International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 10 | Oct - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Smart Rehabilitation Monitoring System Using Wearable Sensors and Internet of Things

Ms. Sanchita Jamdhade
Department of E&TC JSPM's BSP
Wagholi Pune, Maharastra

Ms. Vaishnavi Jarad
Department of E&TC JSPM's BSP
Wagholi Pune, Maharastra

Mr. Pranav Joshi
Department of E&TC JSPM's BSP
Wagholi Pune, Maharastra

Mr. Yogesh Kale
Department of E&TC JSPM's BSP
Wagholi Pune, Maharastra

Mrs. Ashwini Girish Meshram
Deparment of E&TC JSMP's BSP
Wagholi Pune, Maharastra

Abstract— Physical rehabilitation is an important part of recovery after injuries, surgeries, and conditions that affect body movement. Conventional rehabilitation often depends on periodic clinical assessment and manual observation of exercise performance. This paper proposes a Smart Rehabilitation Monitoring System using wearable sensors, an embedded controller, and Internet of Things (IoT) technology to support the monitoring of rehabilitation exercises. The proposed system uses motion sensors to collect movement-related data such as orientation, angular motion, and exercise repetitions. A microcontroller processes the sensor readings and transmits relevant information to a monitoring interface through wireless communication. The interface can display exercise activity, session duration, repetition count, and movement-related feedback. The system is intended to assist patients and physiotherapists in observing exercise progress, particularly during home-based rehabilitation. The proposed design focuses on affordability, portability, and remote monitoring. It is a supportive monitoring tool and is not intended to replace professional medical assessment. Prototype implementation and experimental testing are required to evaluate its measurement accuracy, reliability, and practical usefulness.

Key Words— Smart Rehabilitation, Wearable Sensors, Internet of Things, Motion Monitoring, Physiotherapy, Embedded System.

1. INTRODUCTION

Physical rehabilitation helps individuals improve movement, flexibility, coordination, and functional ability after an injury, surgery, or a medical condition affecting mobility. Rehabilitation exercises are generally performed under the guidance of a physiotherapist, who observes the patient's movements and provides instructions for correct exercise performance.

In conventional rehabilitation, progress is often assessed during scheduled clinical visits. When exercises are performed at home, the physiotherapist may not be able to observe every session directly. Manual recording of exercise repetitions and duration may also require additional effort. These limitations create an opportunity to develop electronic monitoring systems that collect movement-related information and make it easier to review exercise sessions.

Developments in wearable sensors, embedded controllers, wireless communication, and the Internet of Things have created opportunities for monitoring physical activities outside clinical environments. Wearable motion sensors can measure changes in orientation and movement, while connected applications can display collected information for review. Research on rehabilitation monitoring has explored inertial sensors and wearable technologies for tracking body movements and exercise performance.

The proposed Smart Rehabilitation Monitoring System combines wearable motion sensing, microcontroller-based processing, wireless communication, and a monitoring dashboard. Depending on the selected sensor and calibration method, the system can record movement-related parameters, estimate exercise repetitions, and present session information. The objective is to support exercise tracking and provide useful information to patients and physiotherapists. The system is designed as a supportive monitoring solution rather than a diagnostic device.

2. OBJECTIVES OF THE SYSTEM

- To monitor selected rehabilitation exercises using wearable motion sensors.
- To collect movement-related data through an embedded controller.
- To estimate exercise repetitions and session duration using defined processing rules.
- To transmit monitoring information wirelessly to a dashboard or mobile interface.
- To maintain session records that can help users and physiotherapists review exercise progress.
- To develop a portable, cost-conscious prototype suitable for supervised testing.
- To evaluate measurement reliability by comparing sensor-based counts with manually recorded observations.

3. PROPOSED SYSTEM

The proposed system consists of a wearable sensing unit, a microcontroller, a wireless communication interface, a data storage platform, and a user dashboard. A motion sensor is

attached securely to the selected body segment according to the exercise being monitored. The sensor collects movement-related data and sends it to the microcontroller.

The microcontroller reads and processes the sensor data using predefined rules. After calibration, movement thresholds or changes in orientation can be used to identify selected exercise movements and estimate repetitions. The processed information may include exercise type, repetition count, session duration, and recorded movement values.

The controller transmits relevant data through Wi-Fi or Bluetooth, depending on the selected hardware and application requirements. A mobile application or web dashboard displays the received information. If cloud storage is implemented, session records can be saved for later review by an authorized user. The final selection of hardware and software should be based on the exercises to be monitored, required measurement range, connectivity, and budget.

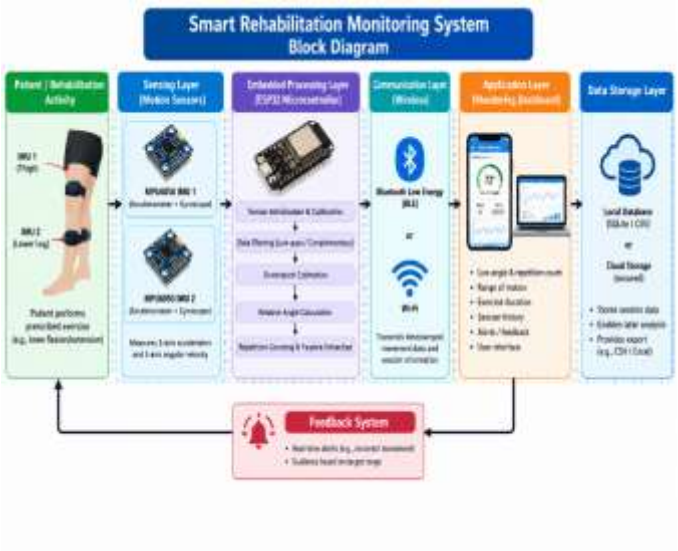


Fig. 1. Block diagram of the proposed Smart Rehabilitation Monitoring System.

4. HARDWARE AND SOFTWARE REQUIREMENTS

4.1 Hardware Components

Component	Function
ESP32 development board	Reads sensor data, processes movement information, and supports wireless communication.
MPU6050 motion sensor	Measures acceleration and angular velocity for movement monitoring.
Wearable strap or band	Holds the sensor securely on the selected body segment.
USB power supply or suitable battery	Supplies power to the controller and sensor.
Laptop or smartphone	Displays monitoring information and supports configuration.
Wi-Fi or Bluetooth connection	Transfers data to the monitoring interface.

Optional components include an OLED display for local readings, a buzzer for configured local indications, and a cloud database for session storage.

Hardware-Based System

1. ESP32 development board



Fig. 1.1 ESP32 development board

Main function: Processing and control unit.

The ESP32 acts as the brain of the system. It receives motion data from the IMU sensors, performs calculations, counts exercise repetitions, and transmits the processed information to a smartphone or computer.

Detailed working

1. Sensor communication: The ESP32 communicates with the MPU6050 sensors through the I²C digital interface using the SDA and SCL signals.
2. Data acquisition: It reads acceleration and angular-velocity measurements at a predefined sampling rate.
3. Signal processing: It filters noisy readings and uses an orientation-estimation algorithm to estimate body-segment orientations.
4. Angle calculation: It calculates the relative orientation of the two body segments to estimate the selected joint angle.
5. Repetition counting: It detects movement cycles using calibrated thresholds and a state-based algorithm.
6. Wireless transmission: It sends timestamped measurements and exercise statistics

through Bluetooth Low Energy (BLE) or Wi-Fi.

7. Fault handling: It can detect missing sensor readings or communication failures and flag invalid measurements.

Example

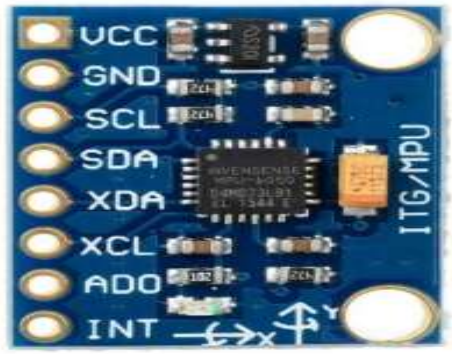
When a patient performs a knee-flexion exercise, the ESP32 processes measurements from sensors attached to the thigh and lower leg. It estimates the relative angle, detects completed repetitions, and updates the monitoring application.

Why it is needed: Without the ESP32, the sensor measurements would not be processed and coordinated by the proposed embedded system.

2. MPU6050 IMU sensor

Main function: Motion measurement.

The MPU6050 contains a three-axis accelerometer and a three-axis gyroscope. It measures acceleration along three axes and angular velocity around three axes.



Fg.1.2 MPU6050 IMU sensor

- **Detailed working**

A. Accelerometer

The accelerometer measures acceleration along the X, Y, and Z axes. When the sensor is stationary, the gravity component helps estimate its tilt relative to the vertical direction.

B. Gyroscope

The gyroscope measures rotational velocity around the X, Y, and Z axes. Integrating angular velocity over time provides an estimate of rotation, although errors can accumulate as drift.

C. Sensor fusion

The accelerometer and gyroscope have complementary strengths. A complementary filter or another sensor-fusion algorithm can combine their measurements to improve orientation estimation.

D. Relative joint-angle estimation

Two sensors are attached to adjacent body segments.

- IMU 1 measures the orientation of the thigh.
- IMU 2 measures the orientation of the lower leg.
- The processing algorithm calculates their relative orientation.
- The appropriate joint-angle estimate is extracted using a defined coordinate convention and calibration procedure.

- **Why two sensors are useful**

One sensor measures the orientation of one body segment. Two sensors provide information about the relative orientation of adjacent segments, making joint-angle estimation more practical.

However, accurate anatomical joint angles require appropriate sensor alignment, calibration, and validation against a reference instrument.

3. MAX30102 heart-rate sensor



Fg.1.3 MAX30102 heart-rate sensor

This component adds optional physiological monitoring to the rehabilitation system.

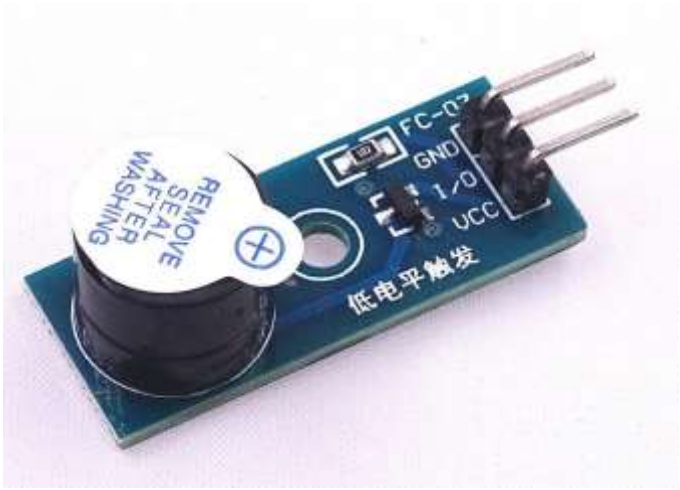
How it works

1. Red and infrared LEDs emit light into the skin.
2. A photodetector measures light reflected by the tissue.
3. The amount of reflected light changes as blood volume varies with each heartbeat.
4. The sensor's electronics produce a digital optical signal.
5. The ESP32 or a software library processes that signal to estimate pulse rate in beats per minute (BPM).
6. The measured value is displayed or transmitted alongside the exercise data.

The MAX30102 is an optical heart-rate and pulse-oximetry sensor. Its readings are sensitive to motion, placement, skin contact, and other measurement conditions.

Role in rehabilitation: It can help record how heart rate changes during a session. It should not be used by itself to determine whether an exercise is medically safe, and readings should not be treated as diagnostic results.

4.Buzzer or vibration motor



Fg.1.4Buzzer or Vibration motor

This component gives feedback without requiring the patient to continuously watch the display.

Working in the system -

1. The ESP32 checks the repetition count, movement status, or configured alert conditions.
2. When a condition is met, it sends a control signal to the output circuit.
3. A buzzer produces a sound, or a vibration motor provides tactile feedback.
4. The output stops after the programmed duration.

Possible feedback examples include:

- A short beep when the prescribed repetition target is reached.
- A vibration when a sensor becomes disconnected.
- A warning signal when a configured monitoring threshold is crossed.

A suitable driver transistor or MOSFET may be necessary for a motor or other load that draws more current than a GPIO can supply. Medical alerts must be designed and validated carefully; an ordinary prototype buzzer is not a certified emergency alarm.

5.Breadboard, jumper wires and connectors.



Fg.1.5 Breadboard, Jumper wires and Connectors

These components connect the hardware during development.

Working in the system

- The breadboard allows circuits to be assembled without soldering.

- Jumper wires carry power, ground and communication signals.
- Connectors make sensor replacement and testing easier.
- The developer can test the circuit before designing a permanent PCB.

For an academic prototype, use short, secure connections and common ground where required. Check every module's voltage compatibility before connecting it to the ESP32.

6. Wearable strap and enclosure



Fg.1.6 Wearable Strap and Enclosure

The strap keeps the motion sensor in a consistent position on the patient's limb. The enclosure protects the electronics from accidental contact and minor impacts.

Working in the system -

1. The sensor is mounted at a defin on the forearm, upper arm, or leg.
2. The strap limits unwante movement.
3. The patient performs the rehabilitation exercise.
4. The controller interprets the rea on the sensor's mounting orientation and calibration.
5. The enclosure protects the circuit during normal handling.

A loose strap can create false movement readings. The design should also avoid sharp edges, excessive pressure, exposed conductors and uncomfortable battery placement.

4.2 Software Requirements

Arduino IDE can be used to program the ESP32 using embedded C/C++. The Serial Monitor helps observe sensor readings during development. A web dashboard or mobile interface can display session data. HTTP or MQTT may be selected for internet-connected data transfer, and a cloud database may be added if remote storage is required.

5. WORKING METHODOLOGY

Step 1: Sensor Placement and Calibration. The motion sensor is attached to the body segment involved in the selected exercise. Baseline readings are recorded in a defined starting position. Correct placement and calibration are necessary for consistent measurements.

Step 2: Data Acquisition. The motion sensor measures acceleration and angular velocity. The controller reads the sensor values at a configured sampling interval.

Step 3: Data Processing. The ESP32 processes the collected readings. Filtering may be applied to reduce noise, and predefined thresholds or movement-state logic are used to identify the selected exercise pattern.

Step 4: Repetition Estimation. A repetition is counted when a defined sequence of movement states is completed. The algorithm must be adjusted and tested for each exercise.

Step 5: Wireless Transmission. Processed parameters are sent to a monitoring interface through Wi-Fi or Bluetooth. HTTP or MQTT may be used where appropriate.

Step 6: Data Display and Recording. The interface displays exercise name, repetition count, session duration, and selected motion readings. If storage is implemented, records may be saved with timestamps.

Step 7: Progress Review. The user and an authorized physiotherapist may review recorded information. The system does not independently determine whether recovery is medically satisfactory.

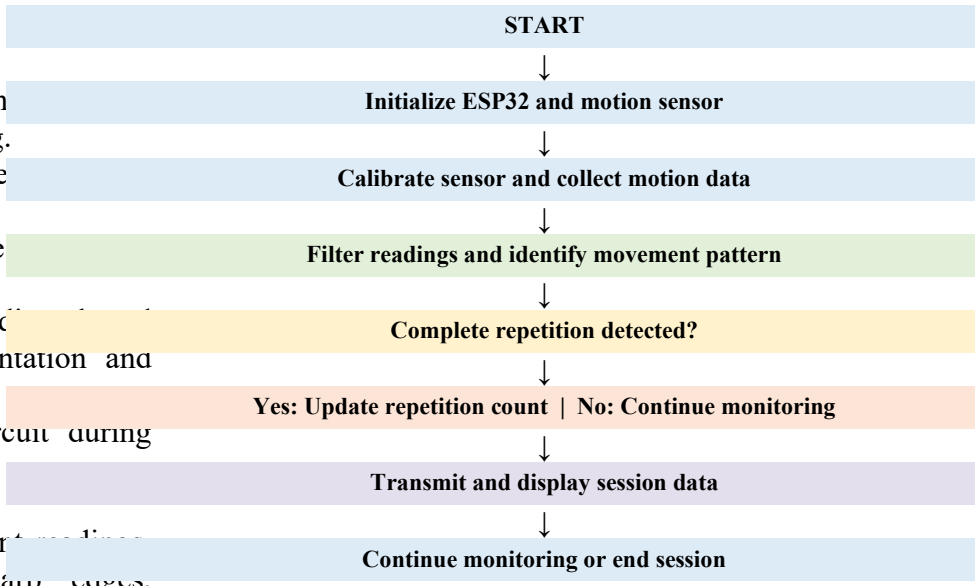


Fig. 2. Flowchart of the proposed rehabilitation monitoring process.

6. SYSTEM DESIGN AND DATA MONITORING

The system is designed around collection, processing, communication, and presentation of movement-related data. The sensing layer collects readings from the wearable sensor, while the processing layer converts raw readings into parameters useful for exercise monitoring. The communication layer transfers processed information to a local or remote interface.

The dashboard may display exercise name, session start time, session duration, repetition count, and selected movement measurements. If cloud storage is enabled, the system can maintain historical records for comparison between sessions. Access to stored information should be restricted to authorized users because rehabilitation records may contain sensitive personal information.

For an initial prototype, a single motion sensor and one predefined exercise can be used to validate the data path. Additional exercises and an advanced interface can be considered after testing.

7. EXPECTED RESULTS AND PERFORMANCE EVALUATION

The proposed system is expected to collect motion-sensor data and present selected exercise-monitoring parameters through a user interface. With appropriate sensor placement, calibration, and processing logic, the prototype should be capable of estimating repetitions for the specific exercise for which it has been configured.

Performance should be evaluated through controlled tests. The automatically estimated repetition count can be compared with a manually recorded reference count. Sensor readings should be checked for stability, and data transmission should be examined under intended operating conditions. Numerical accuracy, response time, reliability, and cost-effectiveness must be reported only after measurements have been collected.

Parameter	Evaluation method
Repetition-count agreement	Compare system count with a manually recorded count.
Sensor stability	Observe readings while the sensor is stationary.
Response time	Measure delay between movement detection and display.
Data transmission	Check for missing or delayed records.
Session recording	Verify saved records against the displayed session.
Repeatability	Repeat the same exercise under consistent conditions.

8. ADVANTAGES AND APPLICATIONS

Advantages

- Supports monitoring of selected rehabilitation exercises.
- Records exercise repetitions and session duration electronically.
- Enables wireless transfer of monitoring data.
- Can be developed as a portable, modular prototype.
- May reduce manual recording effort and support session review.

Applications

- Home-based physiotherapy exercise monitoring.
- Monitoring of selected limb-movement exercises.
- Exercise tracking in physiotherapy centres.
- Supervised rehabilitation sessions.
- Academic research on wearable healthcare devices.

9. LIMITATIONS AND SAFETY CONSIDERATIONS

Monitoring performance depends on sensor placement, calibration, movement patterns, and the processing algorithm. A single motion sensor may not capture all aspects of a complex exercise, and different movements may produce similar readings. The prototype must be tested for each exercise it is intended to monitor.

Wireless monitoring depends on compatible hardware, software, and network availability. Cloud-based functions require appropriate data security and access control. The device should be comfortable to wear and should not restrict normal movement. The system is intended to support monitoring, not to diagnose a condition, prescribe treatment, or replace professional assessment. Exercise selection and rehabilitation decisions should remain under the guidance of a qualified healthcare professional.

10. FUTURE SCOPE

The system can be enhanced by introducing multiple wearable motion sensors to monitor different body segments. Advanced signal-processing techniques may improve movement classification and repetition estimation. Machine learning may be explored for identifying predefined exercise patterns if suitable training data and validation procedures are available. A dedicated mobile application could provide session summaries and progress visualizations. Future work may include secure data sharing, longer-duration testing, and evaluation under professional supervision. Any clinical use would require appropriate validation, privacy safeguards, and assessment against relevant healthcare requirements.

11. CONCLUSION

The Smart Rehabilitation Monitoring System proposes an embedded and Internet of Things-based approach for monitoring selected rehabilitation exercises. The design combines a wearable motion sensor, an ESP32 controller, wireless communication, and a monitoring interface to collect, process, and display movement-related information.

The proposed system aims to support the recording of exercise repetitions, session duration, and selected motion parameters. Its modular architecture provides opportunities for future

improvements in sensor integration, data visualization, and remote monitoring. However, system reliability depends on correct sensor placement, calibration, and exercise-specific processing. Implementation and experimental evaluation are necessary to determine accuracy, repeatability, and usefulness. The system is intended to complement professional rehabilitation guidance rather than replace clinical assessment.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to their project guide and the Department of Electronics and Telecommunication Engineering at JSPM's Bhivrabai Sawant Polytechnic, Wagholi, Pune, for their guidance and support in preparing this research paper. The authors also acknowledge the technical literature and research publications that helped them understand wearable sensing, embedded systems, and rehabilitation monitoring. This acknowledgement should be retained only if it accurately reflects the support received.

REFERENCES

1. "Sensors and Systems for Physical Rehabilitation and Health Monitoring—A Review," Sensors, vol. 20, no. 15, article 4063, 2020. DOI: 10.3390/s20154063. Verify author list and publication metadata from the original article before submission.
2. "Wearable Sensors and Smart Devices to Monitor Rehabilitation Parameters and Sports Performance: An Overview," Sensors, vol. 23, no. 4, article 1856, 2023. DOI: 10.3390/s23041856. Verify author list and publication metadata from the original article before submission.
3. J. Qi, P. Yang, A. Waraich, Z. Deng, Y. Zhao, and Y. Yang, "Examining Sensor-Based Physical Activity Recognition and Monitoring for Healthcare Using Internet of Things: A Systematic Review," Journal of Biomedical Informatics, vol. 87, pp. 138–153, 2018. DOI: 10.1016/j.jbi.2018.09.002.
4. J. M. Winters and P. E. Crago, *Biomechanics and Neural Control of Posture and Movement*. New York: Springer, 2000.
5. R. S. H. Istepanian and B. Woodward, *M-Health: Fundamentals and Applications*. Hoboken, NJ: Wiley, 2017.
6. S. Patel, H. Park, P. Bonato, L. Chan, and M. Rodgers, "A review of wearable sensors and systems with application in rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, vol. 9, article 21, 2012.
7. M. J. Deen, "Information and communications technologies for e-health," *Medical Devices: Evidence and Research*, vol. 6, pp. 47–57, 2013.
8. Espressif Systems, *ESP32 Series Datasheet*. Available: https://www.espressif.com/
9. TDK InvenSense, *MPU-6000 and MPU-6050 Product Specification*. Available: https://invensense.tdk.com/
10. Arduino, *Arduino Documentation*. Available: https://docs.arduino.cc/

BIOGRAPHIES (OPTIONAL)



Ashwini Girish Meshram is a Lecturer in the Department of

E&TC, JSPM's BSP, Wagholi, Pune

Email: **ashupauru.2@gmail.com**



Sanchita Prakash Jamdhade is a Student in Department of E&TC, JSPM's BSP, Wagholi, Pune.

E-mail: **sanchitaprakashjamdhade@gmail.com**



Vaishnavi Chandrakant Jarad is a Student in Department of E&TC, JSPM's BSP, Wagholi, Pune.

E-mail: **vaishnavijarad29@gmail.com**



Pranav Vijay Joshi is a Student in Department of E&TC, JSPM's BSP, Wagholi, Pune.

E-mail: **pranav7261@gmail.com**



Yogesh Ashok Kale is a Student in Department of E&TC, JSPM's BSP, Wagholi, Pune.

E-mail: **yogeshkale1193@gmail.com**