

# KNEEIoT – AUTOMATED KNEE MOVEMENT MONITORING USING IoT FOR TELEREHABILITATION

**Mrs. Arsha C Dinesh**

*Department of Electronics and Communication Engineering*  
St Thomas College of Engineering and Technology, Mattannur Kannur, India  
arshacdinesh@stthomaskannur.ac.in

**Abhinand R**

*Department of Electronics and Communication Engineering*  
St Thomas College of Engineering and Technology, Mattannur Kannur, India  
abhinandrajesh327@gmail.com

**Marjana T**

*Department of Electronics and Communication Engineering*  
St Thomas College of Engineering and Technology, Mattannur Kannur, India  
marjanat2k4@gmail.com

**Ramees Muhammed Kandoth**

*Department of Electronics and Communication Engineering*  
St Thomas College of Engineering and Technology, Mattannur Kannur, India  
rameesmuhammedkandoth@gmail.com

**Safna O V**

*Department of Electronics and Communication Engineering*  
St Thomas College of Engineering and Technology, Mattannur Kannur, India  
sidhiquesafna04@gmail.com

**Abstract**— Rehabilitation following knee injury or surgical treatment requires carefully guided exercises and continuous monitoring to support proper recovery. Conventional physiotherapy generally depends on repeated hospital visits and direct supervision by therapists, which can be inconvenient and time-consuming for many patients. This work introduces an Internet of Things (IoT) based knee tele-rehabilitation system that enables patients to perform rehabilitation exercises while being monitored remotely. The proposed design utilizes an ESP32 microcontroller as the central processing unit and integrates motion sensors along with physiological sensors that measure heart rate, oxygen saturation, and body temperature. These sensors allow the system to track joint movement and the patient's health condition in real time. A stepper motor mechanism is included to provide assisted movement when required during therapy sessions. Visual indicators and sound alerts guide the patient throughout the exercise process. The rehabilitation program can operate in both manual and automatic modes through an Android application connected to a cloud platform. If the system detects repeated incorrect attempts while performing an exercise, it activates the automatic mode to assist the movement according to predefined settings. In addition, the system temporarily stops operation when abnormal physiological values are detected and resumes only after the parameters return to safe limits. By combining sensing, automation, and remote communication, the proposed system improves accessibility, safety, and efficiency in knee rehabilitation.

**Keywords**—Internet of Things, tele rehabilitation, knee therapy, remote monitoring, physiotherapy automation

## I. INTRODUCTION

Knee injuries and post-surgical conditions often require a structured rehabilitation program that focuses on restoring mobility and strengthening the joint gradually. Physiotherapy exercises play a critical role in helping patients regain proper knee function. In traditional rehabilitation practices, patients are usually required to visit hospitals or physiotherapy clinics regularly so that therapists can guide the exercises and monitor recovery progress. While this method is effective, it

may create difficulties for individuals who need long-term therapy or those who live far from medical facilities.

Advancements in Internet of Things (IoT) technology have opened new possibilities for remote healthcare monitoring. IoT systems can connect sensors, embedded devices, and cloud platforms to collect and transmit health-related data in real time. This capability allows healthcare professionals to monitor patient activity and progress even when the patient is outside a clinical environment.

The system proposed in this study combines motion monitoring, physiological sensing, and motor-assisted therapy into a single integrated platform. Patients can perform prescribed exercises at home while their movement data and health parameters are transmitted to a cloud server for supervision. The design also incorporates safety mechanisms to ensure that therapy sessions remain within safe limits. Through this approach, the system aims to make rehabilitation more accessible while maintaining effective monitoring and guidance.

## II. RELATED WORKS

The development of tele-rehabilitation systems has gained significant attention in recent years due to the rapid growth of Internet of Things (IoT) technologies and wearable healthcare devices. Several researchers have proposed different approaches to support remote physiotherapy and patient monitoring.

Patel et al. [1] presented an extensive review on wearable sensor technologies used in rehabilitation and healthcare monitoring. Their work highlighted how wearable devices can collect physiological and motion-related data to assist clinicians in evaluating patient recovery. The study emphasized the importance of sensor-based monitoring systems in improving rehabilitation assessment and enabling continuous patient observation outside clinical environments.

Gubbi et al. [2] discussed the overall architecture and vision of the Internet of Things and its applications in various domains, including healthcare. Their research explained how IoT devices, cloud computing, and network connectivity can be combined to build intelligent healthcare systems capable of real-time monitoring and data analysis.

Similarly, Islam et al. [3] investigated the role of IoT in healthcare applications and proposed a framework for remote patient monitoring using connected sensors and cloud-based

platforms. Their study demonstrated how physiological parameters can be continuously observed to support early detection of abnormal conditions and improve patient care.

In the field of rehabilitation robotics, Kiguchi and Hayashi [4] developed an exoskeleton-based system designed to assist human joint movement. Their work focused on motor-assisted rehabilitation, where robotic mechanisms help patients perform controlled movements during therapy sessions. Although such systems provide accurate motion support, their high cost and complex design often limit their use to hospital environments.

Russell [5] explored the concept of tele-rehabilitation using telemedicine technologies. The study demonstrated that remote physiotherapy programs can improve patient accessibility to rehabilitation services while reducing travel requirements and healthcare costs.

Although these studies have contributed significantly to the development of remote rehabilitation and healthcare monitoring systems, many existing solutions focus primarily on either motion tracking or physiological monitoring independently. Only a limited number of systems combine both aspects with automated motor assistance and real-time safety mechanisms. Therefore, the proposed IoT-based knee tele-rehabilitation system aims to integrate motion sensing, physiological monitoring, motor-assisted therapy, and cloud connectivity into a unified platform that can support both hospital-based and home-based rehabilitation, particularly for knee and post-operative therapy. These systems improve movement precision and reduce therapist dependency.

### III. PROBLEM STATEMENT

Effective knee rehabilitation after injury or surgery requires accurate movement guidance, continuous physiological monitoring, and consistent supervision by trained physiotherapists to ensure safe and successful recovery. However, conventional rehabilitation practices depend largely on frequent hospital visits and direct in person observation, which can be time consuming, costly, and inconvenient for patients, especially those in remote or underserved areas. Lack of continuous monitoring at home may lead to incorrect exercise execution, reduced therapy adherence, delayed recovery, or potential re injury. Furthermore, absence of real time physiological assessment limits the ability to detect pain, fatigue, or abnormal health conditions during therapy sessions. Therefore, there is a need for an intelligent, cost effective, and remotely accessible rehabilitation system that enables real time monitoring, guided exercise control, automated assistance, and continuous communication between patients and healthcare providers to ensure safe, accurate, and efficient knee rehabilitation outside the clinical environment.

### IV. PROPOSED SYSTEM

#### A. System Architecture

The proposed IoT-based Knee Tele-Rehabilitation System consists of sensing, processing, actuation, and communication modules integrated into a unified framework. Motion and physiological data are acquired through sensors and processed by a central microcontroller. The processed data are transmitted to a cloud server for remote monitoring, while real-time feedback is provided to the patient through a display interface. A motor-assisted mechanism enables controlled rehabilitation movement in automatic mode. The overall architecture ensures safe, supervised, and adaptive rehabilitation in both clinical and home environments.

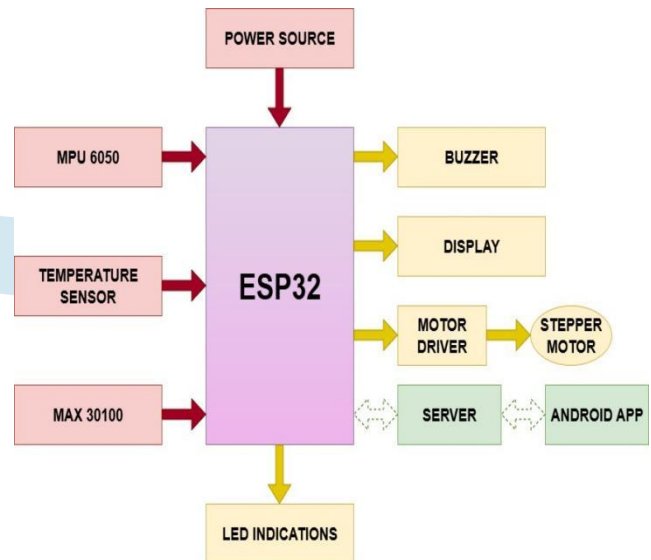


Fig1. System Block Diagram

#### B. Hardware Implementation

The proposed system is centered on the ESP32 microcontroller, which functions as the primary processing and communication unit. It is responsible for acquiring sensor data, executing control algorithms, and enabling wireless communication through integrated Wi Fi connectivity for cloud based supervision.

Joint movement and angular displacement are measured using the MPU6050 inertial measurement unit. This sensor provides real time acceleration and gyroscopic data, which are processed to evaluate range of motion and exercise accuracy during rehabilitation sessions. Physiological monitoring is performed using the MAX30100 sensor, which measures heart rate and oxygen saturation levels to ensure patient safety throughout therapy. In addition, a temperature sensor is incorporated to detect abnormal thermal variations around the knee joint that may indicate inflammation or discomfort.

Motor assisted rehabilitation is achieved through a stepper motor interfaced with a motor driver circuit, enabling precise angular control during automatic mode operation. The motor movement is governed by predefined parameters configured by the physician. A display module provides real time feedback, including angle measurements and system status, while LED indicators and a buzzer generate visual and audio alerts during abnormal physiological conditions or operational mode transitions.

#### C. Software Implementation

The embedded firmware programmed into the ESP32 manages sensor data acquisition, signal filtering, and decision making processes. Sensor readings are continuously evaluated against predefined motion and physiological thresholds to determine exercise correctness and safety compliance.

An Android based mobile application serves as the user interface for both patients and healthcare providers. The application facilitates selection between manual and automatic modes, displays exercise instructions, and enables remote configuration of rehabilitation parameters. All session data are transmitted to a cloud server for storage, monitoring, and real time supervision by medical professionals.

The system operates in two distinct modes. In manual mode, patients perform prescribed exercises under remote guidance, and performance is assessed using motion data. If incorrect execution is detected in three consecutive attempts,

the system automatically transitions to automatic mode, where controlled movement is delivered through the motor mechanism according to predefined settings. Furthermore, if abnormal physiological readings are detected during therapy, the system immediately halts operation and resumes only after parameters return to safe limits, thereby ensuring patient safety and operational reliability.

## V. WORKING METHODOLOGY

The working of the system is based on three combined operations: monitoring, control, and safety. First, the system continuously monitors knee movement and health parameters using motion and physiological sensors. The collected data are processed by the controller to check whether the exercise is performed correctly. Second, based on the evaluation, the system controls the rehabilitation process by allowing the patient to perform exercises manually or by activating motor-assisted movement if required. Third, a safety mechanism continuously checks for abnormal health conditions and immediately stops the system if any unsafe parameter is detected.

By combining monitoring, intelligent control, and safety supervision, the system ensures accurate, controlled, and secure knee rehabilitation.

### A. Data Acquisition and Processing

The rehabilitation procedure begins with the collection of movement and physiological information from the patient. The MPU6050 sensor measures the orientation and angular movement of the knee joint during exercise. Using the accelerometer and gyroscope data, the system determines the joint angle and evaluates the range of motion achieved by the patient.

At the same time, physiological parameters are monitored using the MAX30100 sensor, which measures heart rate and oxygen saturation levels (SpO<sub>2</sub>). A temperature sensor is also used to detect unusual temperature changes that may indicate inflammation or discomfort around the knee joint.

All sensor readings are received by the ESP32 microcontroller, where the data are filtered and compared with predefined threshold values determined by the physician. The processed data are then transmitted to the cloud platform for storage and remote monitoring.

### B. Manual and Automatic Mode Operation

The system supports two modes of rehabilitation: manual mode and automatic mode. In manual mode, the patient performs the prescribed exercises while following instructions provided through the mobile application. The system continuously observes the joint movement to determine whether the exercise is carried out correctly.

If the patient is unable to achieve the required movement after several attempts, the system automatically shifts to automatic mode. In this mode, the stepper motor assists the knee movement according to the predefined angular limits and speed parameters. This assisted motion helps patients who have limited strength or mobility perform the rehabilitation exercise properly.

By switching between these two modes, the system ensures that therapy can continue even when the patient experiences difficulty performing the movement independently.

### C. Safety and Control Mechanism

Patient safety is a critical aspect of the rehabilitation process. During both manual and automatic operation, the system continuously monitors physiological parameters to ensure that the patient remains within safe limits.

If abnormal values are detected, such as a sudden increase in heart rate, a decrease in oxygen saturation, or an unusual temperature reading, the system immediately stops the rehabilitation process. At the same time, visual indicators and audio alerts notify the patient about the detected condition.

The therapy session resumes only after the physiological parameters return to normal levels. This safety mechanism prevents potential health risks and ensures that the rehabilitation process remains controlled and secure.

## VI. APPLICATIONS

The proposed IoT-based Knee Tele-Rehabilitation System has wide applicability in both clinical and home-based healthcare environments. It can be used for post-operative rehabilitation following knee replacement or ligament reconstruction surgeries. The system is also suitable for patients recovering from sports injuries, arthritis-related joint stiffness, and mobility impairments.

In addition, the system supports remote physiotherapy services, making it beneficial for patients residing in rural or geographically distant areas with limited access to healthcare facilities. Hospitals and rehabilitation centers can integrate this framework into telemedicine platforms to monitor multiple patients simultaneously. The system can further be adapted for elderly care and long-term physiotherapy programs requiring continuous supervision and progress tracking.

## VII. FUTURE SCOPE

Several improvements can be considered for future development of the system. Machine learning techniques could be integrated to analyze patient data and predict rehabilitation progress more accurately. Such algorithms may also recommend personalized exercise plans based on patient performance.

Additional biomechanical sensors could be incorporated to provide more detailed analysis of joint movement. The overall design may also be miniaturized into a wearable device to enhance portability and comfort.

Cloud-based dashboards for clinicians could provide advanced data visualization and easier monitoring of patient progress. Furthermore, the system concept can be extended to support rehabilitation of other joints such as the hip, shoulder, or elbow.

## VIII. CONCLUSION

This work presented an IoT-based knee tele-rehabilitation system designed to support remote physiotherapy and continuous patient monitoring. The proposed system integrates motion sensing, physiological monitoring, and motor-assisted control within a single framework. By allowing patients to perform rehabilitation exercises at home while still being supervised remotely, the system improves accessibility and convenience.

The combination of manual and automatic rehabilitation modes enables the therapy process to adapt according to patient performance. Safety monitoring further ensures that rehabilitation sessions remain within healthy limits. With its cost-effective and scalable design, the proposed system offers a promising approach for improving knee rehabilitation and expanding access to physiotherapy services.

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