Malnad College of Engineering

Under the auspices of M.T.E.S ®
(An Autonomous Institution Affiliated to VTU, Belgaum)
P.B No. 21, Hassan-573 202, Karnataka

MINI PROJECT (23IS506)

"Intelligent Movement Analysis for Assisted Physiotherapy: Real-Time Monitoring And Feedback"

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CERTIFICATE

Certified that the mini project work carried out by 4MC23IS042, 4MC23IS046, 4MC23IS058, 4MC23IS129 is a Bonafede work, submitted during academic year 2025-26, in partial fulfilment for the award of B.E degree in Information Science & Engineering. All the corrections suggested during the internal evaluation are incorporated in the project report. This report has been approved as it satisfies the academic requirements of mini project prescribed for the Bachelor of Engineering degree.

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Abstract

Physiotherapy exercises require precise execution to ensure effective rehabilitation and prevent secondary injuries. However, unsupervised home-based physiotherapy often results in poor adherence and incorrect posture. This project proposes an intelligent physiotherapy monitoring system that employs computer vision, pose estimation, and machine learning to analyze human motion in real time. The system captures video input from a standard webcam, extracts skeletal keypoints, and evaluates user performance by comparing movements against predefined exercise models. It identifies deviations in joint angles and movement trajectories, generates immediate corrective feedback, and assigns quantitative accuracy scores. Historical performance data is also stored to track rehabilitation progress over time. The system provides an affordable and scalable digital physiotherapy solution, enhancing patient autonomy and improving rehabilitation outcomes. Many patients struggle to follow physiotherapy routines correctly when practicing at home, which can slow their recovery or cause further discomfort. This project introduces an easy-to-use digital physiotherapy assistant designed to help users perform exercises safely and accurately. Through a webcam, the system observes the user's movements and uses pose-detection techniques to understand their posture and body position. It then compares these movements with professionally approved exercise models and offers instant feedback to help correct errors. The system also tracks progress over time, allowing users and therapists to monitor improvement. By combining affordability, accessibility, and real-time guidance, this solution supports better rehabilitation without requiring constant in-person supervision.

Effective physiotherapy depends heavily on the accuracy and consistency of exercise performance, yet conventional rehabilitation often lacks sufficient supervision, particularly in home-based settings. To mitigate this limitation, this project develops an intelligent physiotherapy support framework integrating real-time human pose estimation with machine learning–based movement assessment. The system utilizes webcam video to extract skeletal features and evaluates user posture through joint-angle analysis and temporal motion modeling. Deviations from expert-defined exercise standards are detected, and users receive immediate corrective instructions. Additional features include accuracy evaluation, progress tracking, and automated performance reporting. The proposed framework enhances the accessibility and reliability of physiotherapy practice, offering a cost-effective tool for remote rehabilitation and continuous monitoring.

Chapter-1 :Introduction

1.1 Introduction to the area

Physiotherapy is an essential component of modern healthcare, playing a crucial role in restoring mobility, strength, coordination, and functional independence for individuals recovering from injuries, surgeries, neurological conditions, or chronic musculoskeletal disorders. In most rehabilitation programs, patients are expected to perform a set of exercises regularly, not only in clinical settings but also at home as part of their long-term recovery routine. These exercises typically require precision in posture, joint alignment, and repetition to achieve the desired therapeutic outcomes. Even minor deviations in movement can reduce effectiveness, create muscle imbalances, or in some cases, cause further injury.

While physiotherapists provide expert supervision during clinical sessions, it is not feasible for them to continuously monitor patients during home-based exercises. As a result, many individuals struggle to maintain correct form without professional guidance. Incorrect posture, incomplete movements, or lack of body awareness can significantly delay the recovery process. Traditional solutions such as printed instructions, video demonstrations, or mobile apps offer general guidance but do not provide real-time, personalized feedback. This highlights a significant gap in the rehabilitation process—one where patients lack continuous, interactive, corrective supervision outside clinical environments.

Recent advances in artificial intelligence, computer vision, and machine learning have opened new possibilities in healthcare, especially in the domain of movement analysis. Pose-estimation algorithms can detect human body posture, identify skeletal joint positions, and analyze movement patterns using only a standard camera. These technologies make it possible to automatically evaluate exercises, compare them with physiotherapist-defined standards, and instantly flag incorrect actions. By integrating such systems with feedback mechanisms, patients can receive immediate guidance similar to live therapist supervision.

The growing interest in digital health, telemedicine, and remote rehabilitation further emphasizes the need for intelligent systems that support patients outside hospital environments. The COVID-19 pandemic accelerated the demand for remote healthcare solutions, demonstrating the importance of technology in ensuring continuity of care. In this context, intelligent physiotherapy assistance can empower patients to engage more confidently in home-based rehabilitation programs, ensuring they maintain proper form, reduce dependence on frequent clinical visits, and achieve better recovery outcomes.

This project explores the potential of computer vision–based physiotherapy assistance by developing a real-time intelligent movement analysis system. The system uses pose-estimation techniques to track joint angles, assess exercise accuracy, identify postural deviations, and deliver instant corrective feedback to the user. By bridging the gap between clinical supervision and home-based practice, the proposed solution aims to enhance rehabilitation effectiveness, support physiotherapists, and offer a cost-effective, scalable, and accessible alternative to traditional physiotherapy monitoring.

1.2 Potential of the problem

1.2.1 Problem statement

Physiotherapy exercises are designed to restore mobility, strength, and functional stability in patients recovering from injuries, chronic conditions, or surgeries. These exercises must be executed with precision in posture, joint angles, and movement patterns to achieve the intended therapeutic benefits. However, a major challenge in the rehabilitation process is that patients are often required to continue these exercises independently at home, without the continuous supervision of a physiotherapist. As a result, incorrect execution becomes highly common.

Many patients struggle to understand whether they are performing exercises properly, and due to the absence of instant correction, they unknowingly develop poor movement habits. Even slight deviations in body alignment—such as inadequate bending, improper arm elevation, or incorrect back posture—can significantly reduce the effectiveness of therapy. Such deviations can also introduce new complications, cause discomfort, prolong the recovery period, or lead to reinjury. Furthermore, patients with limited body awareness, motor coordination issues, or cognitive difficulties are at an even higher risk of performing movements incorrectly.

The lack of real-time guidance creates a serious gap in the rehabilitation process. Physiotherapists cannot supervise patients around the clock, and frequent clinic visits are often impractical due to time, distance, mobility constraints, or financial limitations.

Traditional aids such as exercise sheets, diagrams, or pre-recorded videos are static in nature and do not adapt to a patient's performance. These tools cannot detect mistakes, offer personalized corrections, or modify guidance based on the user's posture and movement quality.

Although wearable sensor-based rehabilitation technologies exist, they come with several drawbacks, including high cost, complex setup, calibration requirements, and discomfort during prolonged usage. These barriers limit their widespread adoption, especially in home environments. Many existing mobile applications and fitness tools provide general instructions but lack biomechanical analysis and fail to ensure precise execution of physiotherapy exercises.

Given these limitations, there is a need for an intelligent, accessible, and affordable system capable of:

Monitoring a patient's body movements in real time

Identifying posture errors and incorrect joint angles

Providing immediate corrective feedback

Helping users perform exercises safely without constant therapist supervision

Tracking progress across sessions to support long-term rehabilitation

The core problem, therefore, lies in ensuring accurate and safe execution of physiotherapy exercises during unsupervised home-based practice. Without a system that bridges the gap between professional supervision and independent exercise, patients are at risk of performing movements inaccurately, experiencing slower recovery, or developing secondary complications. This project aims to address this critical problem using modern computer vision and AI-based movement analysis techniques.

1.2.2 Existing system and drawbacks

Physiotherapy rehabilitation traditionally relies on direct, in-person supervision by trained physiotherapists. During clinical sessions, therapists guide patients through specific exercises, monitor their posture, assess their joint movements, and provide corrective adjustments whenever necessary. These supervised sessions are highly effective; however, they represent only a small portion of the overall rehabilitation process. Most recovery depends on the patient's consistency and accuracy while performing exercises at home, often without any professional oversight.

To support home-based physiotherapy, several existing systems and methods have been developed, such as printed instruction manuals, exercise charts, and pre-recorded video demonstrations. Mobile applications and online platforms also offer instructional videos and animations to guide patients. In more advanced systems, wearable sensors—such as accelerometers, gyroscopes, and smart bands—are used to monitor body movements and provide basic feedback to users. While these technologies aim to improve patient engagement and exercise adherence, they still fall short in providing reliable, real-time posture correction.

One of the most notable issues is the lack of real-time feedback. Many existing mobile applications, video tutorials, and digital physiotherapy resources only provide static, one-way instruction. They demonstrate how an exercise should be performed but cannot observe the user while they execute it. As a result, users receive no immediate correction when they make mistakes. This absence of interactive monitoring often leads to repeated errors, incorrect posture, and reduced exercise effectiveness, ultimately slowing down the rehabilitation process.

Another major limitation is the dependence on self-assessment. Patients practicing physiotherapy exercises at home must often rely on their own judgment to determine whether their movements are accurate. However, most individuals lack sufficient biomechanical awareness or understanding of proper joint alignment. They may fail to recognize inadequate bending, asymmetrical movements, or improper positioning. This reliance on subjective self-evaluation increases the likelihood of improper execution and inconsistent progress.

Wearable sensor-based systems also present significant challenges. Although sensors such as accelerometers and gyroscopes can capture motion data, these systems are often expensive and require multiple sensors placed on different body parts to achieve full-body tracking. They also demand calibration and frequent adjustments, making them less convenient for daily use. Many patients, especially older adults or those with physical limitations, may find these devices uncomfortable or difficult to operate, limiting their practicality for widespread home-based rehabilitation.

A further drawback is the lack of accurate angle and posture analysis in existing home-based tools. Most traditional digital solutions do not compute joint angles or compare them with physiotherapist-recommended standards. Without precise biomechanical assessment, these tools cannot reliably determine whether an exercise is being performed correctly. This limits their usefulness in therapeutic settings where accuracy is critical for safe and effective rehabilitation.

Limited personalization is another issue affecting current systems. Many tools deliver uniform instructions and fixed exercise routines that do not adjust to a user's individual needs, progress, or mistakes. Physiotherapy, however, requires personalized correction and adaptive guidance, as each patient has unique limitations, strengths, and recovery patterns. The absence of personalized support reduces user engagement and may result in exercises that are too easy, too difficult, or incorrectly performed.

Frequent clinical visits also pose inconvenience and financial burden. Patients who require continuous monitoring or guidance may need to visit physiotherapy centers regularly. For individuals with mobility challenges, elderly patients, or those living in remote or rural areas, such visits can be difficult, time-consuming, and costly. This further emphasizes the need for an accessible, home-based monitoring system.

Additionally, existing systems lack detailed progress tracking. Many digital tools do not store data about user performance, joint angles, error patterns, or improvement over time. Without this information, patients cannot understand their progress, and physiotherapists cannot evaluate long-term outcomes or modify treatment plans effectively. This absence of structured data limits meaningful assessment and reduces the overall efficiency of the rehabilitation process.

1.3 Objective of the Present Work

The primary objective of the present work is to develop an intelligent, real-time physiotherapy movement-analysis system that assists patients in performing rehabilitation exercises with greater accuracy and confidence. The system aims to utilize advanced pose- estimation techniques to detect skeletal keypoints, compute joint angles, and analyze body posture during exercise execution. By comparing the user's movements with physiotherapist- defined reference models, the system is designed to identify deviations, provide instant corrective feedback, and ensure that exercises are performed safely and effectively. Another key objective is to create a reliable platform that reduces the dependency on continuous in-person supervision, enabling patients to practice exercises independently from the comfort of their homes while still receiving guided support similar to that of a professional therapist. Additionally, the system seeks to maintain detailed logs of each session—including joint-angle data, accuracy scores, repetition counts, and performance trends—to facilitate long- term progress tracking. This data-driven approach not only helps users understand their improvement over time but also allows healthcare professionals to monitor patient performance remotely, making rehabilitation more accessible and efficient. Overall, the project aims to deliver an affordable, user-friendly, and technologically advanced solution that enhances the effectiveness of physiotherapy through real-time monitoring, intelligent feedback, and comprehensive progress evaluation.

1.4 Platform and Tools Used

The development of the intelligent physiotherapy movement-analysis system is carried out using a combination of robust software platforms, programming tools, and supporting libraries that enable real-time video processing, pose detection, and data analysis. The primary programming language selected for this project is Python, owing to its simplicity, strong community support, and availability of powerful libraries suited for computer vision and machine-learning tasks. For real-time image and video processing, OpenCV serves as the core library, allowing efficient frame capture, image manipulation, and visualization of skeletal models. The pose-estimation component of the system is implemented using MediaPipe, a lightweight yet highly accurate framework developed by Google that provides 33 landmark keypoints for the human body and supports fast inference speeds even on mid- range hardware. Numerical computations, including vector processing and joint-angle calculations, are performed using NumPy, which ensures high-performance mathematical operations essential for analyzing movement data. For visualization purposes, tools such as Matplotlib are utilized to generate graphs, performance charts, and progress analytics.

Chapter 2. System Analysis

2.1 Literature Survey

The field of human-movement analysis has advanced significantly in recent years due to the rapid growth of computer vision, artificial intelligence, and machine-learning technologies. Early approaches to posture recognition and motion tracking relied primarily on traditional image-processing techniques such as background subtraction, contour detection, and template matching. These methods were often limited by variations in lighting, camera angle, and background noise, which reduced their reliability in real-world environments. The introduction of deep-learning-based pose-estimation models revolutionized the domain by enabling highly accurate skeletal tracking in real time. Among these, OpenPose, developed by Carnegie Mellon University, became a landmark system due to its ability to detect multiple body joints simultaneously using Part Affinity Fields. Its success paved the way for more lightweight, faster models such as MediaPipe Pose and BlazePose, which provide real- time inference even on low-resource devices such as mobile phones and standard laptops. These frameworks offer up to 33 human body keypoints, enabling more detailed biomechanical analysis suitable for physiotherapy applications.

Parallel to advancements in pose estimation, the integration of artificial intelligence in physiotherapy has gained increased attention in academic research. Studies demonstrate that AI-driven systems can significantly enhance rehabilitation outcomes by providing automated movement assessment, adherence monitoring, and personalized guidance. Machine-learning models have been used to classify exercise types, detect incorrect posture, and evaluate rehabilitation progress through joint-angle features. Such systems have shown to improve patient engagement, particularly in home-based settings where supervision is limited. Another related area of research is Human Activity Recognition (HAR), which focuses on classifying human actions using vision-based or sensor-based modalities. Vision-based HAR, powered by deep neural networks, has proven effective for understanding exercise patterns and identifying deviations in motion. Research also highlights that combining HAR with pose-estimation techniques creates a powerful hybrid system that enhances accuracy in detecting movement quality, making it suitable for physiotherapy, sports training, fall detection, and gait analysis.

Overall, existing literature strongly supports the potential of computer vision and AI technologies in automating physiotherapy monitoring. The high accuracy, low latency, and widespread accessibility of modern pose-estimation models indicate that intelligent, real-time rehabilitation systems are both feasible and highly beneficial for home-based and remote physiotherapy scenarios. This background forms the foundation for the present project, which aims to integrate pose estimation, angle computation, and real-time corrective feedback into a comprehensive physiotherapy assistance platform.

2.1.1 Pose Estimation Techniques

Pose estimation is a fundamental computer vision technique used to identify and track the key points of the human body from images or video frames. Over the years, pose estimation has evolved from simple handcrafted feature approaches to advanced deep-learning-based models capable of highly accurate and real-time performance. Early pose-estimation methods relied on background subtraction, edge detection, and geometric template matching; however, these techniques were significantly affected by lighting changes, occlusions, and complex backgrounds, limiting their effectiveness in real-world applications. With the rise of deep learning, more robust and efficient frameworks emerged. One of the most influential systems, OpenPose, introduced by Carnegie Mellon University, uses Part Affinity Fields to detect body joints and the spatial relationships between them, enabling multi-person pose estimation with high accuracy. Despite its precision, OpenPose is computationally intensive, making it less suitable for real-time applications on low-end devices.

To address performance limitations, Google introduced MediaPipe Pose, a lightweight and highly optimized pose-estimation framework capable of real-time inference using CPU alone. MediaPipe detects 33 key body landmarks and integrates a pipeline that combines machine learning models with geometry-based tracking, enabling fast and stable skeletal tracking even on devices with limited computational power. BlazePose, an advanced variant of MediaPipe, extends capabilities by offering full-body 3D landmark estimation, making it ideal for physiotherapy, sports analytics, and fitness applications where depth and angle precision are crucial. These deep-learning models use convolutional neural networks (CNNs) trained on large human-motion datasets, enabling them to generalize well across various poses, lighting conditions, and environments. Collectively, modern pose-estimation techniques have greatly improved the accuracy, robustness, and speed of human-movement analysis, making them essential components for applications such as physiotherapy monitoring, gesture recognition, fall detection, interactive gaming, and augmented reality.

2.1.2 AI in Physiotherapy

Artificial Intelligence (AI) is increasingly transforming the field of physiotherapy by providing automated, data-driven support for movement assessment, rehabilitation planning, and patient monitoring. Traditional physiotherapy relies heavily on visual observation and expert judgment from therapists, which, although effective, can be subjective and limited by time and availability. AI-based systems address these challenges by offering consistent, objective, and continuous evaluation of patient movements. Using machine learning algorithms, computer vision models, and sensor-based analytics, AI can accurately detect deviations in posture, quantify joint movements, classify exercise types, and identify improper execution in real time. Studies have shown that AI-driven physiotherapy tools improve patient adherence, especially during home-based rehabilitation, by delivering personalized reminders, corrective feedback, and performance scores that motivate users to practice regularly. Furthermore, AI can analyze historical movement data to identify long- term progress trends, enabling physiotherapists to create more precise and adaptive treatment plans. Advanced deep-learning models, particularly those used in pose estimation, can detect subtle biomechanical errors that are often difficult to observe manually, such as improper joint angles or asymmetric limb movements. In addition, AI-powered virtual assistants and rehabilitation apps provide interactive guidance, reducing the need for frequent clinic visits and making physiotherapy more accessible to elderly patients, individuals in rural areas, or those with mobility constraints. Overall, AI enhances the accuracy, efficiency, and accessibility of physiotherapy, supporting both patients and therapists by enabling safe, intelligent, and scalable rehabilitation solutions.

Research Shows That

Research shows that artificial intelligence and computer-vision–based physiotherapy systems can significantly enhance the rehabilitation process by improving the accuracy, consistency, and effectiveness of exercise performance. Multiple studies indicate that AI-driven guidance systems help patients maintain proper posture during unsupervised home exercises by detecting deviations in joint angles, limb alignment, and movement patterns. Real-time corrective feedback has been proven to reduce the risk of reinjury and improve therapeutic outcomes, as patients are able to adjust their movements instantly. Research also highlights that AI-powered platforms increase patient adherence to prescribed exercise routines, as users receive continuous motivation through progress tracking, performance scoring, and personalized recommendations. Additionally, machine-learning models trained on large datasets of physiotherapy movements can identify subtle biomechanical errors that are often difficult for the human eye to detect, making them valuable tools for accurate movement assessment. Studies further demonstrate that remote monitoring capabilities enabled by AI reduce the need for frequent in-person physiotherapy visits, thereby lowering treatment costs and increasing accessibility for individuals in rural or underserved regions. Overall, research strongly supports the integration of AI in physiotherapy, emphasizing its potential to enhance rehabilitation quality, improve patient independence, and support therapists through automated, data-driven insights.

Human Activity Recognition

Human Activity Recognition (HAR) is a rapidly growing field within computer vision and machine learning that focuses on identifying and classifying human actions based on visual or sensor-based data. Traditionally, HAR systems relied heavily on wearable sensors such as accelerometers and gyroscopes to capture motion signals; however, such methods required users to wear multiple devices, which often led to inconvenience and limited adoption. With the advancement of deep learning and high-performance computer-vision models, vision-based HAR has become a preferred approach for analyzing complex human movements without the need for physical sensors. Modern HAR systems use convolutional neural networks (CNNs), recurrent neural networks (RNNs), and transformer-based architectures to learn motion patterns, temporal dynamics, and spatial relationships between body joints. By processing pose-estimation data—such as skeletal keypoints extracted through OpenPose, MediaPipe, or BlazePose—HAR models can accurately classify physiotherapy exercises, detect incomplete or incorrect movements, and recognize variations in exercise quality.

In the context of physiotherapy, HAR plays a crucial role in monitoring patient performance, ensuring adherence to prescribed routines, and identifying potential risks caused by improper execution. HAR-based systems can automatically detect whether a user is performing knee raises, arm lifts, squats, leg extensions, or other therapeutic movements, and can evaluate whether each repetition meets the required criteria. Studies show that HAR combined with pose-estimation techniques significantly improves the accuracy of rehabilitation analysis by capturing fine-grained details such as timing, joint alignment, and motion smoothness. Moreover, HAR models can analyze long-term movement patterns to reveal improvements or deteriorations in patient performance, aiding physiotherapists in developing personalized treatment plans. Overall, HAR serves as a foundational technology for intelligent physiotherapy systems, enabling automated exercise recognition, error detection, and continuous monitoring without the need for specialized hardware.

2.2 Findings of analysis

The analysis of existing studies, tools, and technologies reveals several key insights that support the development of an automated physiotherapy monitoring system:

1. Real-time pose estimation is computationally feasible on consumer hardware

Modern pose-estimation frameworks such as MediaPipe and BlazePose demonstrate efficient processing capabilities even on mid-range laptops and standard webcams. These models are optimized for real-time inference, achieving high frame rates without requiring GPU acceleration. This indicates that advanced skeletal tracking can be deployed on accessible hardware, making home-based digital physiotherapy systems practical and cost-effective.

2. Physiotherapy movements can be reliably represented using joint-angle features

Most rehabilitation exercises involve predictable and repetitive limb movements. Analysis shows that joint angles—including elbow, knee, hip, and shoulder angles—provide a robust representation of exercise quality. Joint-angle features capture the key biomechanical aspects of motion, enabling accurate evaluation of posture, range of motion, and movement precision. These numerical features are also well-suited for machine-learning models and rule-based error detection.

3. Patients benefit significantly from immediate, corrective feedback

Studies consistently show that users performing rehabilitation exercises often deviate from correct form when unsupervised. Real-time feedback—such as alerts about incorrect posture, insufficient bending, or unstable balance—helps users adjust movements instantly. This reduces the risk of injury, improves exercise accuracy, and enhances adherence to prescribed routines. Immediate cues also mimic the presence of a physiotherapist, improving user confidence and engagement.

4. Data logging enables long-term progress analysis and rehabilitation planning

Storing session-wise information such as joint angles, repetition counts, duration, and detected errors allows clinicians to track patient progress objectively. Historical data helps identify improvements, stagnations, or regressions in performance. For physiotherapists, these insights support personalized treatment planning, remote assessment, and evidence- based decision-making. For patients, progress visualization increases motivation and promotes consistent participation.

2.3 System Requirements Specification

The System Requirements Specification (SRS) defines the essential capabilities and performance characteristics required for the proposed physiotherapy monitoring system. These requirements ensure that the system meets user needs, functions correctly in real-time environments, and maintains reliability and usability for both patients and physiotherapists.

2.3.1 Functional Requirements

Functional requirements describe the specific operations and behaviors that the system must perform to achieve its intended purpose.

1. User Registration and Authentication

The system must allow users to create accounts using basic credentials and authenticate securely at each login. This ensures personalized exercise plans, secure access to user data, and role-based features (patient/therapist/admin).

2. Real-time Pose Tracking

The system must capture live video input from a webcam and perform continuous pose estimation. It should detect and track key body landmarks (e.g., shoulders, elbows, knees, hips) in real time.

3. Joint-angle Computation

Using the extracted body landmarks, the system must compute joint angles such as elbow angle, knee angle, hip rotation, and shoulder flexion. These angles form the core analytical features for evaluating physiotherapy movements.

4. Movement Comparison with Reference Templates

The system must compare the user's real-time movements with predefined ideal templates created by physiotherapists. Deviations from expected joint-angle thresholds should be detected and analyzed.

5. Live Textual Feedback

Based on the comparison results, the system should provide immediate on-screen textual feedback such as "Raise your arm higher," "Straighten your back," or "Maintain correct posture." This helps users correct mistakes instantly.

6. Automated Movement Scoring

The system must assign scores for each repetition or exercise session based on accuracy, smoothness, completion, and joint conformity. This ensures objective evaluation of patient progress.

7. Exercise Recommendation and Progress Tracking

The platform should recommend exercises based on user performance, progress history, or physiotherapist input. It must also log performance metrics daily and present progress graphs or summary reports.

8. Admin Panel for Adding Physiotherapy Models

- Upload new exercise models
- Modify reference templates
- Update scoring criteria
- Manage user accounts

2.3.2 Non-Functional Requirements

Non-functional requirements define system attributes such as performance, usability, reliability, and security.

1. Response Time Under 150 ms

The system must process video frames and generate feedback within 150 milliseconds to ensure true real-time interactivity. Low latency is essential for responsive physiotherapy guidance.

2. Platform Independence (Windows/Linux/macOS)

The application must run smoothly on multiple operating systems without major modifications. This enhances accessibility and usability for a wider patient base.

3. Simple and Intuitive User Interface

The user interface should be visually clear, easy to navigate, and suitable for patients of all age groups. Buttons, instructions, and feedback messages must be user-friendly and non- technical.

4. Secure Data Handling

All user data—including personal information, movement logs, and medical-related details—must be encrypted and securely stored. The system must adhere to privacy standards and restrict unauthorized access.

5. High Reliability and Minimal Downtime

The system should maintain continuous operation with minimal crashes or interruptions. It must perform consistently across various hardware configurations and handle prolonged usage during rehabilitation sessions.

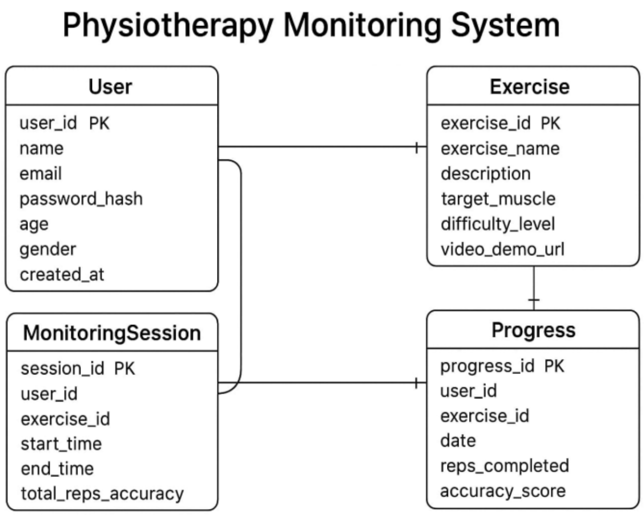
Chapter -3 Design

3.1 Design of Database

The database design for the intelligent physiotherapy movement-analysis system is structured to ensure accurate storage, efficient retrieval, and meaningful interpretation of posture and performance data. It consists of six primary tables—Users, Exercises, Keypoints, Sessions, Feedback Logs, and Progress Reports. The Users table stores all user-related information such as their name, email, password, and optional demographic details. The Exercises table maintains details of each exercise, including descriptions, reference posture angles, and instructions. The Sessions table records each exercise session performed by a user, storing the date, accuracy score, and repetitions. During each session, the Keypoints table stores skeletal landmark coordinates captured frame by frame, while the FeedbackLogs table records real-time corrective messages generated by the system. Long-term performance summaries are stored in the Progress Reports table, highlighting overall improvement patterns and weak areas.

3.1.1 ER Diagram

The ER diagram represents the logical relationship between these tables. A single user can perform multiple sessions, and each exercise can be attempted many times, forming one-to-many relationships. Each session generates several keypoints and multiple feedback logs, enabling detailed analysis of movement accuracy. This model supports the complete flow of data, linking user identity, exercise selection, captured posture data, feedback information, and progress tracking into one integrated structure.



3.1.2 Schema Diagram

The schema diagram further defines the internal structure of each table. The Users table contains fields like user_id, name, email, password, age, and gender. The Exercises table stores exercise_id, exercise_name, description, and reference angles. The Sessions table includes session_id along with foreign keys for user_id and exercise_id, session_date, accuracy score, and repetitions completed. The Keypoints table holds the joint name along with x and y coordinates for every skeleton point detected during the session. The Feedback Logs table contains feedback text, severity levels, and timestamps, while the Progress

Reports table summarizes overall performance, weak joints, and improvements over time. This structured schema ensures smooth handling of large volumes of motion-related data.

3.1.3 Data Flow Diagram

The data flow diagram begins with the user interacting with the system through login and exercise selection. Once an exercise is selected, the system activates the posture-detection module, which captures webcam frames and extracts skeletal key points. These key points are sent to the movement-comparison engine, where joint angles are calculated and compared with reference posture values. Based on the deviation, the feedback engine generates real- time corrective messages such as “Straighten your back” or “Lift your arm higher.” After the session ends, all session details, keypoints, and feedback logs are stored in the database. The stored data is later used to generate detailed performance summaries and progress reports that help users understand their long-term improvement.

3.2 Design of Functions

The functional design of the system includes real-time webcam frame capture, detection of skeletal landmarks using pose estimation techniques, calculation of joint angles, comparison of angles with ideal reference values, and generation of corrective feedback. Vector mathematics and trigonometric calculations are used to compute joint angles, while advanced pose-detection models identify key joints like elbows, shoulders, hips, and knees. A feedback engine analyzes deviations and produces on-screen or voice-based instructions to guide the user during exercise execution. Each session’s posture data and feedback are saved in the database, and the system automatically generates periodic progress reports by analyzing historical data and calculating average scores, best-performed exercises, and areas needing improvement.

3.3 Design of User Interface

The user interface is designed to be simple and interactive. It begins with a welcome page followed by a login screen where the user enters their credentials. After logging in, the user is directed to the exercise-selection interface, where each exercise is displayed with a description and reference image. Once an exercise is chosen, the live-movement screen opens, displaying the webcam feed with an overlaid skeleton model, real-time angle values,and a feedback panel showing corrective messages. At the end of each session, a summary screen displays the user's final score, accuracy graph, and list of mistakes. The progress dashboard provides a long-term view of the user's performance, presenting charts, trend lines, and improvement statistics across multiple sessions.

3.4 Design of Reports

The report design includes detailed session-performance reports, joint-angle error distribution graphs, and long-term progress charts. These reports highlight the user's accuracy levels, frequency of mistakes, and improvement patterns across various exercises. They also identify recurring errors, such as improper knee bending or incorrect shoulder alignment, helping users understand and correct their weaknesses. By integrating all these components— database design, interface design, movement analysis, and reporting—the system offers an intelligent, real-time physiotherapy assistance platform that enhances rehabilitation efficiency and supports continuous progress tracking.

Chapter 4 — Implementation

4.1 Modules Implemented

The implementation phase focuses on converting the system design into a functional physiotherapy assistance application. Several core modules were developed to ensure smooth workflow and accurate movement analysis. The system begins with the Welcome Module, which guides the user into the platform, followed by a User Authentication Module that manages login and verifies user credentials. The core functionality is handled by the Pose Detection Module, which captures skeletal key points from the webcam, and the Angle Calculation Module, which computes joint angles needed for exercise evaluation. These values are then processed by the Real-time Feedback Module, which provides instant corrective suggestions based on posture deviations. An Admin Exercise Upload Module allows administrators to add new exercises and reference models to the system. To support user improvement over time, the Progress Tracking Module stores session data and generates performance summaries.

For data storage, essential tables were created in MySQL/SQLite, including Users, Exercises, Sessions, Key points, Feedback Logs, and Progress Reports. These tables store user information, exercise definitions, session details, real-time key points, generated feedback, and long-term progress data, enabling the system to function efficiently and maintain structured movement-analysis records.

4.2 Tables with attributes

The implementation of the physiotherapy assistance system involves several core modules, each with distinct attributes that contribute to the overall functionality of the application. The Welcome Module serves as the initial entry point and provides users with the first interface they encounter. Its main attributes include loading the starting interface, guiding users to the login page, and offering basic navigation instructions. The User Authentication Module manages login and registration processes, featuring attributes such as input validation, secure credential verification, database lookup for existing users, and initialization of user sessions once authentication is successful.

The Pose Detection Module is central to the system's functionality, as it integrates with the webcam to capture live video and extract skeletal key points using a pose estimation model. Its key attributes include webcam access, real-time frame processing, detection of body landmarks, and error handling in case the camera is unavailable. Complementing this, the Angle Calculation Module takes the extracted skeletal coordinates and computes relevant joint angles needed for assessing exercise movements. Its attributes consist of mathematical angle computations, identifying required landmark pairs, determining angle thresholds, and feeding calculated values into the feedback system.

To ensure users receive instant movement guidance, the Real-time Feedback Module analyzes posture and provides corrective instructions whenever deviations from ideal form are detected. Its attributes include posture comparison algorithms, real-time alert generation, synchronized processing with pose and angle data, and delivery of feedback in visual or textual form. For system administrators, the Admin Exercise Upload Module allows new exercises to be added into the platform. The attributes of this module include uploading exercise reference models, validating exercise metadata, updating the exercise database, and managing reference angle configurations.

Finally, the Progress Tracking Module supports long-term user improvement by recording exercise session data and generating performance summaries. Its attributes include storing session logs, retrieving historical performance data, generating visual summaries or analytics, and maintaining structured records in the database. Together, these modules and their attributes form a cohesive system capable of performing real-time physiotherapy monitoring, providing feedback, and enabling continuous improvement for users.

The Real-time Feedback Module uses calculated angles and posture status to offer immediate corrective guidance. Its attributes include pre-defined rule sets for each exercise, detection of movement errors, generation of text alerts or color-coded warnings, optional audio cues, and real-time synchronization with body movement. It helps users maintain correct form throughout the session.

The Admin Exercise Upload Module supports system scalability by enabling administrators to add new exercises, reference videos, descriptions, and target angle ranges. Its attributes include file validation, metadata extraction, secure upload handling, database updates, and consistency checks to ensure the added exercise aligns with system requirements.

Chapter 5 — Testing

The testing phase is a critical component of the system development lifecycle, ensuring that all functional and non-functional requirements are met before deployment. The proposed physiotherapy monitoring system underwent comprehensive testing to verify its accuracy, stability, and overall performance. Various test cases were designed and executed to validate core modules, including user authentication, real-time pose detection, joint-angle calculation, corrective feedback mechanisms, database logging, and hardware-related error handling.

5.1 Testing Objectives

The primary objectives of the testing phase were:

- To verify that each system module behaves according to specifications.
- To identify and resolve functional issues, inconsistencies, or performance bottlenecks.
- To ensure that the system delivers accurate pose-estimation results and reliable feedback.
- To test the system’s response to abnormal or error-prone conditions, such as hardware disconnection.
- To confirm robustness, user-friendliness, and reliability under real-world usage scenarios.

5.2 Testing Methodology

A combination of unit testing, integration testing, functional testing, and system testing was performed:

1. Unit Testing

Each module—such as the authentication module, pose detection module, feedback logic, and database operations—was tested individually to ensure correct behavior at the function level.

2. Integration Testing

Modules were connected and tested as a group. For example, pose detection output was integrated with joint-angle calculations and the feedback engine to ensure seamless data flow.

3. Functional Testing

Test cases were prepared based on functional requirements (e.g., login validation, pose tracking accuracy, response to incorrect posture).

4. System Testing

The entire system was tested in a realistic environment using webcam input, simulating real user interactions to ensure end-to-end correctness.

5.3 Test Cases and Results

Several essential test cases were executed during the testing phase:

1. User Authentication

- **Valid Credentials:**
  The system successfully authenticated the user and redirected to the dashboard.
- **Invalid Credentials:**
  An appropriate error message ("Invalid username or password") was displayed without granting access.

This confirmed the correctness and security of the login mechanism.

2. Pose Detection and Landmark Extraction

- When the user came within the camera frame, body landmarks were detected correctly.
- If the system failed to identify a human body (e.g., user moved out of frame), a warning message ("Pose not detected") was displayed.
- Landmark detection accuracy was steady even under moderate lighting variations.

3. Joint-Angle Computation and Incorrect Posture Detection

- The system accurately computed joint angles for elbows, shoulders, knees, and hips.
- When the user performed an incorrect movement:
  - The system generated instant corrective feedback such as "Raise your arm higher" or "Correct your posture."
- Threshold-based deviation detection produced consistent and reliable results.

4. Feedback Generation

- Textual feedback was displayed in real time with no noticeable latency.
- Both corrective alerts and success confirmations were validated for correctness.

5. Hardware Error Handling

- When the webcam was disconnected or unavailable, the system displayed a clear error message and prevented further processing.
- System stability was preserved without crashes or unexpected termination.

6. Data Logging and Storage

- Exercise scores, timestamps, and movement metrics were correctly recorded in the database.
- Historical data was retrieved without errors, confirming database integration accuracy.

5.4 Test Summary

All test cases related to:

- Login validation
- Real-time pose detection
- Joint-angle computation
- Corrective feedback
- Error and exception handling
- Camera disconnection scenarios
- Database storage and retrieval

Chapter 6 — User Manual

6.1 Installation Procedure

The installation process ensures that the physiotherapy monitoring system is correctly configured and ready for execution. The following steps outline the complete setup procedure:

Step 1: Install Python Environment

The system requires Python 3.10 or higher. Users must download and install Python from the official website. During installation, the *“Add Python to PATH”* option should be enabled to ensure proper command-line functionality.

Step 2: Install Required Python Libraries

After Python is installed, the necessary libraries must be installed using **pip**. These include:

- **OpenCV** – for real-time video capture and image processing
- **MediaPipe** – for pose estimation and landmark extraction
- **NumPy** – for mathematical operations and joint-angle computation
- **Matplotlib** – for generating visual graphs and progress charts

These libraries can be installed using the command:

pip install opencv-python mediapipe numpy matplotlib

Additional optional packages may be required depending on system features (e.g., `mysql-connector-python` or `sqlite3` for database connectivity).

Step 3: Configure the Database

The system supports MySQL or SQLite**:**

- For MySQL**,** the user must install MySQL Server, create a database, and update connection credentials (host, username, password, and database name) in the project’s configuration file.

- For SQLite**,** no installation is required; the system will automatically generate a `.db` file.

The database tables for storing user details, exercise sessions, and performance logs must be created as per schema provided in the project.

Step 4: Set Up the Project Environment

All project files must be placed in a working directory. Environment variables, database credentials, and file paths should be configured as needed. Users should ensure their webcam is functioning properly, as it is required for pose detection.

Step 5: Execute the Main Application

Once the setup is complete, the user can launch the system by running the main script:

python main.py

Upon execution, the application interface initializes and displays the welcome screen. The user can then:

- Log in or register
- Select a physiotherapy exercise
- View real-time skeletal tracking
- Receive corrective feedback
- Monitor progress through the dashboard

Step 6: User Navigation Through the Interface

The interface typically includes the following screens:

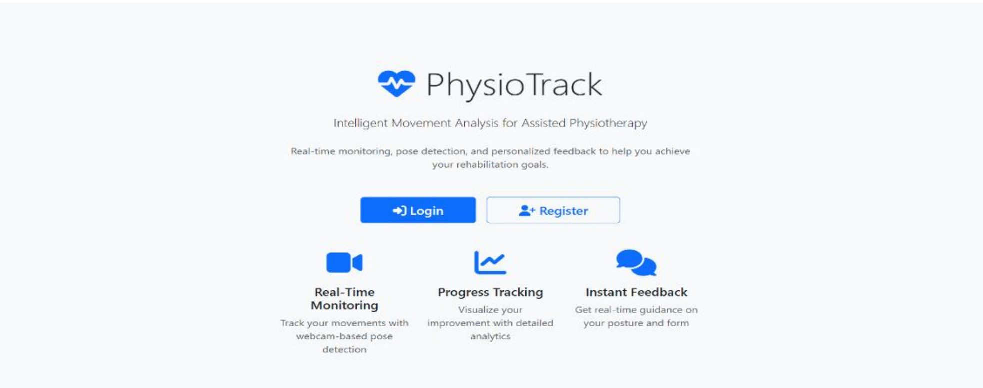
1. **Welcome Page** – Introduction and entry point
2. **Login/Registration Screen** – User authentication
3. **Exercise Selection Page** – Allows users to choose an exercise
4. **Real-Time Monitoring Window** – Displays webcam feed and pose skeleton
5. **Feedback Panel** – Shows live corrections and posture alerts
6. **Progress Dashboard** – Displays historical performance and session analytics

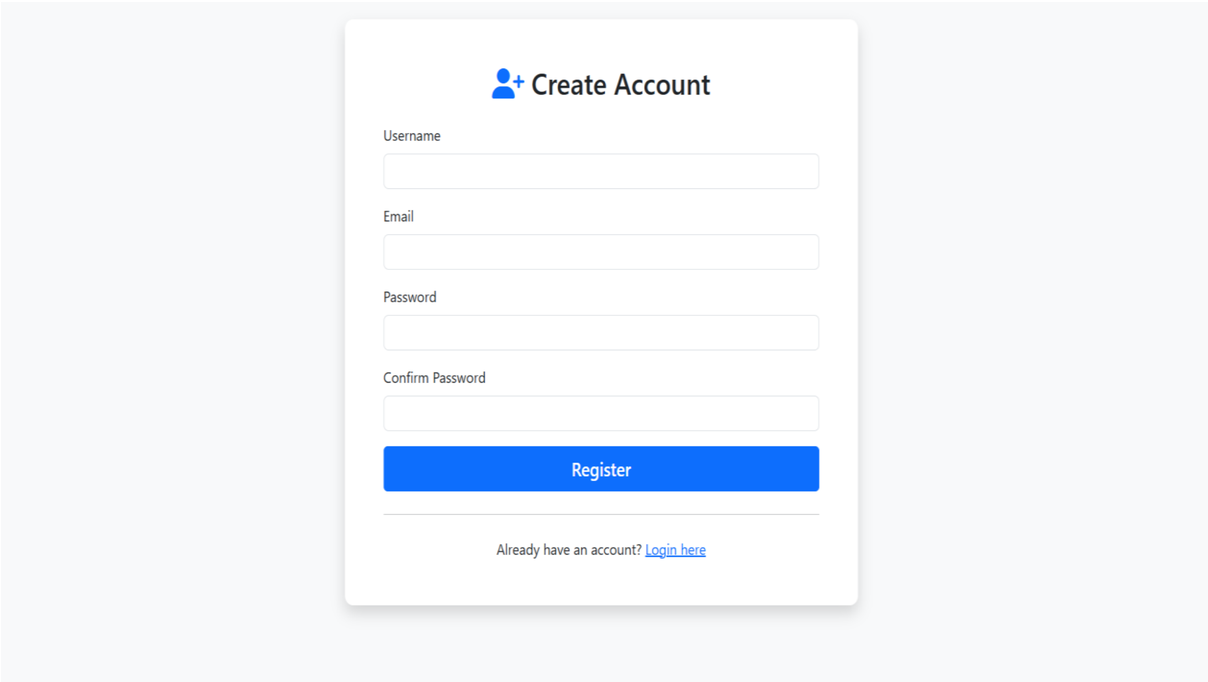
6.2 Requirements

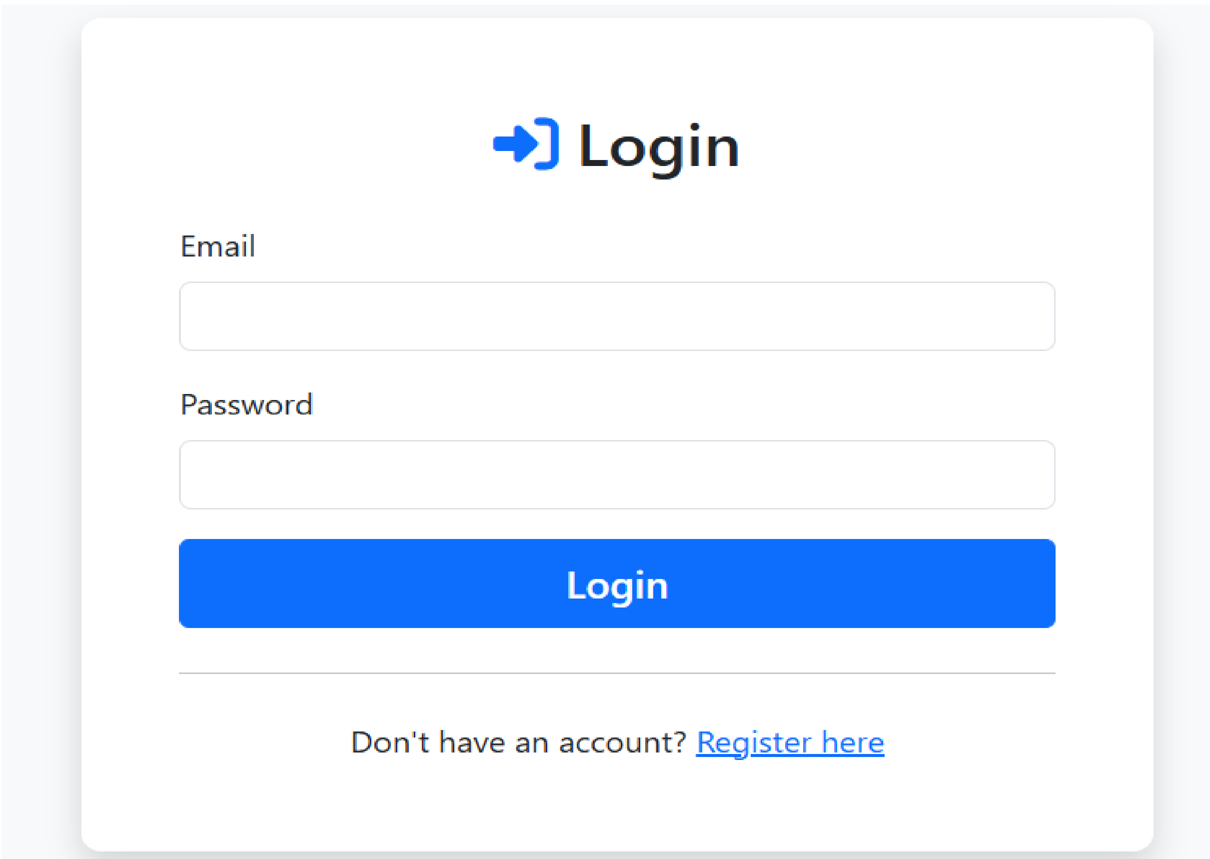
The user manual for the physiotherapy monitoring system requires clear documentation that guides users through the installation, setup, navigation, and operation of the application. It must include detailed instructions for installing Python 3.10 or higher, ensuring that Python is added to the system PATH, and installing essential libraries such as OpenCV, MediaPipe, NumPy, and Matplotlib using pip. The manual should also describe the prerequisites for database configuration, including the installation of MySQL Server if MySQL is used or the automatic handling of SQLite databases. Users must be guided through creating the required database tables for storing user information, exercise sessions, and performance logs, as well as configuring credentials such as host, username, and password. In addition to software requirements, the manual must outline the necessary hardware such as a functioning webcam, sufficient RAM and processing power, and adequate storage space.

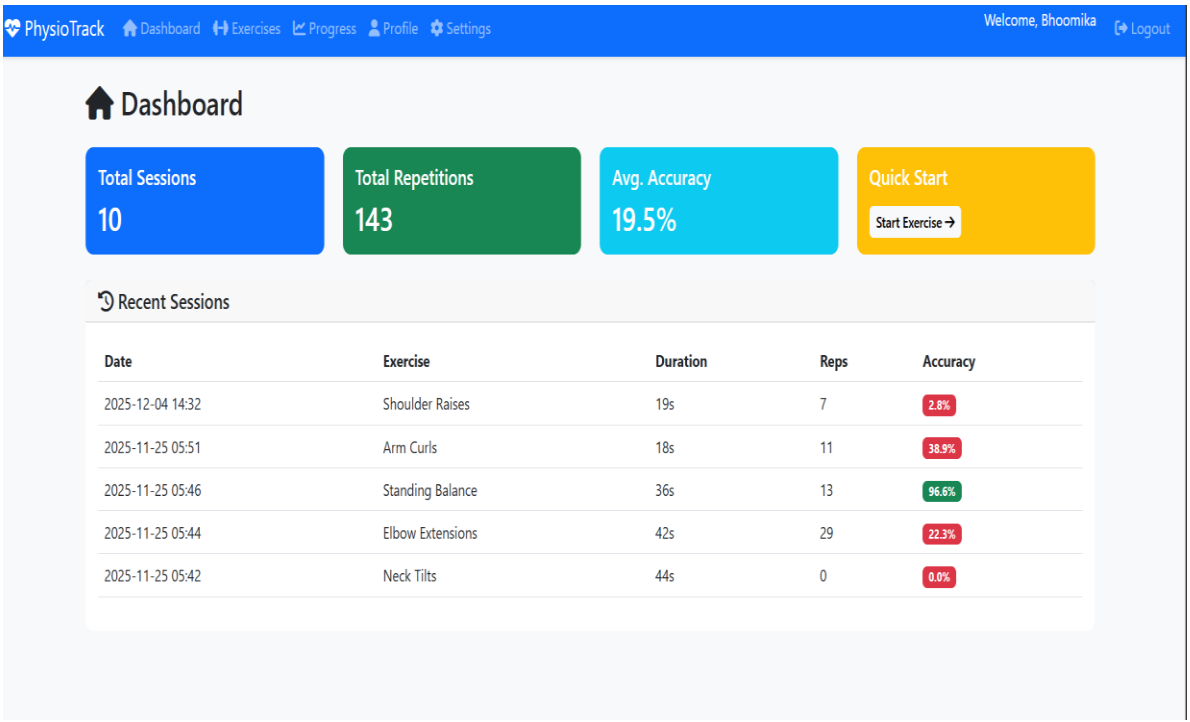
The user manual must also contain instructions for setting up the project environment by placing all project files in a working directory and configuring environment paths and variables. It must explain how to launch the system using the command python main.py and describe the initialization process that leads to the welcome screen. Furthermore, the manual should present detailed navigation guidelines for each interface component, including the welcome page, login and registration screen, exercise selection page, real-time pose detection window, feedback panel, and progress dashboard. It should describe how users can log in, choose physiotherapy exercises, follow real-time skeletal tracking, receive corrective feedback, and view performance analytics. Overall, the Chapter 6 user manual requires comprehensive instructions, clear operational guidance, and well-structured explanations to ensure users can install, configure, and operate the physiotherapy monitoring system with ease and accuracy.

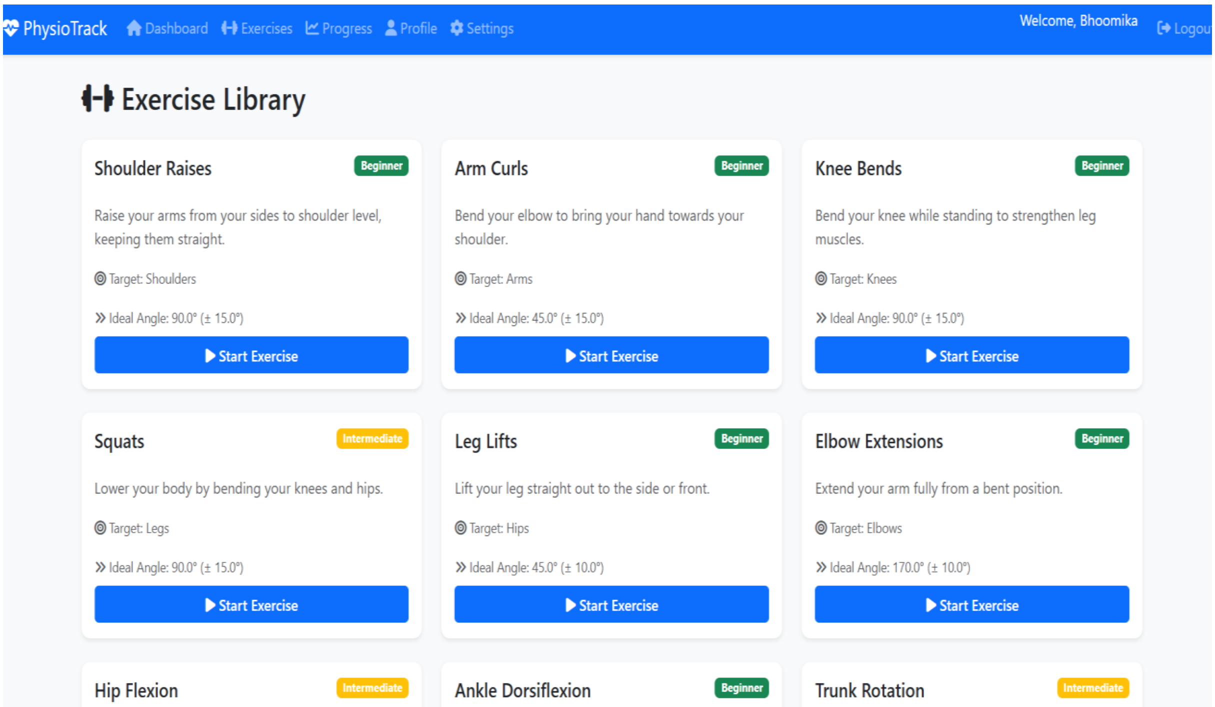
6.3 Screenshots

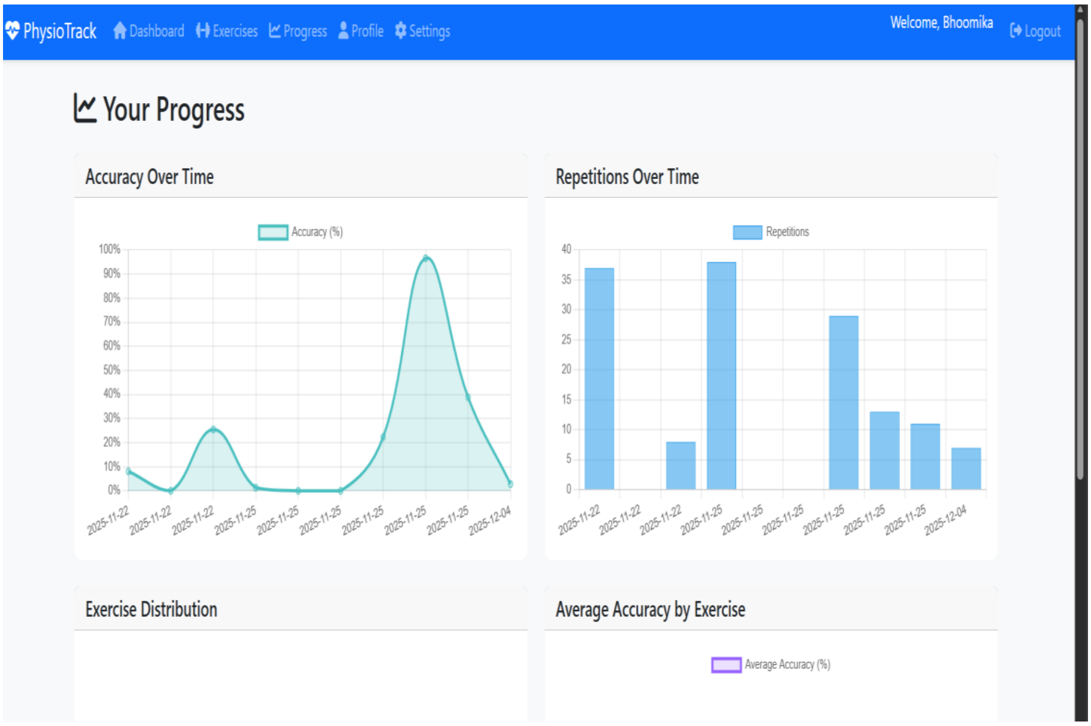



Create Account
Username
Email
Password
Confirm Password
Register
Already have an account? Login here


Login
Email
Password
Login
Don't have an account? Register here


PhysioTrack
Dashboard
Exercises
Progress
Profile
Settings
Welcome, Bhoomika
Logout
Dashboard
Total Sessions
10
Total Repetitions
143
Avg. Accuracy
19.5%
Quick Start
Start Exercise
Recent Sessions
Date
Exercise
Duration
Reps
Accuracy
2025-12-04 14:32
Shoulder Raises
19s
7
2.8%
2025-11-25 05:51
Arm Curls
18s
11
38.9%
2025-11-25 05:46
Standing Balance
36s
13
96.6%
2025-11-25 05:44
Elbow Extensions
42s
29
22.3%
2025-11-25 05:42
Neck Tilts
44s
0
0.0%


PhysioTrack
Dashboard
Exercises
Progress
Profile
Settings
Welcome, Bhoomika
Logou
Exercise Library
Shoulder Raises
Beginner
Raise your arms from your sides to shoulder level, keeping them straight.
Target: Shoulders
Ideal Angle: 90.0° (± 15.0°)
Start Exercise
Arm Curls
Beginner
Bend your elbow to bring your hand towards your shoulder.
Target: Arms
Ideal Angle: 45.0° (± 15.0°)
Start Exercise
Knee Bends
Beginner
Bend your knee while standing to strengthen leg muscles.
Target: Knees
Ideal Angle: 90.0° (± 15.0°)
Start Exercise
Squats
Intermediate
Lower your body by bending your knees and hips.
Target: Legs
Ideal Angle: 90.0° (± 15.0°)
Start Exercise
Leg Lifts
Beginner
Lift your leg straight out to the side or front.
Target: Hips
Ideal Angle: 45.0° (± 10.0°)
Start Exercise
Elbow Extensions
Beginner
Extend your arm fully from a bent position.
Target: Elbows
Ideal Angle: 170.0° (± 10.0°)
Start Exercise
Hip Flexion
Intermediate
Ankle Dorsiflexion
Beginner
Trunk Rotation
Intermediate



PhysioTrack
Dashboard
Exercises
Progress
Profile
Settings
Welcome, Bhoomika
Logout
Your Progress
Accuracy Over Time
Accuracy (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2025-11-22
2025-11-22
2025-11-22
2025-11-25
2025-11-25
2025-11-25
2025-11-25
2025-11-25
2025-11-25
2025-12-04
Repetitions Over Time
Repetitions
40
35
30
25
20
15
10
5
0
2025-11-22
2025-11-22
2025-11-22
2025-11-25
2025-11-25
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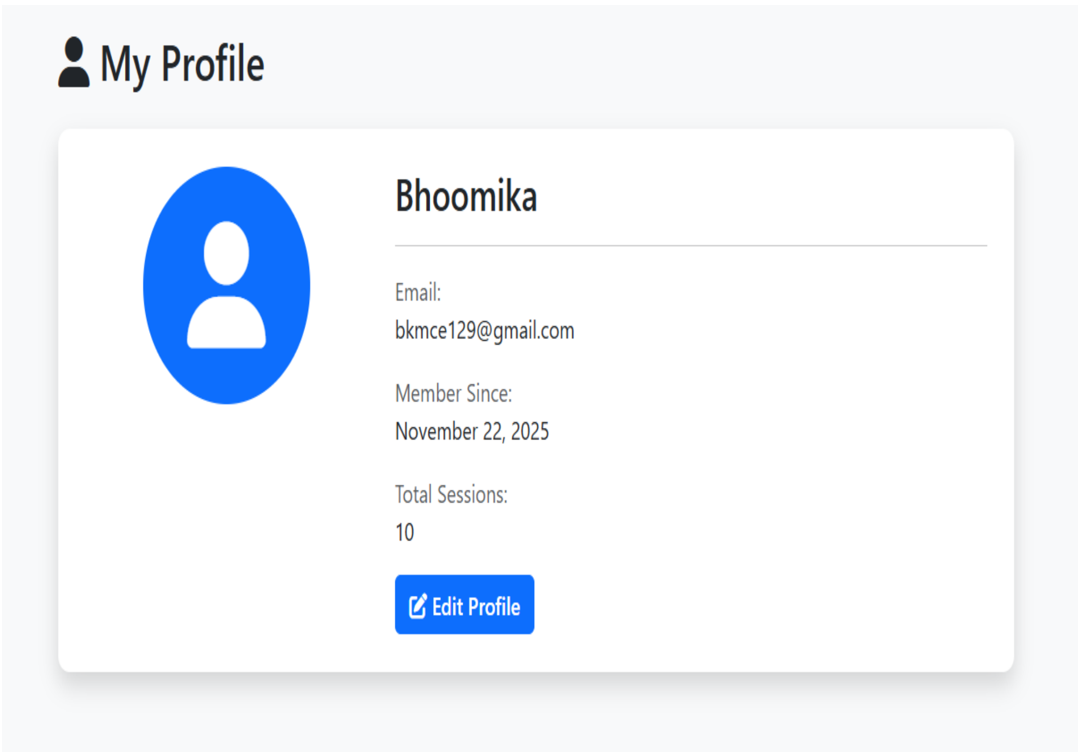
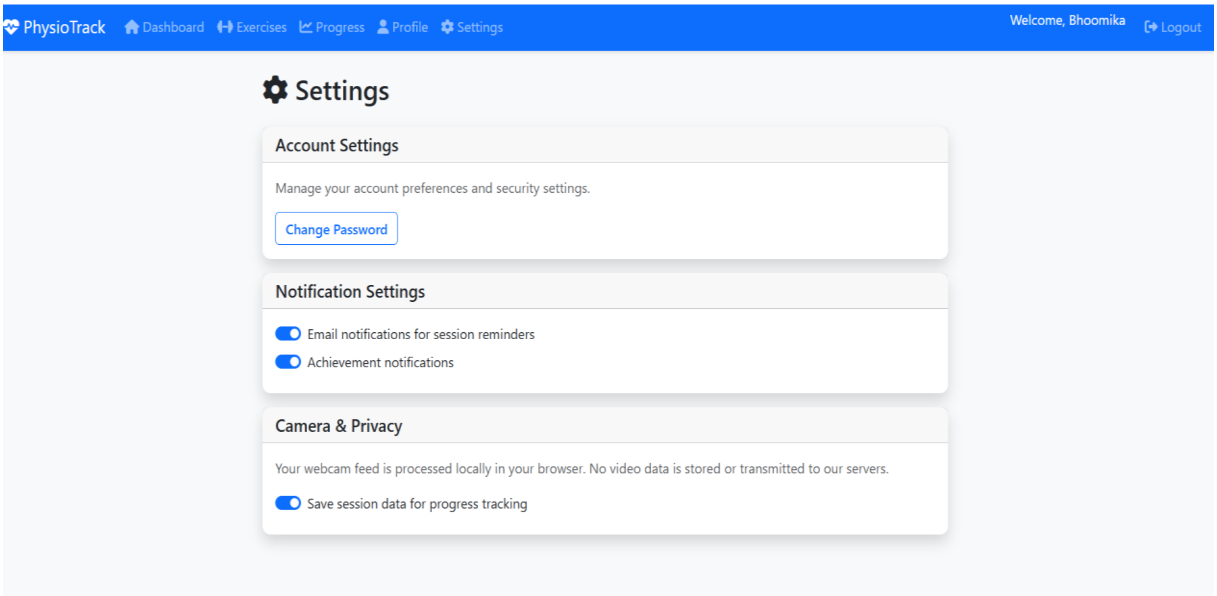
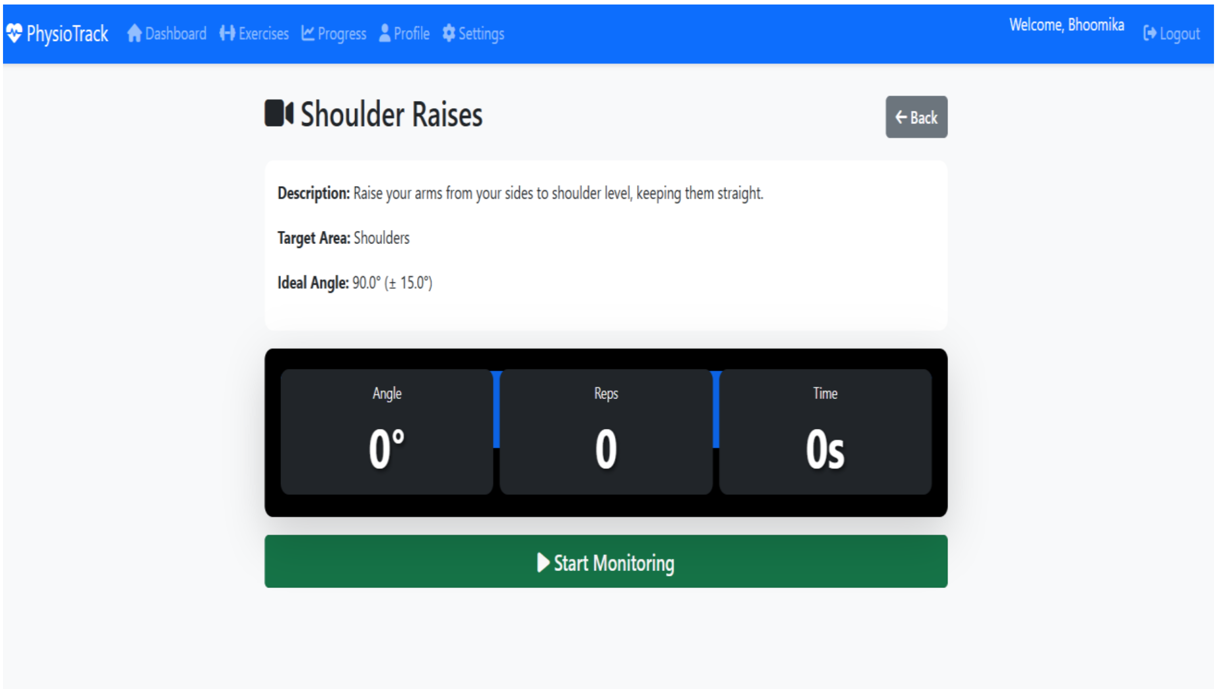
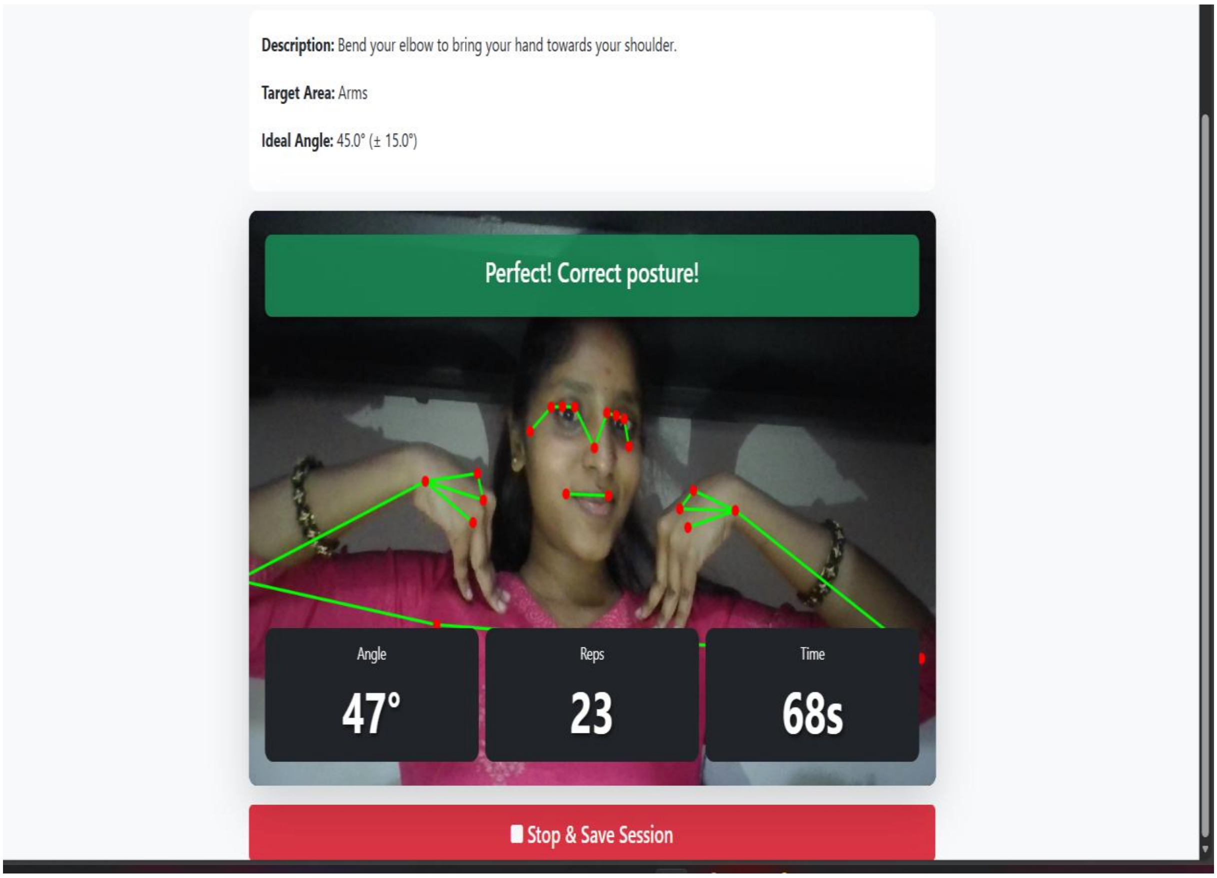
2025-12-04
Exercise Distribution
Average Accuracy by Exercise
Average Accuracy (%)



My Profile
Bhoomika
Email:
bkmce129@gmail.com
Member Since:
November 22, 2025
Total Sessions:
10
Edit Profile


PhysioTrack
Dashboard
Exercises
Progress
Profile
Settings
Welcome, Bhoomika
Logout
Settings
Account Settings
Manage your account preferences and security settings.
Change Password
Notification Settings
Email notifications for session reminders
Achievement notifications
Camera & Privacy
Your webcam feed is processed locally in your browser. No video data is stored or transmitted to our servers.
Save session data for progress tracking


PhysioTrack
Dashboard
Exercises
Progress
Profile
Settings
Welcome, Bhoomika
Logout
Shoulder Raises
Back
Description: Raise your arms from your sides to shoulder level, keeping them straight.
Target Area: Shoulders
Ideal Angle: 90.0° (± 15.0°)
Angle
0°
Reps
0
Time
0s
Start Monitoring


Description: Bend your elbow to bring your hand towards your shoulder.
Target Area: Arms
Ideal Angle: 45.0° (± 15.0°)
Perfect! Correct posture!
Angle
47°
Reps
23
Time
68s
Stop & Save Session

Chapter 7 — Conclusion and Future Scope

7.1 Conclusion

This project demonstrates the effective integration of artificial intelligence, computer vision, and physiotherapy principles to create a real-time movement monitoring system. By utilizing pose estimation, joint-angle analysis, and automated corrective feedback, the system ensures that physiotherapy exercises are performed with greater accuracy and consistency. This reduces the risk of improper posture and enhances user confidence during home-based rehabilitation.

The system eliminates the need for constant physiotherapist supervision by offering automated guidance, making physiotherapy more accessible to individuals in remote or underserved regions. The implementation successfully showcases how AI-driven solutions can support healthcare professionals, increase exercise adherence, and promote safer, more efficient rehabilitation practices.

Overall, the project achieves its objectives by providing a cost-effective, user-friendly, and reliable digital physiotherapy tool capable of assisting patients in performing exercises correctly.

7.2 Future Scope

While the current system is functional and effective, several enhancements can significantly broaden its impact and usability:

1. Mobile Application Development

Implementing the system as an Android or iOS app would increase accessibility, allowing users to practice physiotherapy exercises anywhere using their smartphone camera.

2. 3D Pose Estimation

Integration with **depth cameras** (e.g., Kinect, Intel RealSense) can enable 3D pose tracking, improving accuracy in angle measurement and detecting movements that are difficult to evaluate in 2D.

3. Wearable Sensor Integration

Incorporating **IMU sensors**, smart bands, or pressure sensors can enhance data precision, especially for complex rehabilitation exercises requiring detailed motion analysis.

4. Voice-Guided Physiotherapy

Adding voice instructions and real-time audio feedback can make the system more interactive and user-friendly, improving the user experience.

5. Adaptive Exercise Difficulty

Machine-learning algorithms can analyze user progress and automatically adjust the difficulty or intensity of exercises according to improvement levels.

6. Cloud-Based Monitoring

Integrating cloud storage and remote dashboards would allow physiotherapists to monitor patient progress from anywhere, making the system scalable for hospitals and clinics.

7. Gamification and Engagement

Adding game-like elements such as points, levels, and visual rewards could increase user motivation and adherence to long-term rehabilitation routines.

These enhancements can transform the system from a standalone application into a comprehensive digital physiotherapy ecosystem.

7.3 References

The following sources and documentation provided foundational support for the development of this project:

1. **MediaPipe Pose Documentation** – Used for understanding pose-estimation techniques, landmark extraction, and model architecture.
2. **OpenCV Documentation** – Provided guidance for video processing, image manipulation, and real-time frame handling.

3. **NumPy and Matplotlib Documentation** – Used for numerical operations, angle calculations, and graph generation.
4. **IEEE Research Papers** – Provided theoretical insights on AI in physiotherapy, pose estimation, and human movement analysis.
5. **WHO Rehabilitation Guidelines** – Ensured the exercises selected align with global physiotherapy standards and evidence-based rehabilitation practices.
6. Additional academic journals and publications related to pose estimation, computer vision, and activity recognition.