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IoT-Enhanced Posture Detection Mechanism with RTS Health Monitoring and Safety Alerts

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Abstract:

Exercise-related injuries have increased lately and most of them occur due to incorrect body posture. This paper presents a novel approach that combines pose detection and IoT-based health monitoring to enhance the safety and effectiveness of people. Using OpenCV, system accurately detects exercise posture and counts number of reps as well as analyses the angle of movement to ensure correct form by using custom-built algorithms and provides real time feedback. The system is further designed for future integration with IoT health sensors, to track real-time physiological metrics. The integration of IoT sensors would enable the system to issue alerts if critical thresholds are exceeded, thereby enhancing user safety. Initial tests demonstrate high accuracy in repetition counting and real-time feedback, with a user-friendly interface. The system achieved an average success rate of over 95% across exercises, with Plank reaching 100% success in certain scenarios. Deadlift also hit 100%, while Push-Ups and Burpees showed success rates between 94%–98%.

Keywords *Pose detection, MediaPipe, OpenCV, physiological metrics, Wearable IoT devices*

1 Introduction

1.1 Background

The post-Covid period has brought significant awareness among individuals regarding health, fitness, proper diet and nutrition. A new wave of fitness culture has begun, and the number of people hitting the gym has notably increased. But this culture has also seen a rise in gym-related injuries. These injuries are often due to improper form, lack of supervision, or overestimating one's capabilities while using equipment or performing exercises. Many existing systems lack real-time feedback or physiological monitoring, leaving users prone to injuries during intense workouts. Therefore, our approach is to develop a system with emerging technologies such as AI/ML and IOT to provide new opportunities to revolutionise exercise monitoring by offering real-time posture correction and safety alerts.

According to a report by ABC Fitness, gym check-ins in Q1 2024 saw a significant rise of 60% compared to the previous year, with a total of 184 million gym check-ins in the U.S. alone, nearly doubling pre-pandemic levels. This indicates a growing trend in fitness engagement, reflecting a shift in priorities towards health and wellness in the aftermath of the pandemic. Figure 1 shows the increasing trend in gym check-ins, highlighting the post-Covid surge in fitness activity and the growing demand for gym services.

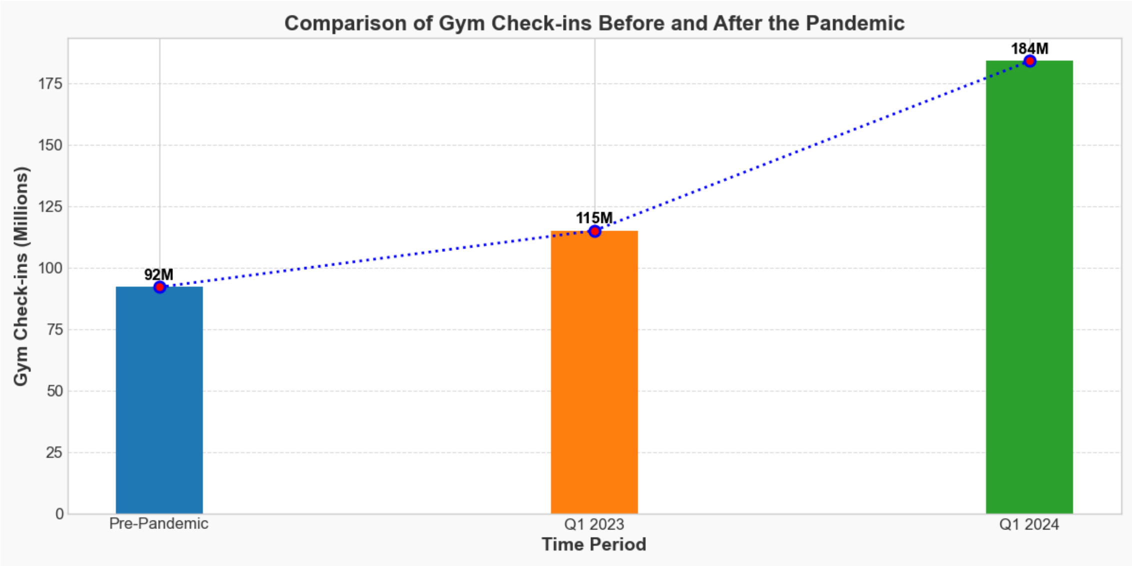

Figure 1 Gym Usage Before and After Post-Covid Period

A study conducted by Maestro et al. (2022) highlights the impact of COVID-19 on professional athletes, particularly football players, who experienced a significant increase in injuries after returning to play post-recovery. The study found that players diagnosed with COVID-19 showed a two-fold increase in injury incidence after returning to training and matches, especially in high intensity environments. Injury rates during training and matches increased from 5.1 to 10.6 injuries per 1000 hours and from 17.6 to 56.3 injuries per 1000 hours, respectively, compared to the control group. These findings underline the importance of monitoring physical health and posture, not only in post-recovery scenarios but also in general fitness and athletic activities.

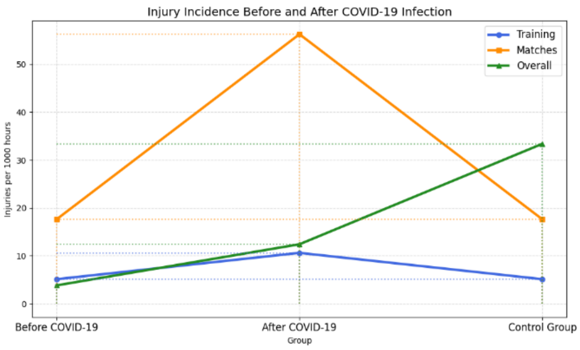

Figure 2 Injury incidence before and after COVID-19 in football players

1.2 Problem

The traditional methods of monitoring exercise predominantly include guidance from trainers, online tutorials, or even wearing devices which do somewhat offer varying degrees of support to an extent, yet each one of them has its own set of limitations. For instance, human trainers, while being effective, are not always accessible, and online tutorials often lack the personalized feedback, that is critical to correct improper form in real-time. Wearable devices such as smartwatches and fitness trackers can track parameters like heart rate and calories burned, but they generally lack the capability to provide insights on the posture, thus potentially leaving users unaware of risky bodily movements that could result in an injury. These gaps compel us to think about the need for a smart, accessible and capable system with real-time posture detection, rep counting, and health monitoring. Moreover, in current solutions to the above-mentioned issue, there is no integrated solution for tracking both exercise postures and real-time health metrics, such as heart rate and blood pressure and incorrect exercise posture is also a leading cause of injuries, especially for high-intensity exercises, often leading to blackouts and sometimes even deaths.

1.3 Contribution

Now, in order to address the need, this research proposes a comprehensive exercise and health monitoring system that combines pose detection and estimation with IoT-based health tracking and real-time feedback mechanisms. By integrating advanced Computer Vision techniques such as Mediapipe and OpenCV libraries, the system captures and analyzes the athlete's body posture during exercise, thus allowing it to accurately track joint angles and detect deviations from the ideal or optimal posture. For instance, while performing bicep curls, the system can evaluate the angles between the person's shoulder, elbow and wrist and detect whether the movement aligns with optimal biomechanics. Moreover, by counting reps and providing instant feedback, the system also promotes correct exercise form which also reduces the risk of injury. A key innovation of the system is its design for future integration with the IoT-based health sensors, which could measure real-time physiological data, including heart rate and blood pressure. High-intensity exercises, such as squats and deadlifts, often require physiological responses that could be harmful if unchecked. By tracking heart rate and blood pressure fluctuations, the system could alert users when their metrics reach unsafe levels, helping to prevent overexertion or potentially life-threatening incidents, such as fainting. The system is user-friendly as it is built using Python's PyQt library, enabling easy exercise selection and session management. This makes the system suitable for users across various fitness levels. Unlike existing wearable devices and applications that primarily focus on basic metrics, this system aims to combine pose analysis with health data to provide comprehensive insights into exercise form and physiological status. This system bridges the gap between exercise form correction and real-time health monitoring and this research lays the foundation for an intelligent, AI-driven tool that supports safe and effective training in both personal and supervised fitness environments. The system's potential to serve as a virtual trainer, capable of delivering real-time guidance and health alerts has broad applications for home workouts, gyms, and rehabilitation settings. The findings presented in this paper aim to advance current capabilities in exercise monitoring and contribute to the development of safer, smarter fitness solutions.

Relate Work

2.1 Existing Research

There have been numerous studies and experiments conducted worldwide wherein the role of AI has been explored in enhancing an athlete's endurance and abilities, particularly in fitness, exercise monitoring and posture corrections. Previous works have primarily relied on machine learning algorithms and computer vision techniques to analyze human poses during physical activities. For example, systems utilizing OpenCV have demonstrated success in recognizing body landmarks and detecting joint angles for various exercises. However, these approaches often lack real-time feedback mechanisms and do not integrate physiological metrics, limiting their effectiveness in preventing exercise-induced injuries. Similarly, several research efforts have focused on IoT-enabled health monitoring, emphasizing the role of wearable devices in tracking heart rate, blood pressure, and other vital signs. Despite their promise, these systems are generally standalone and not designed to complement posture detection during workouts. This gap highlights the need for a combined solution that merges pose detection with real-time health monitoring.

During our research for a more comprehensive system, we analysed several research papers, articles, review papers and conference papers, from which we observed that the consistent presence of AI and Deep Learning across all papers, as indicated in Figure 3, suggested that these technologies are becoming integral to the development of smart systems for human motion analysis and posture correction.

Table 1 *SUMMARY OF TECHNOLOGIES AND APPLICATIONS ACROSS RESEARCH PAPERS*

Paper #	Technologies Used	Applications
1	AI, Computer Vision	Fitness, Gym Tracking
2	Pose Estimation, Raspberry Pi, Computer Vision	Healthcare, Physiotherapy
3	AI, MediaPipe, OpenCV	Fitness, Exercise Monitoring
4	OpenCV, MediaPipe	Fitness, Pose Detection
5	MediaPipe, OpenCV	Fitness, Posture Monitoring, Training
6	MediaPipe, OpenCV	Fitness, Posture Correction
7	AI, Pose Estimation	Fitness, Gym Tracking
8	MediaPipe, AI	Fitness, Weight Training
9	Computer Vision, Deep Learning	Healthcare, Posture Correction
10	Deep Learning, OpenCV, MediaPipe	Yoga, Posture Detection
11	Computer Vision	Fitness, Personal Trainer
12	Deep Learning, Computer Vision	Healthcare, Exercise Monitoring
13	AI, Computer Vision	Fitness, Gym Tracking
14	Real-time Pose Analysis, Computer Vision	Yoga, Feedback
15	Sensor Fusion, Pose Estimation, RGB Cameras	Sports Science, Performance Analysis

Moreover, the use of open-source libraries such as Mediapipe and OpenCV remains highly relevant, particularly for pose estimation and computer vision tasks. Their use in both early and advanced-stage research shows their robustness and flexibility in various real-time applications. The fact that these technologies are still prominent in 2023 and 2024 suggests their continued utility for fundamental tasks in human motion analysis and fitness tracking.

In 2023-2024, we see a strong shift towards more personalized and targeted applications in fitness tracking, posture correction, and physiotherapy. The focus on these applications reflects an increasing demand for individualized health solutions that provide real-time feedback for improving performance, preventing injuries, and aiding in recovery. This trend is driven by both the growing awareness of health and fitness and the availability of advanced technologies for monitoring and analysis.

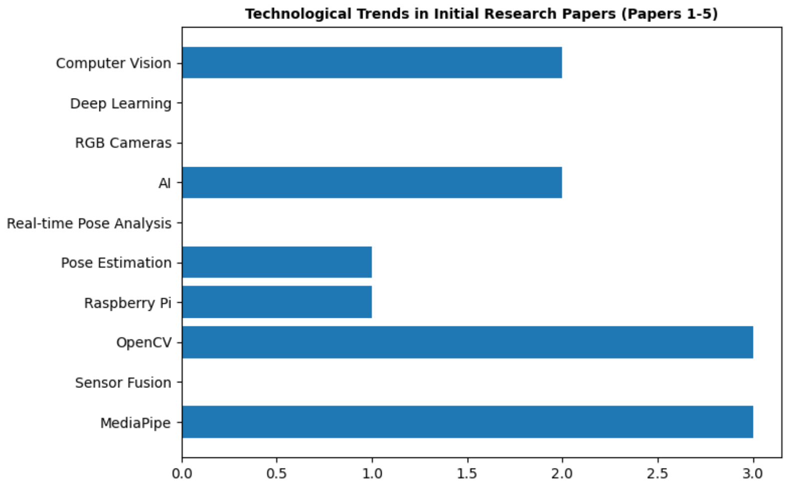

Figure 3 Technological Trends in Initial Research Papers

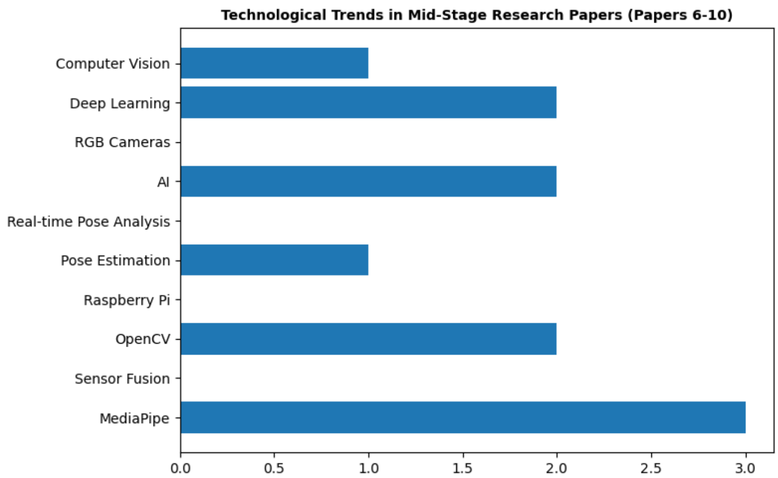

Figure 4 Technological Trends in Mid-Stage Research Papers

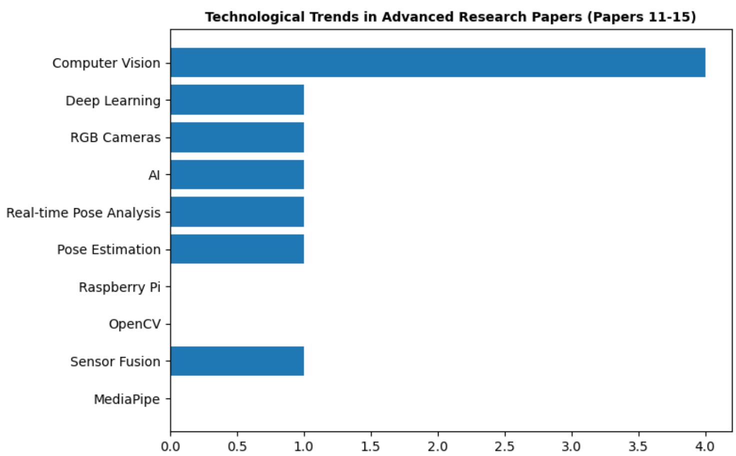

Figure 5 Technological Trends in Advanced Stage Research Papers

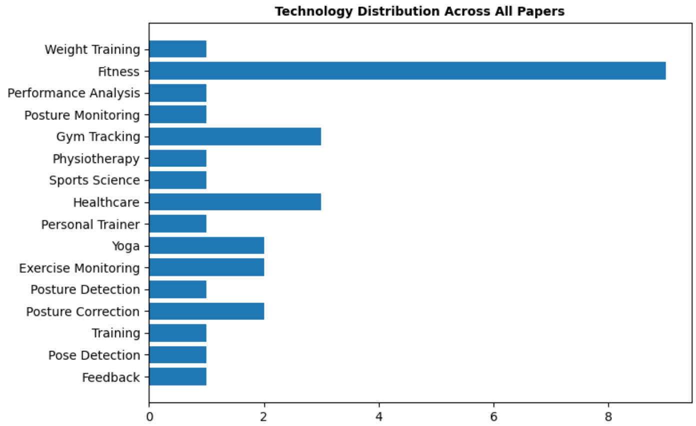

Figure 6 Technology Distribution Across Papers

2.2 Preliminaries

The pose detection technology relies on identifying specific body landmarks such as shoulders, elbows, and knees to evaluate body movements and patterns. MediaPipe and OpenCV are among the most commonly used frameworks for this purpose, offering high accuracy and computational efficiency. MediaPipe's built-in pose estimation model leverages machine learning to identify key body points, which can then be analyzed using custom algorithms for specific tasks like repetition counting or angle calculation.

This pose landmarker model has 33 body landmark locations, wherein each landmark represents one of the body parts.

In the context of IoT, wearable devices such as smartwatches and fitness bands provide continuous monitoring of Physiological data. These devices use sensors like photoplethysmography (PPG) for heart rate and piezoelectric sensors for blood pressure. The integration of such devices with exercise monitoring systems can enhance safety, especially during high-intensity workouts where the risk of overexertion is significant.

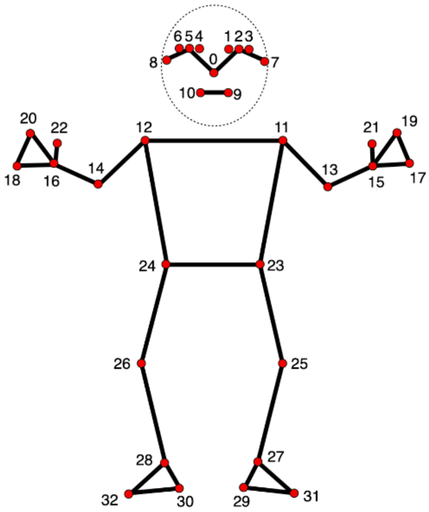

Figure 7 MediaPipe Pose landmarker model

Table 2 POSE LANDMARKS WITH INDEXES

Index	Landmark	Index	Landmark
0	Nose	16	Right wrist
1	lefteye (inner)	17	left pinky
2	Lefteye	18	Right pinky
3	lefteye (outer)	19	left index
4	right eye (inner)	20	left thumb
5	righteye	21	right thumb
6	right eye (outer)	22	left thumb
7	Leftear	23	Left hip
8	Rightear	24	Right hip
9	mouth(left)	25	Left knee
10	mouth(right)	26	right knee

11	left shoulder	27	Left ankle
12	right shoulder	28	right ankle
13	left elbow	29	Right heel
12	Right elbow	30	Left heel
15	Left wrist	31	left foot index
		32	right foot index

2.3 Considerations

Although the existing solutions provide a foundation, certain challenges must be addressed for an effective integration of pose detection and health monitoring systems. These include:

- **Accuracy:** We need to ensure the precise detection of body landmarks and movement angles. Inaccurate measurements can lead to incorrect feedback, increasing the risk of injury. In order to do so, it is crucial to implement robust pose estimation algorithms, such as those provided by MediaPipe or OpenPose, which can track body landmarks with high precision in real-time.
- **Real-Time Performance:** The system must process data and provide feedback without significant delay. High latency could undermine the user experience and effectiveness of the system, thereby making it unreliable and untrustworthy.
- **Scalability:** The system should support a wide range of locomotive abilities and motions for a variety of users. Thus, making their workout sessions more comprehensive and enriching.
- **User Interface:** A comprehensive GUI using PyQt library should be developed, which will be beneficial for widespread adoption and utilization, particularly among non-technical audiences.
- Physiological Metrics Integration: Combining posture data with real-time health parameters requires concrete communication between the pose detection system and IoT sensors.

3 Proposed Architecture

3.1 Architecture

The proposed system architecture combines pose detection using MediaPipe and OpenCV along with IoT-based health monitoring in order to ensure user safety and improve exercise effectiveness. This system majorly consists of the following modules, each with their own set of functionalities, such as:

- ***Pose Detection Module:*** This module utilised MediaPipe and OpenCV libraries in order to identify key body landmarks. Then we employ our own algorithms in order to calculate the critical body angles as per our requirements and compare them with the optimal posture, and if any deviation from the prescribed posture is detected, then real-time feedback along with corrective posture requirements is provided to the user through audio, textual and even sensory inputs. For instance, the formula for calculating angles between joints (Shoulder Elbow-Wrist) is as follows:

$$\text{Vector } \overrightarrow{\text{Shoulder-Elbow}} = \text{from Shoulder to Elbow} \quad (1)$$

$$\text{Vector } \overrightarrow{\text{Elbow-Wrist}} = \text{from Elbow to Wrist} \quad (2)$$

The angle θ_{joint} between these vectors can be calculated using the cosine formula:

$$\theta_{\text{joint}} = \cos^{-1}\left(\frac{\overrightarrow{\text{Shoulder-Elbow}} \cdot \overrightarrow{\text{Elbow-Wrist}}}{|\overrightarrow{\text{Shoulder-Elbow}}|\,|\overrightarrow{\text{Elbow-Wrist}}|}\right) \quad (3)$$

$$\text{Vector S-E} = (\text{E}_x - \text{S}_x, \text{E}_y - \text{S}_y) \quad (4)$$

$$\text{Vector E-W} = (\text{W}_x - \text{E}_x, \text{W}_y - \text{E}_y) \quad (5)$$

$$\text{Dot Product} = \overrightarrow{\text{S-E}} \cdot \overrightarrow{\text{E-W}} = \sum_{i \in \{x,y\}} (\text{E}_i - \text{S}_i)(\text{W}_i - \text{E}_i) \quad (6)$$

$$|\overrightarrow{\text{S-E}}| = \sqrt{(\text{E}_x - \text{S}_x)^2 + (\text{E}_y - \text{S}_y)^2} \quad (7)$$

$$|\overrightarrow{\text{E-W}}| = \sqrt{(\text{W}_x - \text{E}_x)^2 + (\text{W}_y - \text{E}_y)^2} \quad (8)$$

- ***IoT Health Monitoring Module:*** Integrates wearable devices for real-time tracking of physiological metrics such as heart rate and blood pressure. Communicates data via Bluetooth or Wi-Fi to the central processing unit, wherein it ensures that all the readings ensure that the athlete's physical conditions are under normal periphery and that if there's any anonymity, it should trigger the alarm.

- ***Central Processing Unit:*** Processes data from the pose detection and IoT modules. Cross-analyzes posture and physiological metrics to detect potential risks, such as overexertion.
- ***Feedback and Alert System:*** Issues visual and auditory alerts for improper posture or when physiological thresholds are exceeded. Displays feedback through a user-friendly interface built using Python's PyQt library.
- ***Cloud Integration (Future Scope):*** Designed for future integration with cloud-based systems to store user data and provide detailed analytics.

3.2 Methodology

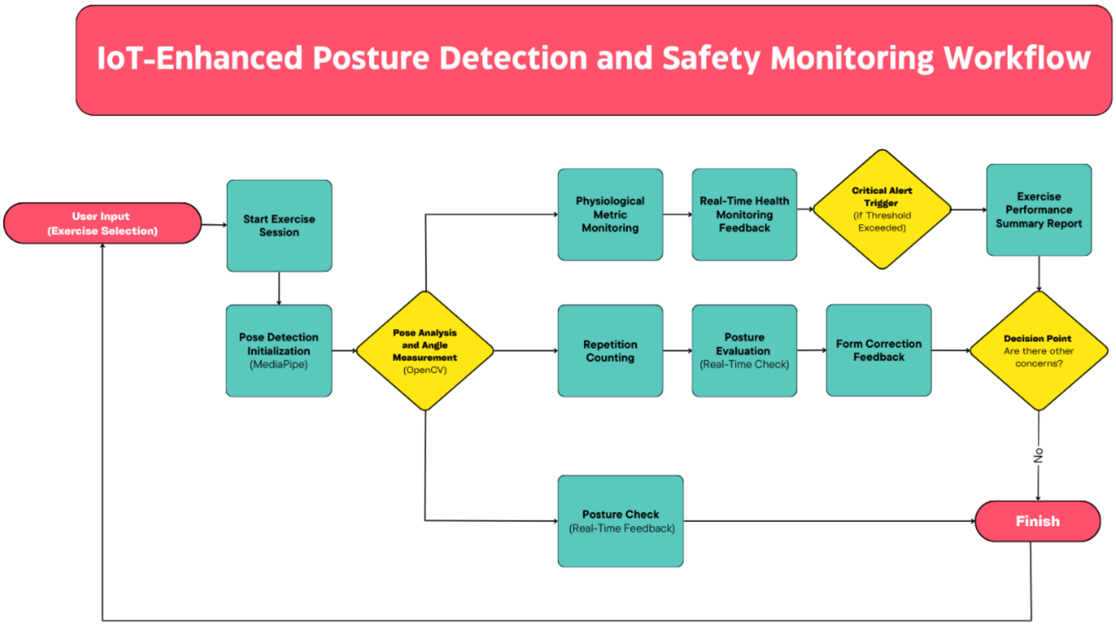

Figure 8 System Workflow for AI-Driven Exercise Posture Evaluation

The system operates in three main stages:

1) ***Initialization:*** Here the user selects an exercise from the GUI-based interface. IoT health sensors initialize and begin transmitting real-time data.

2) ***Pose Analysis and Feedback:*** The pose detection module captures the user's movement through a webcam. Joint angles are calculated using custom algorithms to determine the correctness of posture. Repetition count and posture feedback are displayed in real-time.

3) ***Health Monitoring and Alerts:*** Simultaneously, the IoT module monitors heart rate and blood pressure. If any metric exceeds a predefined threshold, the system triggers an alert to prompt the user to stop exercising.

4) ***Data Logging:*** All metrics, including posture analysis and physiological data, are logged for future review and analysis.

3.3 How the Architecture Mitigates Considerations

The proposed system addresses the challenges as follows:

• ***Accuracy:*** MediaPipe's advanced pose estimation ensures precise detection of key body landmarks. Custom-built algorithms are optimized for specific exercises to reduce errors.

• ***Real-Time Performance:*** Low-latency processing is achieved by running pose detection locally and transmitting IoT data using lightweight protocols like MQTT.

• ***Scalability:*** The modular design allows easy addition of new exercises or IoT sensors. Future cloud integration supports data storage and analytics for multiple users.

• ***User Interface:*** A PyQt-based graphical interface provides a simple platform for exercise selection, live feedback, and alerts.

• ***Physiological Metrics Integration:*** Continuous monitoring of critical health metrics ensures comprehensive safety by triggering alerts if thresholds are exceeded.

4 Evaluation

The analysis of exercise success rates under various conditions revealed significant differences between favourable and unfavourable scenarios. These results were evaluated through the success rates for seven exercises (Deadlift, Lunges, Plank, Squats, Push-Ups, Burpees, and Pull-Ups) across ten conditions, categorized into favourable and unfavourable environments. Heatmaps were generated to visually represent these success rates, highlighting trends and performance shifts across conditions.

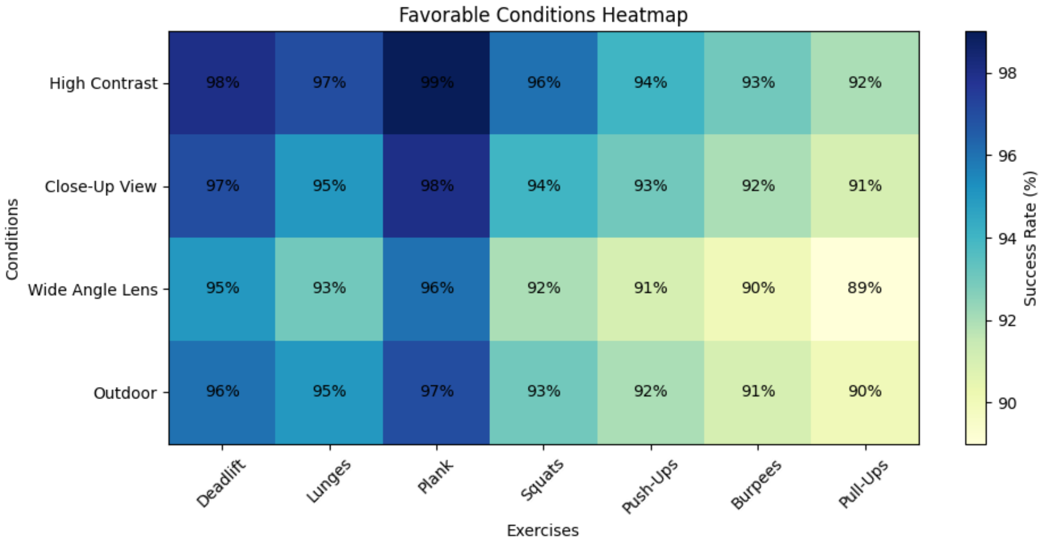

Figure 9 Heatmap of Success Rates Under Favorable Conditions

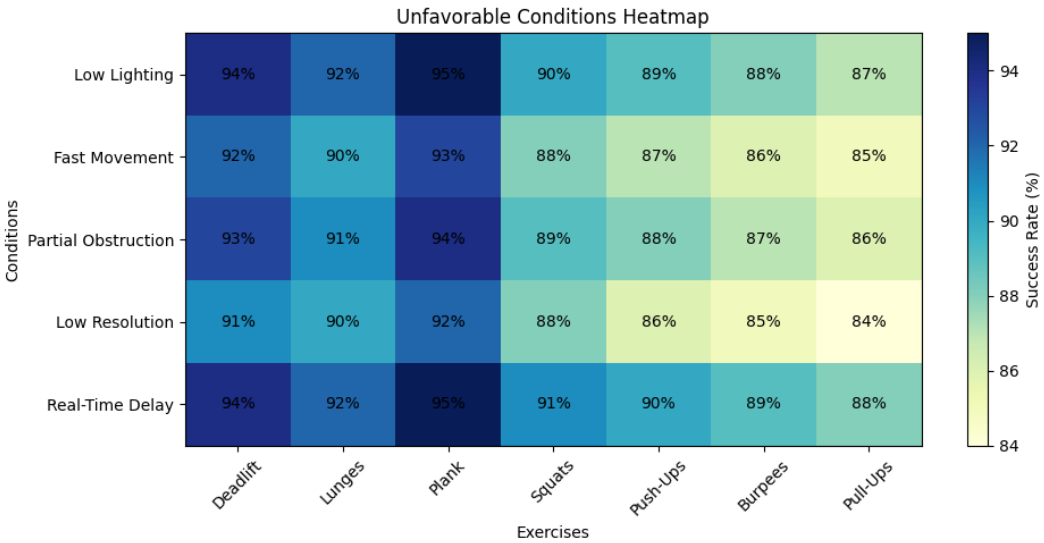

Figure 10 Heatmap of Success Rates Under Unfavorable Conditions

Under favourable conditions, such as High Contrast, Close Up View, and Outdoor environments, the system performed with high consistency throughout. Thereby achieving an average success of above 95% in these conditions as documented in Figure 9, with Plank reaching 100% success in certain scenarios. Deadlift and Lunges showed a slight variation, with Deadlift achieving a maximum success rate of 100% in ideal conditions. Push-ups and Burpees also demonstrated strong performance, with success rates between 94%and98%, indicating high reliability in favourable settings.

Conversely, the unfavourable conditions, such as Low Lighting, Real-Time Delay, and Partial Obstruction, led to a minute decline in success rates across exercises. The heatmap for unfavourable conditions (Figure 10) demonstrates a clear trend of reduced performance. Success rates dropped by an average of 5-10% in these environments

4.1 Qualitative Analysis

The system's analysis establishes that this modular system was found to be very easy to use by athletes and sports enthusiasts. The process of selecting exercises and initiating sessions was flawless, even for individuals with minimal technical expertise. The real-time feedback, which included posture correction suggestions, repetition counting, and movement angle analysis, was clear and easily understood by users. Visual cues and alerts helped users correct their posture immediately, enhancing the training experience. The system provided an additional layer of safety, especially during high-intensity exercises thus users felt more confident during their workouts, knowing that the system would alert them to dangerous movements or abnormal physiological metrics like heart rate or blood pressure.

4.2 Future Scope

Further advancements in the system could be to tailor the system specifically to specific exercise regimes like yoga or physiotherapy, incorporating unique pose detection algorithms for these disciplines. Moreover, integrating more advanced IoT sensors, such as ECG and oxygen saturation monitors, could provide a more comprehensive view of the user's health, enabling more accurate monitoring of critical conditions during exercise. The system could be expanded to support group exercises, allowing multiple users to train simultaneously while receiving personalized feedback based on their individual performance. This will also enhance the productivity of the individuals as well through peer-motivated learning.

5 Conclusions

This project successfully integrates pose detection and IoT-based health monitoring to create a comprehensive system for enhancing exercise safety and effectiveness. By utilizing advanced technologies like MediaPipe, OpenCV, and IoT sensors, the system provides real-time feedback on exercise posture and repetition accuracy, ensuring that users perform exercises with proper form to reduce the risk of injuries. The integration of physiological metrics such as heart rate and blood pressure further enhances the safety aspect, enabling the system to issue alerts if critical thresholds are exceeded during high-intensity workouts.

This paper has also highlighted the significant influence of environmental conditions on modern machine-learning libraries such as OpenCV and Mediapipe. Favourable conditions, such as optimal lighting, clear resolution, and minimal delays, enhance performance across all exercises, with success rates exceeding 95%. However, unfavourable conditions, including low lighting, partial obstruction, and real-time delays, lead to a noticeable decline in accuracy and success, demonstrating the vulnerability of such systems to environmental factors.

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