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| RESEARCH ARTICLE

Gamified Computer Vision and AI Coaching for Youth Tennis: Real-Time Feedback and Player Style Matching

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| ABSTRACT

This article introduces a computer vision-based platform that combines pose estimation technologies with large language models to create an interactive training system for youth tennis players. Players upload videos of forehand, backhand, and serve strokes for automated comparison against coaching demonstrations, receiving similarity scores and specific posture correction recommendations. A supplementary module compares student techniques with those of professional athletes, identifying which ATP or WTA playing styles align most closely with individual form characteristics. Progress tracking incorporates gamification through achievement badges, performance visualization dashboards, and skill-based challenge sequences that sustain learner engagement. The platform extends beyond recorded session evaluation by offering live feedback capabilities through a specialized language model trained on annotated datasets of tennis biomechanics, functioning as an automated coaching assistant during practice. Technical implementation encompasses pose detection algorithms, including YOLO-Pose and MoveNet, as well as motion comparison metrics such as cosine similarity and Dynamic Time Warping, and language model integration for generating personalized guidance. The platform addresses educational accessibility, psychological development factors, and community-building opportunities, demonstrating how automated coaching technologies can expand access to professional-grade instruction, enhance motivation among developing athletes, and support sustained skill progression through quantitative performance analytics.

| KEYWORDS

Computer Vision, Artificial Intelligence Coaching, Youth Tennis Training, Real-Time Feedback Systems, Gamified Learning Platforms

| ARTICLE INFORMATION

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1. Introduction

Tennis requires precise technique, where subtle form modifications can lead to significant improvements in court performance. Traditional coaching relies on scheduled in-person sessions that require a considerable financial investment and careful coordination of the coach's and player's schedules [1]. The adoption of sports technology offers alternative routes to data-driven coaching methods [7], making real-time analytics and personalized feedback accessible to athletes across a range of skill levels. These technological tools help players develop their techniques through systematic methods, improving competitive results and deepening their engagement with the sport.

Professional athletes utilize motion capture systems and biomechanical laboratories, which provide detailed analyses of their movements [9]. In contrast, youth and recreational players often lack similar structured opportunities for quantitative feedback. Video recordings of player performances yield predominantly subjective insights rather than objective measurements [6]. This creates significant gaps in real-time, actionable feedback that could enhance skill development and overall performance, leaving young athletes struggling to identify specific areas for improvement and limiting their competitive potential.

This article presents a platform integrating computer vision technology with large language models to enhance youth tennis education [10]. The system evaluates player techniques in real-time through sophisticated image recognition [5], delivering personalized feedback on form and execution. The platform matches individual playing styles with professional role models [6], offering insights into elite athlete techniques and strategies. Gamification elements foster engagement and motivation [9], transforming learning into interactive experiences that encourage continuous improvement. This approach makes professional-quality coaching resources accessible and affordable, bridging the gaps for young players as they develop their skills and passion for the sport.

1.1 Research Background

Pose estimation models, including YOLO-Pose, OpenPose, and MoveNet, have transformed real-time keypoint detection for sports analysis applications [2]. These models utilize deep learning algorithms to identify and track body positions during athletic performance [3], thereby facilitating the assessment of technique across various sports disciplines. Dynamic Time Warping and vector-based cosine similarity provide powerful tools for comparing motion sequences with precision [4]. Dynamic Time Warping aligns temporal sequences, enabling the evaluation of athlete movement variations even at different execution speeds, proving invaluable for analyzing performance subtleties and developing injury prevention protocols.

Artificial intelligence applications in sports coaching, as demonstrated by golf swing analysis systems, show that interactive feedback mechanisms enhance learning retention [7]. Players receive instant technical feedback that shows their strengths and identifies areas requiring improvement, helping them to build skills at a faster pace. Current training approaches employ point systems, achievement badges, and competitive leaderboards to maintain athlete engagement [1]. Younger participants respond well to these competitive structures because they create enjoyable practice environments that encourage regular attendance, leading to noticeable performance improvements.

1.2 Novel Contribution

This platform surpasses traditional video analysis by providing comprehensive skill development through integrated features that address multiple training dimensions [6]. Gamified skill development offers structured learning experiences, incorporating levels, achievement streaks, and dynamic leaderboards that encourage consistent practice and motivate performance improvement over time [9]. The competitive framework sustains long-term engagement while tracking measurable progress metrics.

Personalized stroke matching tailors individual development goals by analyzing player strokes and comparing them against the techniques of ATP and WTA professional athletes [10]. This customized approach enables users to identify specific areas for improvement and align training with elite player tactics and styles. Athletes gain concrete role models whose biomechanical patterns align with their natural movement preferences, creating realistic pathways for technical development.

Real-time artificial intelligence-driven feedback delivers instantaneous performance assessment using advanced language models fine-tuned with expert coaching insights [8]. This data-driven guidance helps users understand strengths and weaknesses [5], allowing timely adjustments and continuous game growth. The system functions as a virtual coaching assistant, providing actionable technical corrections during practice sessions without requiring the presence of a human supervisor.

2. Technical Architecture

The extraction pipeline accepts mobile video uploads or live camera streams, accommodating diverse user environments and interaction modes [3]. Preprocessing steps include background subtraction to isolate the subject, frame normalization to maintain consistent lighting and color profiles, and frame rate adjustment to ensure smooth motion capture [5]. State-of-the-art algorithms, such as YOLO-Pose and MoveNet, extract 2D keypoints that denote critical body positions [2]. An optional 3D depth estimation feature provides enhanced understanding of spatial movement.

Technology	Primary Function
YOLO-Pose	Real-time 2D keypoint detection
OpenPose	Multi-person pose estimation
MoveNet	Lightweight body position tracking
3D Depth Estimation	Spatial movement analysis

Joint-Angle Conversion	Time series biomechanics data
Keypoint Extraction	Critical body position identification

Table 1: Pose Estimation Technologies and Applications [2], [3]

Pose sequences convert into joint-angle time series data, capturing intricate body movements and alignments over time for detailed analysis [4]. The system employs Dynamic Time Warping or cosine similarity to compare extracted sequences against reference templates, enabling precise evaluation of movement patterns [8]. The output includes a match percentage indicating overall similarity and provides detailed suggestions for key posture adjustments to enhance performance.

The style matching module draws from an extensive reference dataset composed of annotated strokes performed by professional athletes [10]. Advanced clustering algorithms map student motion embeddings to the nearest professional clusters, facilitating the identification of stylistic nuances and achieving better alignment with expert techniques. The feedback mechanism is fine-tuned on a diverse dataset comprising paired pose data alongside expert commentary, enabling the generation of contextually relevant feedback [8]. The system delivers low-latency feedback, such as actionable prompts like "widen your stance" or "increase your follow-through height," in real-time to facilitate immediate corrections during practice [5].

Metric Type	**Application**
Dynamic Time Warping	Temporal sequence alignment
Cosine Similarity	Vector-based pattern matching
Embedding Clustering	Professional style categorization
Match Percentage	Overall similarity scoring
Posture Adjustment	Specific correction recommendations
Reference Template Comparison	Movement pattern evaluation

Table 2: Motion Analysis Comparison Metrics [4], [8]

2.1 Comparative Insight

Traditional instructional methods require continuous coach oversight and provide limited quantitative feedback to students [10]. This platform delivers unlimited, detailed quantitative input while minimizing the need for constant supervision [6]. The capability allows scalability across large numbers of learners while significantly lowering training expenses. The system generates longitudinal data logs that track each player's progress and development over time, providing valuable insights into performance trends and areas for improvement [9].

Generic video analysis tools lack the sophisticated comparison capabilities and real-time feedback mechanisms that define this platform [5]. Standard video recording allows retrospective review but offers no automated technical assessment or personalized correction suggestions. The platform's integration of pose estimation, similarity metrics, and language model feedback creates a comprehensive training environment unavailable through conventional video tools [10]. Athletes receive immediate, specific guidance during practice sessions, rather than waiting for delayed review from their coach.

Professional training facilities employ motion capture systems and biomechanical analysis laboratories that cost hundreds of thousands of dollars and require specialized technical staff [6]. This platform makes comparable analytical capabilities accessible through consumer-grade smartphones and tablets, democratizing access to advanced training technology [9]. Young athletes in underserved communities gain exposure to professional-grade feedback without requiring expensive equipment or access to facilities.

Feature	Benefit
Gamification Elements	Enhanced user engagement
Professional Stroke Matching	Personalized development goals
Real-Time Feedback	Immediate technical corrections
Longitudinal Data Tracking	Progress monitoring over time
Achievement Badges	Motivation and consistency
Performance Dashboards	Visual progress representation

Table 3: Platform Features and Benefits [6], [9]

2.2 Potential Applications

Youth training programs benefit from affordable and scalable implementation models suited for tennis academies operating under budget constraints [9]. The structured curriculum develops fundamental skills while integrating advanced techniques to enhance young athlete performance [6]. Coaches can monitor multiple students simultaneously, using the platform's automated feedback to supplement rather than replace human instruction.

Remote coaching scenarios enable asynchronous review by coaches who assess training sessions at their convenience [10]. Coaches provide detailed feedback on technique and strategy, fostering continuous learning environments regardless of geographical barriers [7]. Athletes refine their skills through personalized guidance and support, eliminating the need for synchronous scheduling with distant coaches.

Sports analytics applications enhance talent identification and biomechanics initiatives by creating comprehensive datasets [11]. The core methodologies and training frameworks can be easily transferred to other sports, such as golf, baseball, and martial arts [7]. This flexibility encourages learning across different sports, allowing athletes from various disciplines to apply shared insights and training methods [1], thereby improving their overall performance and athletic growth.

Application Domain	Primary Use Case
Youth Training Programs	Affordable scalable coaching
Remote Coaching	Asynchronous session review
Sports Analytics	Talent identification systems
Cross-Sport Extension	Golf, baseball, and martial arts adaptation
Biomechanics Analysis	Comprehensive performance datasets
Community Development	Underserved population access

Table 4: Application Domains and Use Cases [7], [10]

Conclusion

Future development directions include integration of wearable sensor technology for precise force measurement capabilities, enabling quantitative tracking of physical interactions and movement dynamics during stroke execution. Immersive virtual reality replay systems could provide multi-angle performance visualization, allowing athletes to examine technique from perspectives unavailable through conventional video review. These spatial analysis tools would deepen kinesthetic awareness and technical understanding among youth players. Federated learning implementations offer pathways for continuous model enhancement while maintaining strict privacy protections, allowing the system to refine algorithms through distributed training datasets without requiring centralized video storage or transmission. This architecture preserves data sovereignty for individual users and training facilities while contributing to collective model improvements across the platform ecosystem. Enhanced privacy frameworks address growing concerns regarding youth athlete data collection and storage practices. Expanded sensor integration, immersive visualization technologies, and privacy-preserving learning mechanisms represent logical evolution pathways for computer vision coaching systems. These advancements will strengthen technical precision, deepen athlete engagement through novel interaction modalities, and establish robust data governance frameworks that balance innovation requirements with ethical obligations toward youth participants in automated training environments.

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