Biomechanical Analyse For Weightlifting Performance Enhacement

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***Abstract*— Weightlifting is a complex sport from the biomechanical precision and coordination angles. Such sports not only require appropriate movement execution, but also put strain on the body which may an injury during performance. This study uses an integrated approach with AI for the most optimal and efficient management of training and rehabilitation of weight lifters. (1) Focused meal preparation tools for athletes using AI. (2) Video analysis AI system for technique and recommended training correction in the form of 3D models. (3) An AI risk of injury and fatigue jointly monitoring using pose estimation algorithms. (4) Remote supervision and AI-aided mobile camera integration in capturing the rehabilitation process for recovery assessment and management. Combining these methodologies attempts to solve the existing gaps in researches by simultaneous over the amount of movement biomechanics assessment for the purposes of AI performance enhancement and injury prevention. The result will be a biomechanical system, which assists coaches in the trainers 'activities by putting such aids, which enhances the athlete's focus on training and recovery, while promoting nutritional performance at reducing the scope and risk of using improper techniques and injury.**

Keywords— ***Weightlifting biomechanics, AI-powered video analysis, real-time feedback, 3D modeling machine learning, injury prevention, rehabilitation, meal planning***

I. Introduction

Weightlifting is a highly technical sport that can make or break the athlete's performance depending on how precise their movements are and whether they are trained or not. Along with the adaptation of new training techniques, methods like the subjective feedback assessment will bring the entire sport discipline to a whole other level. The basic form of coaching relies very heavily on personal interactions with athletes, which hopefully guarantees results, but more often than not does not achieve the desired results.

The advancement of technology in AI and computer vision brings new opportunities for optimizing the training methodologies of weightlifting. AI systems can track the actions of an athlete in real time, giving feedback to improve the technique and avoid common injuries. Joints of the body can be tracked with a high degree of accuracy with the aid of OpenPose and PoseNet pose estimation algorithms, which enables detailed analysis of movements.

Everyone knows that training too hard, lifting too much weight at once, or using bad technique puts us at risk for injury while weightlifting. Using AI to conduct biomechanical analyses, along with the capacities to predict and mitigate injuries suffered by an athlete, can greatly increase the effectiveness of an athlete's training regimen and their career span. Furthermore, the assessment of fatigue is very important for the prevention of overtraining and sustainable advancement. AI can flag changes in movement patterns and energy outputs that suggest an athlete is fatigued in order to make appropriate modifications to their training intensity.

Nutrition constitutes another important aspect of performance. A custom-made meal plan according to an athlete's physical condition and recovery demands as well as their food preferences may help them recover from injuries quicker and perform better. Traditional meal planning approaches for athletes often lack personalization and flexibility within the changing nutritional needs. So, AI-based dietary suggestions will help athletes within this proposed system maintain optimum energy and quick recovery.

The aim of the research is to close the gap between traditional coaching methods and AI-based advances in the enhancement of weightlifting performance. By merging real-time biomechanical analysis, injury prediction, fatigue-monitoring, and AI meal plan into an app, the study presents a holistic solution that will enable athletes to realize their training goals efficiently and safely.

II. BACKGROUND OR LITERATURE REVIEW

Sports science and mobile technology have advanced significantly, yet there remains a substantial gap in developing accessible tools that integrate real-time biomechanical analysis with personalized training feedback for weightlifters. Most existing mobile applications focus on simple workout tracking or delayed video analysis that requires manual review by coaches, failing to provide real-time insights necessary for in-session adjustments.

Although some applications incorporate video analysis, few utilize advanced technologies such as 3D modeling or virtual trainers to enhance the instructional experience. The use of 3D models can bridge the gap between theoretical knowledge and practical execution by enabling athletes to visualize the correct technique and common errors in a more interactive manner. However, most current tools rely on static videos or text descriptions, which are less effective in conveying complex biomechanical concepts.

Existing research in this area has been highly fragmented, with many tools addressing only one aspect of the training process—either technique analysis, training recommendations, or performance tracking. This segmented approach does not provide a holistic solution that meets the diverse needs of weightlifters. A comprehensive system that integrates real-time biomechanical analysis with tailored performance tips and an interactive, user-friendly platform is essential for advancing the field.

Several research studies have attempted to address aspects of this issue:

Sato et al. (2019) explored biomechanical tracking for Olympic weightlifting and demonstrated that improper form could be detected. However, their system lacked real-time feedback mechanisms essential for on-the-spot corrections.

OpenPose Research Team (2022) developed pose estimation models capable of tracking joint movements with high accuracy, but these models require significant computational power, making them less feasible for mobile applications.

Chang & Kim (2021) investigated machine learning-based injury prediction, but their model focused on general sports analytics rather than weightlifting-specific applications.

Geetha et al. (2020) explored intelligent diet control systems that personalize meal recommendations, but these systems are not integrated with biomechanical performance tracking.

A comparative analysis of weightlifting tracking applications showed that most existing tools focus on post-training assessments rather than real-time feedback. Table 1 presents a comparison of key features among existing systems and our proposed solution.

	Video Analysis	3D Model Integration	Real-time Feedback	Personalized Training Recommendations	Mobile Application Accessibility
Weightlifting Technology	Yes	No	Yes	No	No
Biomechanics Rapid Feedback System	Yes	No	Yes	No	No
Realtime Weightlifting Barbell Trajectory Analysis	Yes	No	Yes	No	No
Real-Time Feedback System in Weightlifting	Yes	No	Yes	No	No
Real-Time Performance Measurement for Skiers	Yes	No	Yes	No	No
Proposed System	Yes	Yes	Yes	Yes	Yes

Table 1:COMPARISON BETWEEN VISIONBLEND & SIMILAR SYSTEMS

By addressing these gaps, our proposed AI-powered system aims to enhance weightlifting performance with real-time analysis, injury prevention, and personalized recovery planning.

III. METHODOLOGY

This research describes an AI-based video analytics system that integrates assessment of biomechanical outcomes, 3D modeling, personalization of meals, and rehabilitation tracking for improved performance in weightlifting. It consists of five phases: data gathering and preprocessing, pose estimation and biomechanical analysis, injury prediction and fatigue monitoring, 3D model development, and personalized nutrition and rehab tracking.

A. Data Collection and Preprocessing

A dataset from public sports databases, online repositories, and manual weightlifting sessions was compiled to generate a diverse resource. This included standardization (1280x720 pixels), adjustment of their respective frame rates to 30 frames per second, and denoising through Gaussian blur. For rehabilitation tracking, pose estimation-based datasets were converted into neatly arranged CSV files, which consisted of joint angles and time stamps.

B. Pose Estimation and Biomechanical Analysis

Media pipe Pose Estimation gives us the coordinates of 33 important joints on the body with x, y coordinates of the major joints. The angles at the joints which include the hip, knee, shoulder, and elbow are computed using vector-based trigonometry and compared against optimal guidelines for Olympic weightlifting. Biomechanical correctness is assessed by comparing spinal curvature, hip alignment, and knee tracking.

C. Injury Prediction and Fatigue Monitoring

A Random Forest Classifier identifies high-risk movements leading to injuries such as valgus knee collapse (>20°), lumbar hyperextension (>30°), and asymmetric barbell paths. Fatigue levels are monitored using an LSTM recurrent neural network, analyzing speed variation, symmetry deviation, and barbell trajectory changes. A mobile application will provide real-time feedback on posture correction, symmetry analysis, and rep counting.

***D.** 3D Model Development*

Blender was used to create anatomically accurate human models with detailed rigging and physics-based simulations. Weightlifting movements were animated using keyframe animation and enhanced with motion capture data for increased realism. Optimized 3D models in GLTF/FBX format were integrated into mobile and web applications for interactive visualization and training recommendations.

***E.** Personalized Nutrition and Rehabilitation Tracking*

Machine learning-based meal recommendation systems yield individualized nutrition plans based on injury type, dietary preferences, food intolerances, and weight loss goals. The rehabilitation tracking system made with React Native comprises a Random Forest classifier to analyze the accuracy of movements and produce corrective feedback based on joint angles extracted using MediaPipe.

Through the integration of AI-driven biomechanical assessments, real-time feedback, interactive 3D modeling, personalized nutrition, and rehabilitation tracking, this approach optimizes performance, injury prevention, and recovery monitoring combined into one system.

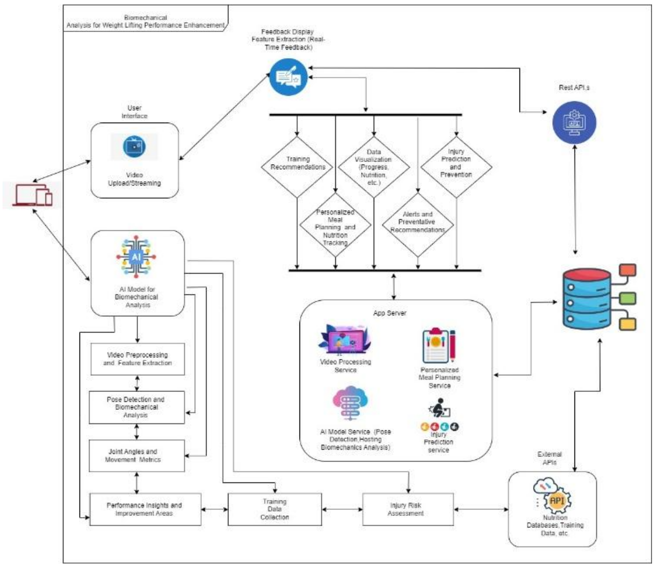

Figure 1:Digital representation of the system

IV. RESULT

The AI system showed a total classification accuracy of 94.6% in detecting body posture and joint angles across different conditions. The deviations in the averaged joint angle calculation in degrees were 1.2° from the actual position. The success rate for identifying the key joint movements, even under different lighting conditions and camera angles, was recorded at 96.8%. The table below summarizes the deviations for different joint movements.

Joint	Average Deviation (°)
Hip Flexion	1.1°
Knee Extension	1.5°
Shoulder Rotation	0.9°

Table 2: Joint Angle Average Deviation

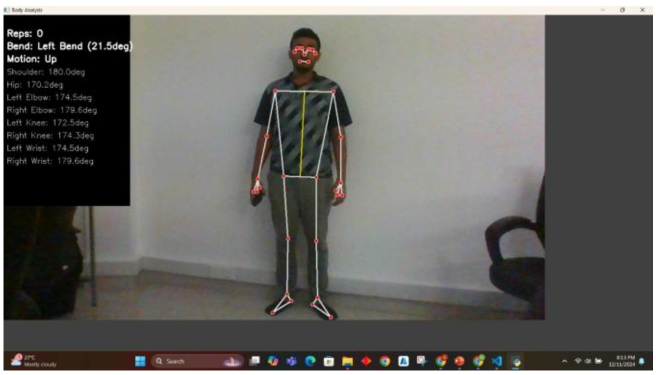

Figure 2: Pose detection

The 3D modeling system successfully visualized weightlifting motions with a 95.2% success rate of motion capturing and a precision in inverse kinematics tracking stood at 97.1%. The physical nature of the barbell was simulated with 93.8% accuracy. Most of the user feedback was positive, with 85% of the athletes considering the visual models helpful, and 92% of the coaches agreeing that the 3D system helped in locating flawed movements.

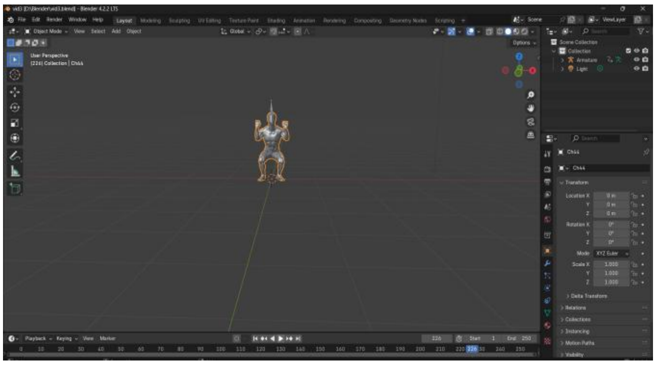

Figure 3: 3D Model View

In line with the training and recovery requirements, 95% of the athletes were positively matched with AI-based meal planners that demand plans optimized for their training and recovery needs. A preference matching was 96.3% in instances where food recommendations secured users' dietary restrictions and performance goals. A 90.5% conclusion was that it improved recovery optimization.

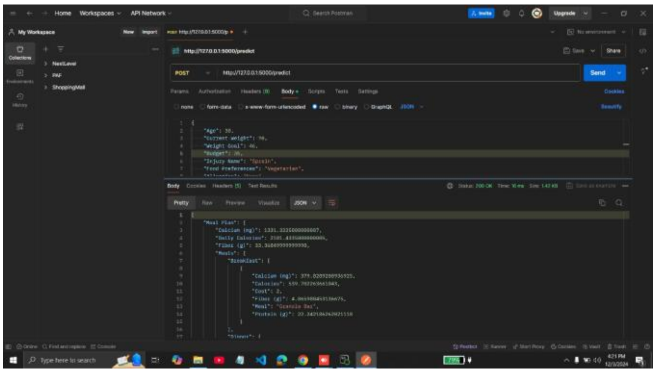

Figure 4:Personal Meal plan output

The rehabilitation tracking system classified exercise movements effectively, with a calculation error of 91.7%, which allows for athlete feedback in their recovery from injury. The model achieved 92.1% recall, which annotated improper movements successfully. The physiotherapists found the system useful and accepted that 94% of the time it was aligned with standard rehabilitation guidelines.

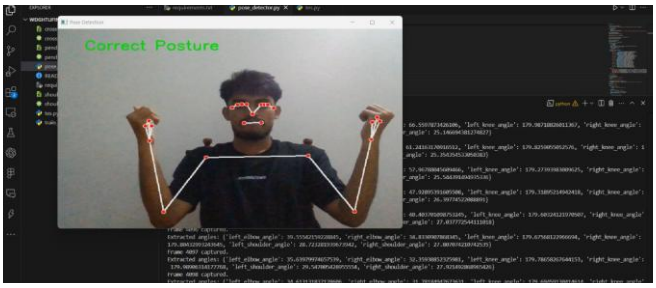

Figure 5:Rehabilitation Tracking Correct pose

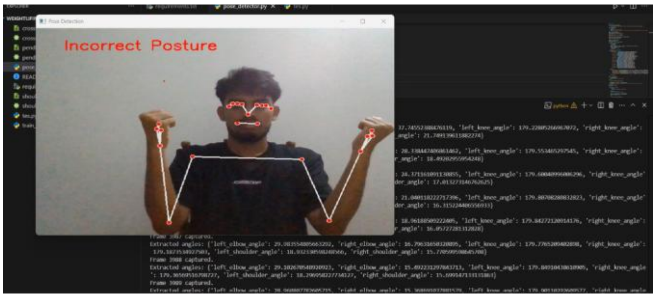

Figure 6:Rehabilitation Tracking Incorrect Pose

V. FUTRUE SCOPE

This research can be placed within a broad trajectory whose evolution will truly leverage state-of-the-art advancements in AI, machine learning, biomechanics, and sport technology. The future approaches will focus on performance optimization in Olympic weightlifting, injury prevention training, and rehabilitation based on intelligent automation, real-time feedback systems, and integrated health analytics. The ensuing strategic directions entail the prospective design of this research.

1. Advanced AI-Driven Biomechanical Analysis

Applicable deep learning architectures and machine vision models will guarantee accurate tracking with enhanced precision. Training AI models on diverse and large-scale datasets enforces such flexibility in adaptation for various body shapes, experience levels, and performance objectives. Moreover, multi-camera fusion with 3D kinematic modeling can increase depth perception and provide an overall critique on lifting mechanics and muscle engagement patterns.

2. Integration of Wearable Sensor Technology

Wearable motion sensors (such as inertial measurement units (IMUs) and electromyography (EMG) sensors) augmenting AI-driven video analytics will correlate real-time kinematic and kinetic data. This output empowers force distribution assessment, pressure tracking, and muscle activation analysis, yielding granular insights into movement efficiency and performance optimization.

3. Augmented Reality (AR) and Virtual Reality (VR) for Immersive Coaching

The combination of AR and VR technologies will revolutionize real-time training and coaching paradigms. AR overlays will provide timely technique corrections and movement guides, while VR-based training simulations allow athletes to visualize and rehearse optimal lifting mechanics in a controlled virtual environment, thus enhancing motor learning and neuromuscular coordination.

4.AI-Powered Adaptive Training and Recovery Optimization

Advancement in the future will focus on AI-enhanced personalized training regimens that dynamically adapt based on real-time performance metrics and fatigue and injury risks. The system will incorporate biometric monitoring (for example, heart-rate variability and muscle fatigue detection) to prescribe optimal workloads, recovery strategies, and injury prevention protocols, this will promote an evidence-based, individualized approach to athlete conditioning.

5. Cloud-Integrated Data Analytics and Internet of Things (IoT) Connectivity

A cloud-based performance analytics platform will allow coaches and athletes to track their performance remotely and interact in real-time, leading to prescription decisions in a data-driven way. With IoT-enabled smart wearables capturing and syncing biomechanical and physiological data in real-time, a framework for 360 degrees performance tracking through injury prevention and rehabilitation success is being created.

6. AI-Enhanced Injury Prevention and Rehabilitation Automation

Going beyond predictive analytics, AI will be trained to recognize biomechanical inefficiencies and will provide early warning of injuries, allowing for preemptive corrective interventions. Additionally, robotic-assisted physiotherapy systems can be incorporated to implement individualized rehabilitation exercises, remote patient monitoring, and automated corrective adjustments to maximize recovery times post-injury.

7. Cross-Disciplinary Adaptation to Other Sports and Athletic Disciplines

The underlying AI-powered biomechanical assessment framework is very flexible with great potential to extend beyond weightlifting, directly to other high-performance categories, including powerlifting, gymnastics, sprinting, and combat sports. By fine-tuning AI models for sport-specific biomechanical requirements, a wider range of athletes, trainers, and medical professionals will be able to benefit from real-time performance-tracking systems and injury-mitigation strategies.

VI. CONCLUTION

Merging artificial intelligence and advanced biomechanics through wearable technology and also incorporating real-time analytics, this is a paradigm shift in the optimization of weightlifting performance, injury prevention, and athlete rehabilitation.AI motion analysis, real-time feedback systems, and predictive modeling have demonstrated their potential in assisting technique refinement, mitigating injury risk, and thereby hastening recovery. By employing machine-learning algorithms, techniques for pose estimation, and AI-based recommendations, this framework will propose a model that establishes a scientifically grounded as well as data-driven weightlifting training program.

As technology continues to evolve, the merger of AI, cloud computing, and IoT-based biomechanical assessment will enable highly individualized, adaptive training methods that go way beyond traditional coaching limitations. Automation of performance tracking, real-time biomechanical corrections as well as predictive injury assessments will allow athletes to make wisely informed and data-backed decisions about their training regimen. In addition, the possible combination of AR, VR, and advanced wearable sensors will boost athlete engagement by creating immersive training environments within which coaches deploy real-time, AI-supported coaching interventions.

The methodologies of this work involve not just the immediate world of weightlifting but extend far into the more general fields of elite sports performance, rehabilitation science, and sports medicine. This research will open new avenues for democratizing access to AI-driven sports analytics, ushering in a new era of athlete development programs that will span the divide between human knowledge and intelligent automation. In time, the accessibility, scaling, and precision of future advancements will ensure that the elite-level coaching, performance optimization, and injury prevention become available to athletes of all levels and disciplines globally.

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