graphical user interface to provide continuous monitoring and feedback.

The system utilizes two MPU6050 sensors to capture motion data from the user's arm[5]. One sensor is positioned on the upper arm, while the other is placed on the forearm. These sensors measure acceleration and angular velocity, enabling the system to track joint movement and orientation effectively.

An ESP32 microcontroller is used to collect and process data in real time. The ESP32 uses I²C communication to read sensor data and does some initial processing to get orientation values. The data that has been processed is then sent wirelessly to a desktop program.

Python and PyQt5 are used to make the software interface, which makes it easy for people to keep track of their rehabilitation exercises. The app shows real-time joint angles, keeps track of how well you do your exercises, and counts how many times you do them based on set limits[6].

The system calculates the elbow joint angle by analyzing the relative orientation between the upper arm and forearm sensors. Based on the calculated angle, the system identifies specific rehabilitation exercises such as flexion-extension and pronation-supination. Threshold-based logic is implemented to count repetitions and verify whether the movements are performed correctly.

A user interface developed using PyQt5 is used to display real-time data, including joint angles and exercise counts. The interface also provides visual feedback and generates reports summarizing the user's performance.

The main goal of the proposed system is to offer an affordable, portable, and effective way to do rehabilitation at home. The system makes physiotherapy monitoring easier to use and more effective by combining wearable sensors, embedded processing, and an interactive interface.

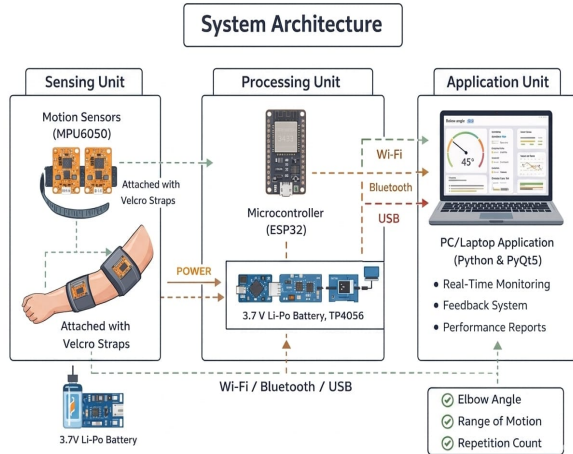


Fig 1 System architecture

IV. METHODOLOGY

The entire process methodology used in the suggested rehabilitation system can be seen in Figure 2. It shows the complete flow of data starting from the collection through to the feedback received by the user. The processes involved include motion sensing, preprocessing, orientation estimation, joint angle computation, exercise detection, and repetitions counting. Each stage performs a specific function in the overall workflow.

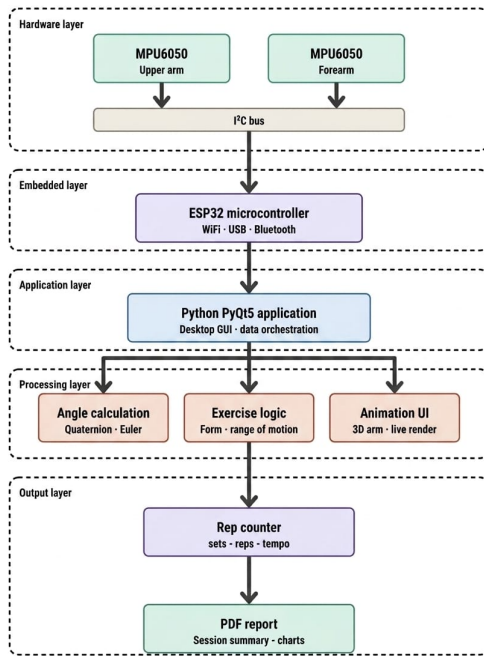


Fig 2 Block diagram of the elbow rehabilitation system

PHASE 1: DATA ACQUISITION

In this stage, motion data is collected using two MPU6050 sensors placed on the upper arm and forearm. These sensors measure three-axis acceleration and angular velocity, enabling precise detection of arm movement. Proper positioning of the sensors ensures accurate capture of joint motion during rehabilitation exercises.

PHASE 2: DATA COMMUNICATION

The acquired sensor data is transmitted to the ESP32 using the I2C communication protocol. The ESP32 acts as the central interface, continuously receiving data from both sensors and preparing it for further processing. Wireless communication such as Wi-Fi or Bluetooth is used to transfer data to the external system.

PHASE 3: DATA PROCESSING

The raw sensor data is subjected to preprocessing to remove noise and improve accuracy. Filtering techniques are applied to reduce disturbances caused by sensor drift and environmental factors[4]. This step ensures that the data used for further analysis is stable and reliable.

PHASE 4: ORIENTATION ESTIMATION

In this stage, the processed sensor data is used to estimate the orientation of the arm segments. Sensor fusion techniques combine accelerometer and gyroscope data to obtain stable orientation values. The orientation is represented in a form that allows easy computation of joint angles.

PHASE 5: JOINT ANGLE CALCULATION

The elbow joint angle is calculated by determining the relative orientation between the forearm and upper arm sensors. The difference between these orientations provides the angle of movement, enabling continuous monitoring of joint motion[3].

where θ represents the elbow joint angle, θ_f is the forearm orientation, and θ_u is the upper arm orientation.

PHASE 6: EXERCISE DETECTION

Based on the calculated joint angle, the system identifies specific rehabilitation exercises such as flexion-extension and pronation-supination. Predefined threshold values are used to determine whether the movement falls within the expected range for each exercise.

PHASE 7: REPETITION COUNTING

Repetition counting is performed by analyzing the transition of the joint angle between minimum and maximum limits. A repetition is counted only when the full range of motion is achieved and the arm returns to its initial position. This approach prevents false counting and improves accuracy.

PHASE 8: VISUALISATION AND FEEDBACK

The processed data is displayed through a graphical user interface developed using PyQt5. The interface shows real-time joint angles, repetition count, and exercise status.

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Feedback is provided to guide the user in performing movements correctly.

PHASE 9: REPORT GENERATION

In the final stage, the system generates a detailed report summarizing the rehabilitation session. The report includes performance metrics such as repetition count, range of motion, and exercise consistency. Graphical representations of joint angle variations are also included to provide better insight into user performance.

V. EXPERIMENTAL IMPLEMENTATION

The Fig 4 represents the hardware structure of the proposed rehabilitation monitoring system, which depicts the entire circuit structure from the sensors to the power supply source. The system employs two MPU6050 sensors mounted on the upper arm and forearm for motion detection purposes. Each sensor is able to measure three-axis accelerations and three-axis angular velocities, providing an efficient way of determining the arm posture and motion.

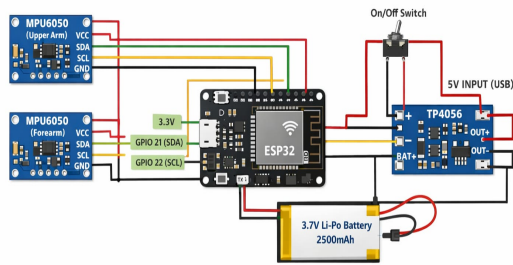


Fig 3 Circuit diagram of the elbow rehabilitation system

The sensing unit consists of two MPU6050 sensors placed on the upper arm and forearm. These sensors measure three-axis acceleration and angular velocity, enabling the system to capture detailed motion data during rehabilitation exercises.

The processing unit is based on the ESP32, which acts as the central controller. The sensors are connected to the ESP32 using the I2C communication protocol, where the Serial Data (SDA) and Serial Clock (SCL) lines are used for data transmission. The ESP32 processes the incoming sensor data and prepares it for further analysis and transmission.

The power supply unit consists of a rechargeable lithium battery connected through a TP4056 charging module. This module provides battery charging and protection features, ensuring safe and efficient power management. A DC input is used for charging, and a switch is included to control the power supply to the system.

All components are integrated using appropriate connectors and wiring to ensure stable operation. The hardware is assembled in a compact enclosure, making the system lightweight and suitable for wearable applications. The complete hardware setup ensures continuous data acquisition, efficient processing, and reliable operation, enabling real-time monitoring of physiotherapy exercises.

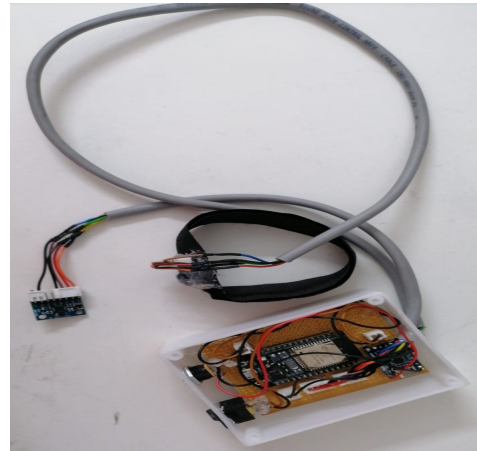


Fig 4 Hardware setup

VI. SOFTWARE IMPLEMENTATION

The software architecture of the rehabilitation monitoring system is shown in Fig. 5, which shows the entire data flow stage from the sensor data acquisition stage to the report creation stage. This process starts with the ESP32 that serves as the main source of the data since it acquires the motion data from the attached IMU sensors.

The core functionality of the software includes real-time angle monitoring, exercise detection, and repetition counting. The received data is continuously updated and displayed on the interface, allowing users to track their performance during rehabilitation exercises. Threshold-based logic is implemented within the software to identify different types of movements and ensure correct execution.

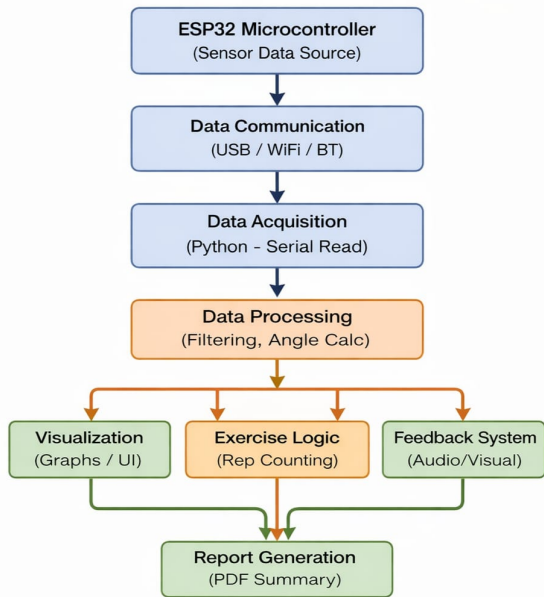


Fig 5 Software workflow

The collected data is analysed by the Python program via serial communication in which the process of data acquisition occurs in real time. The filtered data is used for calculating the angles that are obtained from the sensors, which can be used to analyse the movement of the elbow joint.

The processed data is also applied in three primary functions. First, there is the visualization function that uses real-time graphing and UI components to analyse the angle and movement of the joint. Second, the exercise logic function assesses the motion and counts repetitions based on the thresholds set. Third, there is the feedback function that offers audio and/or visual prompts for executing the motion correctly.

VII. RESULT AND DISCUSSION

The proposed rehabilitation monitoring system was tested under real-time conditions via use of the designed hardware system. The designed hardware prototype tests the system for accuracy in response to movements made by the joint including flexion/extension and pronation/supination. Figure 6 shows the design of the developed hardware prototype. Sensors were mounted on the upper arm and forearm as shown. The system successfully gathered and processed real-time motion data. It successfully detected joint movement and calculated the angle values of the joints.



Fig 6 Final prototype

During experimentation, the system successfully captured motion data from the MPU6050 sensors and processed it using the ESP32. The calculated elbow joint angles were observed to be consistent with the actual movement of the user. The system effectively tracked flexion-extension and pronation-supination exercises with minimal delay.

The repetition counting mechanism was evaluated by comparing the system-generated count with manual counting. The results showed that the system achieved high accuracy in identifying complete movements while avoiding false counts caused by incomplete or improper motions. This indicates that the threshold-based approach is reliable for exercise monitoring. The graphical user interface developed using PyQt5 provided real-time visualization of joint angles and repetition count. The interface responded quickly to incoming data and displayed smooth updates, enabling users to monitor their performance effectively.

In addition, the system generated session reports that included key performance metrics such as range of motion, number of repetitions, and exercise duration. These reports were useful for analyzing user progress and identifying areas for improvement.

Overall, the experimental results demonstrate that the proposed system provides accurate motion tracking, reliable exercise detection, and effective user feedback. The system performs well under real-time conditions and is suitable for practical rehabilitation applications.

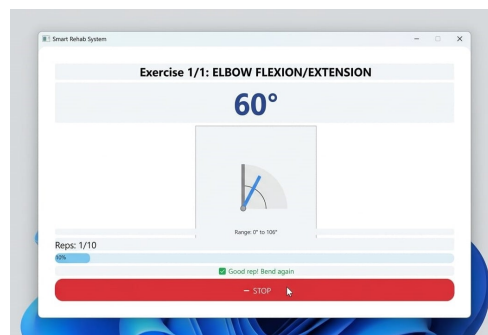


Fig 7 Feedback mechanism

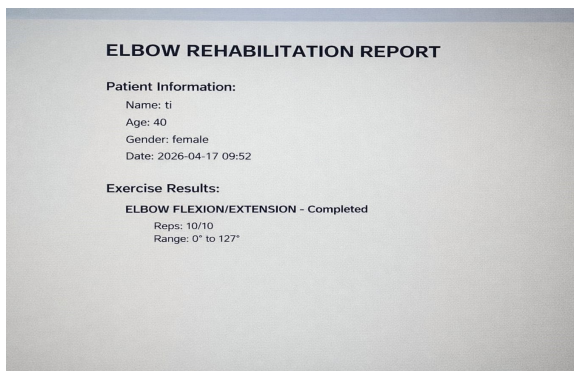


Fig 8 Report generation

VIII. CONCLUSION

This paper presented a smart wearable rehabilitation monitoring system for tracking elbow joint movements during physiotherapy exercises. The system integrates MPU6050 sensors with an ESP32 to capture and process motion data in real time. The proposed approach enables accurate joint angle estimation, effective exercise detection, and reliable repetition counting. The developed software interface using PyQt5 provides real-time visualization and feedback, improving user engagement and exercise accuracy. Experimental results demonstrate that the system performs consistently under real-time conditions and is capable of supporting rehabilitation monitoring effectively. The overall system is low-cost, portable, and easy to use, making it suitable for home-based physiotherapy applications. By enabling continuous monitoring and feedback, the proposed solution contributes to improved rehabilitation outcomes and supports patient recovery.

IX. FUTURE WORK

The proposed rehabilitation monitoring system can be further enhanced to improve its functionality and applicability in real-world scenarios. Future work may focus on integrating advanced machine learning techniques to automatically analyze movement patterns and provide personalized feedback based on user performance.

The system can be extended to support multi-joint monitoring, including shoulder, wrist, and knee movements, by incorporating additional sensors such as the MPU6050. This would enable the development of a comprehensive rehabilitation platform for full-body physiotherapy.

Further improvements can include the integration of cloud-based data storage and remote monitoring, allowing clinicians to access patient data in real time. This would enhance tele-rehabilitation capabilities and reduce the need for frequent hospital visits.

The development of a mobile application interface can also be considered to increase accessibility and user convenience. A smartphone-based platform would allow users to track their rehabilitation progress anytime and anywhere.

In addition, advanced feedback mechanisms such as voice guidance, vibration alerts, and real-time correction suggestions can be incorporated to assist users in performing exercises more accurately.

Overall, these enhancements can improve the intelligence, scalability, and usability of the system, making it more effective for long-term rehabilitation monitoring and patient care.

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