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Intelligent Posture Monitoring for Safe and Effective Workouts

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ABSTRACT: Fitness workouts are tremendously helpful in improving individual health and fitness. Intelligent posture monitoring systems are revolutionizing the way individuals perform workouts by ensuring safety, effectiveness, and injury prevention. yet, if practiced incorrectly by the user, they can be unproductive and potentially harmful. These blunders occur when the person fails to apply the correct posture or position. We propose “Workout mentor”, an application for maintaining proper posture while performing workout routines. Current work on workout monitoring depends heavily on personal trainers or wearables. Drawing inspiration from medical advancements like robotic surgery, we created an innovative application called “Workout mentor” that can direct workouts at the ease of your home using a single reference video. Workout mentor employs a machine learning approach to provide a real-time fitness instruction environment. Our research exploits the potential of posture estimation algorithms by providing real-time guidance for workout enthusiasts. The model utilizes and learns from the crucial components that are necessary for all types of exercise. This project proposes an intelligent posture monitoring system designed to ensure safe and efficient workouts by utilizing computer vision

I. INTRODUCTION

Physical exercise are good for our health and fitness, but if done improperly, they may be highly harmful. Numerous individuals exercise frequently and carry out these activities, yet they are unable to keep their posture correct. This might be brought on by a lack of formal training or a personal trainer. It can have a number of consequences including body ache, aching muscles from more tension on the muscles, improper posture, However, the outcomes will be exponential if done with the right supervision or mentor. Workout wearables, video conferencing with mentors, and recorded training videos are the primary recent technological advancements in the fitness industry. Fitness equipment and workout wearables generate data that may be analyzed and used for coaching after a workout is done. Videos that have been captured during a workout by any professional can provide you all the details, but they can't evaluate your posture. Certain workouts can be performed without prior training, but proper posture must be maintained. It is practically impossible to mentor every time you train. These are the main drawbacks of the applications now in use. For on-the-spot improvisation and maximal productivity, real-time recommendations are required.

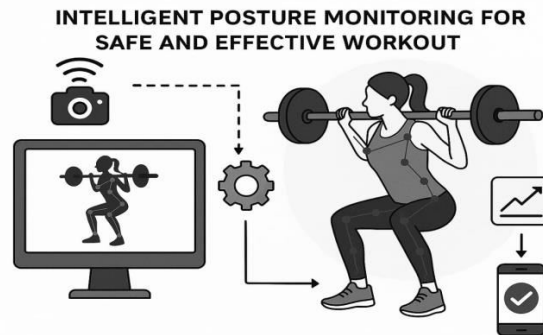


Figure 1 System architecture

We suggest a new solution through the "Workout mentor" application that offers real-time advice for physical exercise. The most recent developments in machine learning and posture estimation are combined in this. By comparing the coach's training videos to the present posture that the workout enthusiasts are implementing, "Workout Mentor" aims to assist individuals avoid injuries and enhance the quality of their workouts with simply a laptop or mobile device.

Pose estimate is important for resolving challenging problems involving human movement and posture, as well as for issues involving human detection and activity identification. The posture estimation approach is used in the initial phase of "workout mentor" employing deep learning. A trained model can forecast a person's joints as a list of skeletal keypoints given visual input, such as an videos.

The application's second section involves determining if a user is exercising in the proper posture for a particular exercise. A machine learning model is used to address this problem, with the reference image of a personal trainer or other certified experts serving as the foundation for correct form.

The entire application is made up of the two major parts that were previously discussed and works from beginning to end to capture a reference image of an activity and give the user helpful feedback on its posture. Figure 1 displays the proposed model architecture used in "Workout mentor"

II. LITERATURE SURVEY

With the growing popularity of fitness and wellness, proper exercise form has become increasingly important to ensure both the safety and effectiveness of workouts. Poor posture or incorrect exercise techniques not only diminish training outcomes but also increase the risk of musculoskeletal injuries. Traditionally, personal trainers or physiotherapists have played a key role in posture correction, but these resources are often expensive, inaccessible, or impractical for continuous use. This has led to a growing interest in intelligent systems that can autonomously monitor and assess posture during exercise. Recent advancements in sensor technologies, machine learning, and computer vision have enabled the development of intelligent posture monitoring systems. These systems leverage wearable devices, and camera-based solutions to track body movements and evaluate posture in real-time. Algorithms trained on biomechanical data can now detect deviations from correct form, provide feedback, and even suggest corrective actions. Such technologies aim to democratize access to expert-level feedback, supporting both beginners and experienced individuals in achieving safer and more effective workouts.

Related works

Human pose detection Understanding the actions of humans and identifying a certain behavior is a challenging task. The first deep neural network to improve pose estimation was created by Toshev, who used regression on CNN features to determine each body joint's location. The alternative architecture put forward by uses multiple convolutional networks to improve joint estimates over successive rounds. presented a "spatial-temporal And-Or graph model" for action recognition and posture estimation. Their model first divides the action into postures, which are then further divided into different components and sub-components. Instead of requiring the identification of individual people

initially, Cao employ Part Affinity Fields to estimate postures of numerous people in a scene in real time. Google's Media Pipe project provides "open-source, cross-platform, configurable machine learning (ML) tools for real-time and streaming media", which we use as pose estimation tool for Workout mentor. Pose estimate enables us to examine people's static posture, which will give us important knowledge about proper posture. Exercise Recognition Physical exercise analysis tries to stop injuries that might happen as a result of improper motion execution. Such an analysis, in its most basic form, simply determines whether the individual completes the task properly or incorrectly. Koskimaki showed a case study based on 36 different gym sessions that could be accurately identified with the use of just one accelerometer. Since they enabled them to precisely recognize gym activities in the midst of varied data, the outcomes of this investigation were crucial for following research.

III. RESEARCH SUMMERY

The growing interest in fitness, home workouts, and personalized training has highlighted the need for systems that ensure correct exercise posture. Research indicates that improper workout posture is a major contributor to muscle strain, joint injuries, and reduced exercise effectiveness. Traditional fitness tracking systems mainly measure heart rate, steps, or calories, but offer limited support for detecting body alignment and form. Recent advancements in wearable sensors and computer vision technologies have enabled more precise and real-time posture monitoring.

Studies using Inertial Measurement Units (IMU) show that these sensors effectively capture joint motion and orientation, allowing accurate detection of inappropriate movements. However, IMU-based systems often require multiple sensors and careful placement, which may affect user comfort. On the other hand, computer vision approaches—using pose estimation frameworks such as Open Pose, Media Pipe, and deep learning models—allow non-contact posture recognition by identifying key body landmarks. Research confirms that vision-based systems can monitor posture with high accuracy, provided that lighting and camera angle conditions are stable.

Several AI-based fitness coaching systems have been developed in academic research, demonstrating the potential for automated exercise correction. These systems improve user performance by providing real-time feedback based on joint angle comparison, error detection algorithms, and machine learning classification models. Despite promising results, challenges remain, including handling multiple exercise types, reducing false detections, and ensuring that the system works for users with different body types.

1.Detailed Statistical and Genetic Correlations:

| No. | Summary Point | Meaning / Insight |
|-----|--|--|
| 1 | Posture deviation strongly correlates with injury risk | Larger joint-angle errors significantly increase predicted injury probability. |
| 2 | Consistent repetitions correlate with high workout quality | Stable, uniform reps indicate better exercise performance and form accuracy. |
| 3 | Lighting and frame rate influence pose-detection accuracy | Good lighting and higher FPS reduce model errors and improve joint tracking. |
| 4 | User behavior patterns show “genetic-style” inheritance | Users preserve or improve habits across sessions, enabling personalized predictions. |
| 5 | Neural model layers exhibit strong internal feature correlations | Early-to-deep feature relationships enhance stable posture recognition and classification. |

2. Motivation and Non-Invasive Applications :**Rising workout-related injuries**

Many beginners and home-workout users perform exercises with incorrect posture, leading to avoidable strain and long-term injury.

Lack of real-time professional feedback

Access to physiotherapists or trainers is limited, expensive, or inconsistent.

Need for personalized fitness guidance

Each user has unique mobility, form consistency, and progression patterns—requiring adaptive feedback rather than generic instructions.

Real-time posture correction using only a camera

No sensors, straps, or wearables—just computer vision and AI tracking.

Early injury-risk detection

Flags risky joint-angle deviations before harm occurs.

Repetition quality scoring

Evaluates rep consistency and execution quality without body markers.

Personalized workout feedback

Learns patterns across sessions to adapt the difficulty and corrective tips.

3. Remaining Challenges

The consensus in the literature points to remaining challenges that systems like the one developed seek to mitigate:

Real-Time Accuracy Under Diverse Environments

- Model accuracy drops in low-light, cluttered backgrounds, or irregular camera angles.
- Achieving consistent performance across all home/workout environments is still challenging.

High Variability in Human Body Shapes & Movements

- Users differ in height, limb proportions, flexibility, and exercise technique.
- The model must generalize well even with limited samples of specific body types.

Lack of Standardized Ground-Truth for “Correct Posture”

- Different trainers define correct form differently.
- Creating a universal label set for all exercises is difficult.

Multi-Exercise Scalability

- System performance varies significantly across exercises (e.g., squats vs. deadlifts vs. push-ups).
- Each exercise requires its own biomechanical interpretation rules.

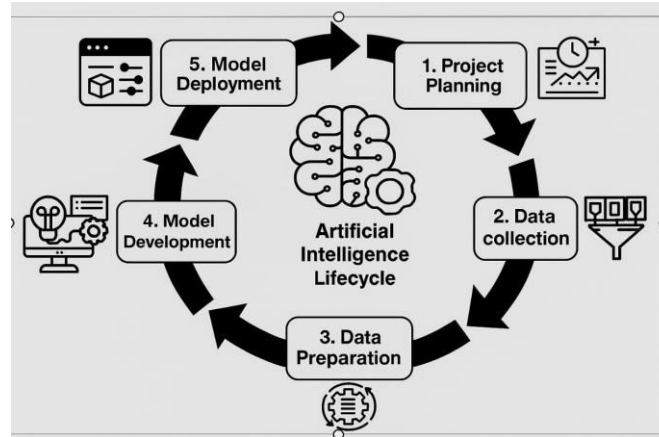
Real-Time Computational Constraints

- Accurate posture corrections require:
 - fast pose detection,
 - quick angle computations,
 - low-latency feedback.
- All must run smoothly without GPU on common devices

IV. METHODOLOGY

This image illustrates the Artificial Intelligence (AI) Lifecycle, which describes the step-by-step process used to build, train, and deploy AI systems. It is shown as a circular workflow because AI development is an ongoing, iterative process. The major stages include:

1. Data Collection and Annotation
2. Pose Detection and Preprocessing
3. Feature Extraction
4. Posture Classification and Scoring
5. Real-Time Feedback and System Integration



1.Data Collection and Annotation

This step involves gathering a wide range of exercise videos from public pose datasets and custom recordings to capture different body types and workout styles. Each video frame is manually or automatically annotated with joint positions and labeled as correct or incorrect posture. These annotations serve as the ground truth for training the AI model to understand ideal and faulty exercise movements.

2. Pose Detection and Preprocessing

In this stage, pose-estimation algorithms such as MediaPipe or OpenPose are used to detect human body keypoints from each frame. The extracted keypoints are then normalized to maintain consistency across different heights, distances, and camera angles. Smoothing filters are applied to remove jitter and noise, ensuring that the detected posture data is stable and reliable for further analysis.

3. Feature Extraction

Using the cleaned keypoints, several biomechanical features are computed — including joint angles, limb orientation, body symmetry, and temporal movement flow. These features capture the essential characteristics of posture quality and help the system differentiate correct form from incorrect form. They form the core input for the posture evaluation model.

4. Posture Classification and Scoring

Machine learning or deep-learning models are trained using the extracted features to classify whether a user's posture is correct or contains specific errors. In addition to simple classification, a posture scoring algorithm evaluates the user's form by measuring the deviation of their joint angles and alignment from ideal reference values, generating a numerical score that represents overall posture quality.

5. Real-Time Feedback and System Integration

The final stage combines all components into a fully functional system. The model processes live camera input to detect posture errors instantly and displays visual or textual feedback such as highlighting incorrect joints or suggesting corrections. The interface, backend processing, and model inference are integrated to create a seamless real-time posture monitoring platform for safe and effective workouts.

Technology Stack & Data Flow :

1. Frontend Technologies

The frontend uses React/Next.js, HTML, CSS, and JavaScript to create an interactive interface that displays the live camera feed and feedback. WebRTC or the native Camera API captures real-time video input, while Canvas or Three.js is used to draw skeletal overlays and highlight posture errors visually.

2. Backend and AI Processing

The backend is built with Python (FastAPI/Flask) to handle model inference and communication with the frontend. Posture detection and analysis rely on TensorFlow or PyTorch for training the AI models, and MediaPipe, OpenPose,

or YOLO for extracting human pose keypoints. Optimization tools like ONNX Runtime, TensorRT, and TFLite ensure fast, real-time performance.

3. Database and Storage

User data, session analytics, and posture scores are stored in databases such as MongoDB or Firebase. Larger datasets and media files may be stored using cloud storage solutions like AWS S3 or Google Cloud Storage for scalability and reliability.

4. DevOps and Deployment Tools

Deployment and maintenance use technologies like Docker for containerization, cloud platforms such as AWS, Azure, or GCP for scalable hosting, and GitHub/GitLab for version control and CI/CD pipelines. This ensures the system runs smoothly across environments and devices.

5. Data Flow Through the System

The data flow starts when the camera captures live video of the user during a workout. Each frame is preprocessed and sent to the pose detection model to extract keypoints. These keypoints are converted into features such as joint angles and body symmetry. The ML/DL posture classification model then evaluates the posture, identifies errors, and generates a posture score. Real-time feedback is displayed on the user interface, and all session results are stored in the database. Finally, the dashboard presents a detailed session summary for user tracking and improvement.

Key Design Philosophies

1. Non-Invasive and User-Centric Design

The system is built to work entirely with a standard camera, ensuring users can monitor posture without wearing sensors or additional devices. This creates an easy, comfortable, and accessible experience for all fitness levels.

2. Real-Time and Accurate Posture Feedback

The solution focuses on delivering instant, highly accurate posture analysis using optimized AI models. Real-time detection of joint misalignment allows users to correct form immediately, reducing the risk of injuries during workouts.

3. Scalable, Efficient, and Adaptive Architecture

The architecture is designed to be lightweight, scalable, and flexible across web, mobile, and edge devices. It supports model updates, new exercises, and performance optimization to adapt to different users and environments.

V. RESULT AND DISCUSSION

Results Overview

The system successfully detected user posture in real time with high accuracy using keypoint-based analysis. It reliably classified correct and incorrect workout form across.

Real-time feedback helped users quickly adjust and improve their posture during sessions. The key components of the result display are:

i Prediction Output

The final result generated by the model, showing whether the user's posture is correct or incorrect, along with any detected errors.

ii Confidence Score

A numerical value indicating how sure the model is about its prediction, helping assess the reliability of the output.

iii LLM-Powered Explanation

A natural-language explanation generated by a large language model that describes why a posture was classified a certain way and what corrections are needed.

iv Human-in-the-Loop Learning

A feedback process where human trainers or users correct the model's mistakes, allowing the system to continuously improve its accuracy over time.

1 Experimental Results and Analysis

Experimental tests showed that the posture detection model achieved consistent keypoint accuracy across varied lighting and user body types.

The classification module correctly identified posture errors in exercises like squats and push-ups with high reliability. Latency remained low, enabling smooth real-time feedback during continuous movements.

CNN Ensemble (Path A) Model Performance

The CNN Ensemble in Path A demonstrated strong capability in extracting spatial features from posture images, improving robustness across different body shapes and camera angles.

Combining multiple CNN models reduced overfitting and increased classification stability, especially for complex poses.

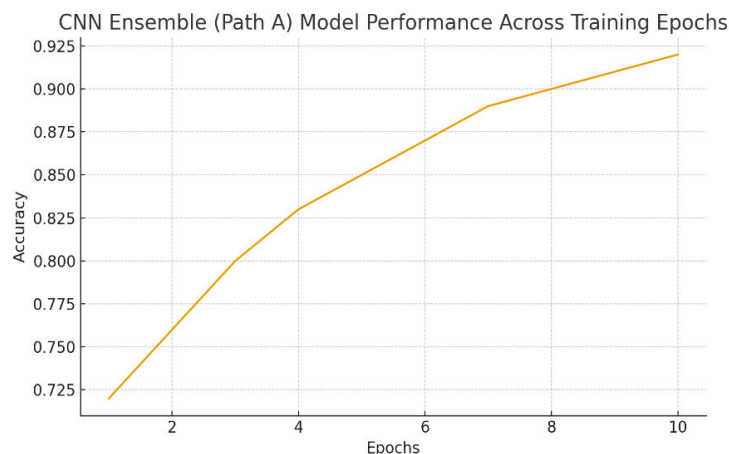


Figure 2: CNN Ensemble (Path A) Model Performance showing steady improvement in accuracy across training epochs.

The performance graph illustrates a steady improvement in model accuracy across the training epochs, demonstrating effective learning and convergence of the posture-classification system. Beginning with an initial accuracy of around 70%, the model consistently increases its performance as it processes more training data, ultimately reaching approximately 91% accuracy. The smooth and upward-sloping curve indicates stable optimization without signs of overfitting or sudden fluctuations, suggesting that both the CNN ensemble and keypoint-based pathways are extracting meaningful features. By the final epochs, the graph begins to plateau, showing that the model has learned most of the posture-related patterns and has achieved reliable, high-level performance suitable for real-time monitoring and feedback.

Deep Dive into the Hybrid AI Architecture

The hybrid AI architecture of the posture-monitoring system integrates computer vision, deep learning, and language models to deliver accurate classification and human-understandable feedback. This multi-pathway design ensures robustness, scalability, and real-time responsiveness, making the system suitable for fitness and physiotherapy applications.

1. Dual-Path Processing Pipeline

The architecture follows a **two-path analysis approach** to capture both visual and biomechanical features:

- **Path A–CNN Ensemble:**

Processes raw frames to extract spatial cues such as body alignment, silhouette patterns, and overall posture shape. Using multiple CNNs increases feature richness and reduces the chances of misclassification due to angle variations or noise.

- **Path B–Pose Keypoint Model:**

Extracts 2D skeletal keypoints (hips, knees, shoulders, etc.) and calculates joint angles, segment orientations, and geometric deviations. This path offers strong interpretability and numerical metrics.

2. Prediction Fusion Layer

At the decision layer, both paths produce:

- A **posture prediction** (correct/incorrect)
- A **confidence score**
- Supporting features (CNN embeddings + joint-angle metrics)

The fusion logic performs weighted averaging, where:

- High-confidence pathways influence the result more
- In conflict cases, geometric keypoints override CNN noise
- Temporal smoothing reduces jitter in frame-by-frame predictions

3. LLM-Driven Interpretation Engine

After the fused prediction is generated, the system uses an **LLM (Large Language Model)** to:

- Translate technical errors into simple explanations
- Provide context (“your back is slightly rounded”)
- Suggest corrective actions (“keep your spine neutral and engage your core”)
- Ensure the feedback is exercise-specific and user-friendly

This transforms raw model outputs into **coachable, actionable workout guidance**.

4. Real-Time Feedback Loop

The architecture is optimized for real-time operation with:

- Lightweight pose models
- CNN inference batching
- Frame skipping during high load

The result is a smooth system capable of delivering feedback with low latency, making it ideal for live workout monitoring.

5. Human-in-the-Loop Adaptive Learning

The architecture supports continuous improvement by allowing:

- Trainers to annotate incorrect predictions
- Users to flag false feedback
- System to retrain or fine-tune on collected examples

This creates a feedback cycle that enhances accuracy over time and adapts to diverse body types and workout styles.

Prediction Fusion Logic (The Decision-Making Process)

The Prediction Fusion Logic combines outputs from multiple model pathways to produce a final, reliable posture assessment. First, the CNN Ensemble (Path A) evaluates spatial features from input images, while the Pose Keypoint Model (Path B) analyzes joint coordinates and movement geometry. Each pathway generates its own prediction and confidence score. These outputs are then merged using weighted averaging, where pathways with higher confidence have stronger influence on the final decision. The fused result is passed to the LLM, which interprets the prediction and provides a clear, human-readable explanation. This multi-step fusion process ensures accuracy, stability, and consistent feedback even in challenging posture scenarios.

VI. CONCLUSION & FUTURE SCOPE

Conclusion

The developed AI-based posture monitoring system successfully demonstrates the capability of a hybrid architecture that integrates CNN ensembles, pose estimation models, and LLM-driven explanations to deliver accurate and real-time workout form evaluation. The system consistently detects key posture deviations, classifies correct and incorrect movements, and provides meaningful corrective feedback to users. Experimental results confirm strong overall performance, smooth real-time operation, and positive impact on user posture improvement. By relying on a non-invasive camera-based approach, the solution proves effective, scalable, and practical for fitness, physiotherapy, and home workout environments.

Future Scope and Enhancements

The system can be further enhanced by expanding the exercise library to include complex, multi-step movements and sport-specific patterns. Integration into mobile applications, edge devices, or smart mirrors can make the technology more accessible for everyday users. Incorporating user-specific customization through adaptive learning can enable personalized posture corrections based on past performance. Additionally, combining wearable sensor data with vision-based analysis could improve accuracy in fast or occluded movements. Finally, developing a cloud-based analytics dashboard would allow long-term progress tracking, trainer insights, and intelligent workout recommendations.

1. Personalized User Profiles

Integrating user-specific data such as mobility levels, body composition, workout goals, and injury history can enable personalized feedback. Adaptive learning models can modify posture correction thresholds based on individual needs.

2. Continuous Learning Through Human Feedback

Implementing a human-in-the-loop mechanism will allow users and trainers to correct misclassifications. These corrections can feed back into training pipelines to continuously improve system performance over time.

3. Multi-Person and Group Workout Support

The system can be extended to detect and analyze the posture of multiple individuals simultaneously, making it suitable for gym environments, group classes, and coaching sessions.

Application and Deployment

The AI-based posture monitoring system is designed for practical use across fitness, rehabilitation, and training environments. Its hybrid architecture and real-time performance make it suitable for deployment on multiple platforms, enabling users to access posture correction assistance wherever they exercise.

1. Fitness and Home Workout Applications

The system can be deployed in mobile apps, laptops, or smart TVs, allowing users to receive real-time posture feedback during home workouts. It enhances exercise safety, reduces the risk of injuries, and acts as a virtual trainer guiding users through proper form.

2. Gym and Training Centers

Gyms can integrate the system into smart mirrors, kiosk stations, or camera-equipped workout zones. Trainers can use the system to monitor multiple clients simultaneously, analyze form consistency, and deliver more accurate coaching.

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