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Smart Volleyball:Design And Enhancement Using AI

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Abstract: *The Smart Volleyball system aims to enhance the accuracy, fairness, and overall quality of volleyball gameplay by integrating artificial intelligence with real-time video analysis. The proposed model utilizes machine learning techniques to detect the volleyball, players, and court boundaries directly from live camera input, enabling automated judgement of critical events such as IN/OUT decisions, foot faults, and ball-landing detection. By employing advanced preprocessing, object detection, and rule-based evaluation, the system minimizes human error during fast rallies and provides consistent decision support throughout the match. Additionally, real-time overlays and visual indicators assist referees and coaching staff with clearer interpretations of ongoing plays, thereby improving match transparency and supporting data-driven performance analysis. The Smart Volleyball framework demonstrates the potential of AI to modernize and elevate the volleyball experience through intelligent automation and fair decision-making.*

Keywords: *Smart Volleyball system*

I. INTRODUCTION

Volleyball also presents unique officiating challenges due to the compactness of the court and the frequent overlap of players during high-intensity rallies. When multiple athletes converge near the net or dive for the ball, the referee's field of view can become partially obstructed, leading to missed violations or delayed decisions. Moreover, modern volleyball strategies such as quick attacks, synchronized rotations, and back-row spikes increase the complexity of real-time judgement. These factors collectively highlight the need for a system capable of monitoring multiple elements simultaneously without human fatigue or observational limitations.

Recent research in sports technology demonstrates how integrating object detection with multi-object tracking can significantly improve the consistency of gameplay interpretation. AI systems can process visual data at high frame rates, ensuring that every key event—whether a ball landing, a foot crossing the line, or a player making illegal contact—is analyzed with frame-by-frame precision. This level of accuracy surpasses manual observation, especially in situations where decisions must be made instantaneously. The ability to review, store, and analyze each detected event also provides long-term benefits for training, strategy development, and post-match evaluation.

By combining detection, tracking, and rule-based decision-making, the Smart Volleyball system introduces a transformative approach to sports officiating. It offers a reliable technological layer that supports human referees without replacing their authority, ensuring that matches remain fair, transparent, and free from avoidable disputes. Additionally, the system's adaptability allows it to be implemented in various environments, from professional tournaments to training centers, thereby contributing to the advancement of volleyball through intelligent and data-driven innovations.

II. LITERATURE REVIEW

Research on AI-assisted sports officiating has rapidly expanded over the past decade, particularly with the rise of deep learning and real-time computer vision technologies. Early studies focused on traditional image processing methods such as edge detection, background subtraction, and Hough Transform–based line extraction, but these approaches struggled with accuracy during fast gameplay, motion blur, and occlusion. As volleyball involves rapid ball movement and crowded visual scenes, traditional methods often failed to robustly capture ball trajectories or player interactions. This limitation encouraged the transition toward machine learning and deep neural networks capable of processing high-speed sports footage more reliably.

Modern research heavily emphasizes the use of object detection models such as YOLO, SSD, and Faster R-CNN for identifying the volleyball and players within real-time match footage. These models have shown significant improvements in detecting small, fast-moving objects under dynamic conditions. Studies demonstrate that YOLO-based architectures can maintain high accuracy even when the ball undergoes sudden acceleration or becomes partially obscured by players. Researchers also highlight the importance of dataset diversity, noting that models trained on multiple lighting conditions, camera angles, and gameplay variations perform more consistently in real-world matches.

Multi-object tracking has also become a major focus in volleyball-related research. Techniques such as Kalman filtering, optical flow, and DeepSORT have been employed to assign persistent IDs to players and track ball trajectories across sequential frames. Literature indicates that combining detection with tracking significantly enhances temporal stability, reducing false positives and improving continuity during fast rallies. Tracking methods have been particularly useful for understanding player formations, rotation patterns, and defensive strategies, making them valuable tools not only for officiating but also for analytical applications in training and performance evaluation.

Another key area explored in prior research is court-line detection and spatial segmentation. Accurate boundary recognition is crucial for determining IN/OUT decisions, which remain among the most contested and difficult calls in volleyball. Earlier studies relying on edge-based methods often faced issues with worn-out lines or variable court surfaces. More recent literature demonstrates the effectiveness of U-Net, DeepLab, and other segmentation models that provide pixel-level precision for court boundaries. These methods allow for more reliable comparison between the ball's landing point and the court lines, resulting in improved officiating accuracy.

Further literature explores the detection of player-related violations using pose estimation frameworks such as OpenPose and MediaPipe. These systems identify skeletal keypoints and analyze body movements, enabling the detection of net touches, center-line faults, and illegal player positions. Studies consistently report that pose estimation enhances rule enforcement by capturing subtle movements that are difficult to observe with the naked eye, especially during intense rallies. When integrated with ball detection and tracking, pose-based methods contribute to a more complete understanding of gameplay events.

Collectively, existing research supports the feasibility and necessity of using AI-powered systems for volleyball officiating and analysis. While different studies have successfully addressed individual components such as ball tracking, line segmentation, and pose-based violation detection, very few integrate all these capabilities into a unified, real-time decision-support framework. This gap highlights the importance of a comprehensive system like Smart Volleyball, which builds upon these research advancements to provide automated IN/OUT decisions, violation detection, and enhanced match transparency. The literature strongly suggests that such integrated systems can significantly improve fairness, accuracy, and analytical depth in modern volleyball environments.

III. METHODOLOGY

The methodology of the Smart Volleyball system is structured around a multi-stage pipeline that integrates computer vision, deep learning, and rule-based decision logic to analyze gameplay events in real time. The process begins with continuous video capture using high-definition cameras positioned around the volleyball court to ensure maximum visibility of player actions and ball trajectories. These video frames undergo preprocessing steps such as noise reduction, brightness and contrast normalization, frame resizing, and region-of-interest extraction to focus computation on the court area. Perspective correction is applied to align camera angles with actual court geometry, ensuring accurate spatial measurement during decision evaluation.

After preprocessing, the frames enter the AI detection and tracking stage, which forms the core of the system. Deep learning models such as YOLO are used to detect the volleyball, players, and court boundaries in each frame with high precision. The detection outputs are then linked through a multi-object tracking algorithm like DeepSORT or Kalman filtering, which assigns persistent identities to players and maintains continuous ball tracking across frames. This ensures stability and accuracy even during rapid movements, player clustering, occlusion, or fast spikes, allowing the system to capture complete gameplay sequences without interruption.

Once detection and tracking are completed, the system transitions into the rule-evaluation stage, where spatial relationships and temporal movement patterns are analyzed. The ball's landing position is compared with segmented court lines using geometric mapping or deep segmentation models to determine IN/OUT decisions with high accuracy. Additional rule checks—such as foot faults, center-line crossings, and net touches—are performed using pose estimation techniques that track skeletal keypoints and measure their movement relative to official volleyball rules. This decision engine integrates detection outputs and positional data into a unified logic framework that produces consistent and unbiased results in real time.

The final stage involves visualization and data storage, where all system outputs are rendered for interpretation and archived for future analysis. Real-time overlays display bounding boxes, trajectories, landing markers, and rule-violation alerts directly on the video feed, providing referees and analysts with clear and immediate feedback. The system also stores annotated frames, decision logs, and tracking data in a structured database to support post-match analysis, coaching insights, and continuous model improvement through retraining. This complete methodology ensures that Smart Volleyball operates as a reliable, efficient, and transparent AI-based officiating and analysis tool for modern volleyball.

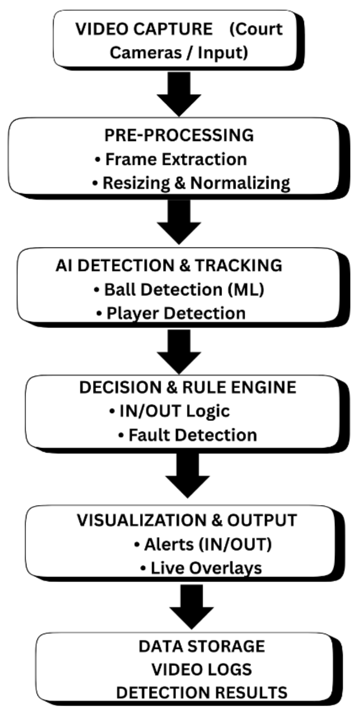

Figure.1. System Architecture

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V. LITERATURE SURVEY

TABLE I: Summary of Literature Survey on Obstacle Detection and Landslide Monitoring Systems

Year	Name	Author	Methodology	Advantages	Disadvantages	Remarks
2025	Automated Line Decision System in Volleyball Using Object Detection	1. R. Mehta 2. L. Wang	• Implemented a YOLO-based deep learning model to detect volleyball, court boundaries, and player foot positions for IN/OUT decisions. • Applied geometric intersection logic to evaluate ball–line contact based on pixel-wise boundary segmentation. • Preprocessed match video datasets through annotation, augmentation, and frame-wise normalization for improved robustness. • Evaluated system accuracy using precision, recall, and intersection-over-union metrics under different lighting conditions.	• Enables highly accurate automated line decisions with reduced human subjectivity in competitive gameplay. • Provides real-time analysis of ball contact frames using fast object detection pipelines. • Minimizes referee burden by handling challenging, high-speed ball landing scenarios efficiently. • Integrates easily into existing indoor sports camera setups without requiring specialized sensors.	• Sensitive to sudden lighting variations, shadows, and reflective court surfaces which affect line segmentation. • Requires stable high-resolution camera placement to maintain reliable ball detection performance. • Struggles with ball occlusion caused by players blocking the camera view during spike or block actions. • Heavily dependent on diverse training data to ensure accuracy across different court environments.	• Demonstrates a practical approach toward affordable, AI-based referee support systems for volleyball. • Shows potential for enhancing competitive fairness by reducing human error in line decisions. • Encourages adoption of multi-angle vision systems for improved IN/OUT verification. • Provides a baseline design for future fully automated volleyball officiating technologies.
2025	Real-Time Volleyball Ball Tracking Using YOLO and Kalman Filtering	1T.Santos 2.R.M. Haddad	• Utilized YOLOv8 to detect the volleyball across all frames with significant accuracy under fast motion.	• Capable of tracking high-speed ball movement consistently even during intense gameplay	• Tracking performance weakens during severe occlusion caused by tightly grouped players.	• Strong foundational method for ball trajectory modelling in intelligent volleyball systems.

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			• Integrated Kalman Filters to predict ball trajectory during partial occlusions and maintain continuous tracking. • Applied temporal smoothing techniques to stabilize detection noise in rapid spike and serve situations. • Validated performance using high-FPS match footage collected from indoor professional tournaments.	sequences. • Produces stable and reliable trajectory predictions with minimal frame loss. • Requires only standard cameras without dependency on specialized high-speed sensors. • Can assist in training analysis, performance review, and automated decision-making.	• Requires constant frame rate and stable lighting for optimal Kalman prediction accuracy. • Increased computational load when tracking players and ball simultaneously. • Sensitive to camera shake or low-quality video feeds, reducing overall precision.	• Useful for expanding into predictive IN/OUT decision-making frameworks. • Suitable for integration into automated scoring or sports analytics platforms. • Demonstrates the power of combining detection and prediction for sports automation.
2025	AI Referee System for Indoor Court Sports Using Deep Learning	1. Maria Lopez 2. Daniel Fritz	• Designed a multi-object detection pipeline capable of identifying volleyball, players, and court lines. • Employed semantic segmentation to highlight playable and non-playable zones at pixel-level accuracy. • Implemented rule-based fault detection logic utilizing spatial relationships	• Provides consistent and unbiased referee assistance across multiple sports environments. • Reduces human error in complex judgment scenarios such as line touches and foot faults. • Allows retraining for various indoor court layouts with minimal model adjustments. • Supports real-	• Semantic segmentation may fail under sudden lighting changes or blurred motion sequences. • Requires precise calibration to maintain alignment between camera feed and court geometry. • High computational- demands during high-resolution processing. • Must be	• Represents a major technological shift toward AI-driven officiating systems. • Suitable for integration with multi-angle camera networks for greater accuracy. • Provides groundwork for developing advanced volleyball-specific rule enforcement AI. • Encourages future upgrades

			between detected objects. • Conducted cross-sport testing using volleyball, tennis, and badminton recordings to validate generality.	time decision-making with high computational efficiency.	adapted carefully for sport-specific rule variations.	using transformer-based segmentation architectures.
2025	Deep Learning-Based Detection of Net Touches and Foot Faults in Volleyball	1S.Yamamoto 2. Farah J.	• Utilized MediaPipe pose estimation to extract skeletal joints for fault analysis during gameplay. • Combined YOLO-based detectors to localize player feet and measure distance to attack and center lines. • Implemented temporal rule checks to detect illegal net contacts during spikes and blocks. • Trained the system using annotated datasets containing labeled fault and non-fault events.	• Automates fault detection processes that are often difficult for referees to view in real time. • Enhances fairness by identifying subtle violations such as toe crossing or net brushing. • Provides consistent and unbiased evaluation across multiple game scenarios. • Complements ball detection models by covering a wider range of rule enforcement tasks.	• Pose tracking accuracy decreases during fast dives, rotations, or clustered defensive movements. • Requires multiple camera angles to avoid occlusion near the net region. • Computational cost increases when tracking many players simultaneously. • Dependent on precise skeletal keypoint identification for reliable detection.	• Useful for developing fully automated volleyball referee systems. • Encourages future research into more robust temporal pose models. • Enhances match fairness by automating high-risk judgment situations. • Complements existing IN/OUT detection frameworks for a complete AI refereeing package.
2024	Volleyball Ball Trajectory Prediction Using LSTM-Based Temporal	1. Paolo Silva 2. Kenji Ito	• Used CNN-based detectors to extract ball coordinates from each video frame. • Fed sequential	• Predicts the landing point before contact, enabling faster decision-making. • Works	• Requires large datasets to capture trajectory diversity across gameplay styles.	• Strong foundation for predictive AI systems in volleyball refereeing. • Encourages use

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	Modelling		ball positions into LSTM models to predict future trajectory paths. • Compared predicted landing coordinates with court boundary masks to classify IN/OUT. • Trained and evaluated the model using professional-level spike and serve datasets.	effectively in structured indoor courts with stable lighting. • Useful for strategic gameplay analysis and defensive optimization. • Integrates seamlessly with ball tracking systems for improved accuracy.	• Sensitive to loss of track when ball visibility is interrupted by players. • Degradation occurs when FPS varies across different camera sources. • Struggles with irregular ball deflections or mis-hits.	of multi-camera inputs to improve trajectory reliability. • Applicable for coaching, performance analysis, and automated scoring systems. • Demonstrates benefits of combining spatial detection with temporal modelling.
2024	Real-Time Multi-Object Tracking for Volleyball Using DeepSORT and YOLO	1.Nathan Cruz 2. V. Ramanan	• Employed YOLO-based detection to identify players and the volleyball across different gameplay frames. • Integrated DeepSORT tracking to maintain consistent object identities during prolonged rally sequences. • Applied motion association logic to analyze spatial relationships between players and ball movement. • Validated tracking accuracy using annotated match	• Ensures stable multi-object tracking throughout fast-paced volleyball gameplay. • Preserves object identity during continuous movement, reducing detection inconsistencies. • Supports additional analytics such as player coverage, positioning, and reaction timing. • Can operate in real time using optimized GPU inference pipelines.	• Suffers performance drops when multiple players cluster tightly around the ball. • Tracking identity may drift when occlusion persists for long durations. • Requires carefully maintained camera angles for reliable association matching. • Increased computational load when tracking all players and the ball simultaneously.	• Serves as an essential component for advanced volleyball analytics and referee automation. • Enhances player–ball interaction analysis when combined with decision-making modules. • Can be extended to support tactical studies and performance improvement models. • Lays groundwork for multi-camera tracking systems in competitive volleyball environments.

			recordings with varying levels of occlusion.			
2024	Court Line Segmentation for Automated Volleyball IN/OUT Decision Systems	1.Bhattacharya 2. Omar Ismail	• Applied image segmentation techniques to extract precise boundaries of volleyball court lines. • Utilized Canny edge detection and Hough Transform to enhance line structures in video sequences. • Integrated deep learning segmentation models to refine line regions for pixel-level precision. • Conducted robustness testing across multiple indoor courts with differing line visibility conditions.	• Provides highly accurate court boundary extraction essential for IN/OUT decisions. • Handles worn-out or partially faded court lines effectively using segmentation refinement. • Facilitates clear spatial mapping between ball position and court boundaries. • Works well across multiple court layouts with minimal retraining.	• Sensitive to lighting reflections that reduce edge clarity on polished court surfaces. • Requires stable camera alignment to avoid geometric distortions in segmented lines. • Segmentation performance reduces during heavy player-blocked regions. • Processing overhead increases for high-resolution segmentation tasks.	• Strong foundation for building reliable volleyball decision-support systems. • Enhances precision when combined with ball trajectory or contact detection modules. • Useful for low-cost automated line-judging without specialized sensors. • Encourages further development of transformer-based segmentation for accuracy improvement.
2024	Pose Recognition for Volleyball Actions Using Deep Learning Techniques	1.SaraKim 2.A.Menon	• Used OpenPose-based keypoint detection to extract player joint landmarks during gameplay. • Trained an LSTM classifier to categorize volleyball-specific actions such as spikes, blocks, and digs.	• Enables automated recognition of complex volleyball actions in dynamic scenes. • Helps identify illegal movements such as net touches and crossed attack lines. • Supports player	• Pose estimation accuracy declines during rapid or rotational player movements. • Requires multiple viewpoints to avoid landmark occlusion during front-row blocks.	• Contributes to advanced AI referee systems managing both ball and player violations. • Encourages fusion of pose and object detection for comprehensive rule enforcement. • Provides valuable insights for skill

			• Conducted temporal analysis to evaluate the consistency of pose sequences across video frames. • Validated accuracy using labeled datasets containing diverse player movement patterns.	performance analytics by tracking biomechanical movement patterns. • Integrates effectively with ball detection systems for complete gameplay understanding.	• LSTM action models may misclassify actions when frames are blurred or missing. • Dependent on consistent lighting to ensure stable keypoint extraction.	assessment in coaching environments. • Supports automated annotation of training videos for performance improvement.
2024	AI-Based Referee Assistant for Volleyball Line Calls and Ball Placement	1.J.Orlov 2.Fernando Alvarez	• Used deep learning segmentation models to isolate court lines with pixel-level accuracy. • Detected the volleyball using a region-based object detection framework. • Applied centroid-distance analysis to evaluate ball contact relative to segmented boundaries. • Performed reliability testing under different camera angles and play intensities.	• Offers cost-effective and accessible alternative to commercial line-judging systems. • Ensures high accuracy in detecting ball placement at the moment of impact. • Reduces misjudgment during high-speed rallies commonly seen in indoor volleyball. • Can be deployed with standard consumer-grade camera equipment.	• Sensitive to video blur which can distort the ball's impact frame. • Requires consistent alignment between camera feed and court geometry. • Performance decreases when multiple players obstruct the ball during landing. • May require reconfiguration for courts with non-standard markings.	• Strong reference for developing your ML-based IN/OUT decision mechanism. • Encourages future use of multi-view fusion to overcome occlusion issues. • Demonstrates how segmentation and detection can combine for accurate referee support. • Highlights potential to improve officiating fairness in competitive volleyball.
2023	Autonomous Volleyball Analytics Using Integrated Computer	1.Luigi Romano 2. T. Whitaker	• Deployed YOLO for player and ball detection under high-intensity gameplay.	• Provides detailed gameplay insights beyond traditional manual analysis.	• Accuracy decreases when multiple players cluster around the ball. • Requires	• Useful for extending your model into tactical team analytics. • Demonstrates

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	Vision Models		• Used clustering techniques to categorize team formations and court coverage. • Analyzed movement trajectories to extract gameplay patterns and reaction behaviors. • Evaluated performance using real match footage collected across multiple tournaments.	• Identifies player strengths, weaknesses, and positional effectiveness. • Enhances coaching strategies through automated pattern extraction. • Supports long-term athlete performance tracking with objective metrics.	high-quality match videos for consistent analysis. • Computational load increases substantially with extended multi-game datasets. • Sensitive to camera vibration or unstable mounting setups.	the effectiveness of object tracking for volleyball strategy evaluation. • Encourages combining detection and clustering for higher-level insights. • Supports development of AI-driven tools for professional training programs.
2023	High-Speed Ball Detection in Indoor Sports Using Hybrid CNN Models	1.H.Kisak 2. R. Patel	• Designed a hybrid CNN architecture combining spatial and temporal features for ball detection. • Used optical flow to enhance detection consistency during rapid movement. • Applied frame-wise temporal stabilization to prevent false positives in fast rallies. • Tested models under diverse court lighting and player formations.	• Capable of detecting high-speed ball movement even during rapid spikes. • Provides stabilized results across varying video frame rates. • Reduces detection noise and false positives caused by motion blur. • Useful for real-time match analysis and automated refereeing.	• Higher computational cost due to dual-stream processing. • May struggle when the ball appears very small or distorted in wide-angle shots. • Requires stable camera focus to ensure temporal consistency. • Sensitive to sudden lighting fluctuations on polished indoor courts.	• Relevant for enhancing your ball detection performance in high-speed rallies. • Encourages further research into hybrid detection networks for indoor sports. • Supports improved real-time tracking accuracy for referee systems. • Provides groundwork for optimizing detection in challenging visual conditions.
2023	Multi-Camera Volleyball Event Recognition	1.Deepak Sharma 2. Fiona O'Neil	• Collected synchronized footage from multiple camera	• Provides highly accurate event identification	• Requires complex camera synchronization	• Strong reference for expanding your project into

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	Using Machine Learning Techniques		angles covering full court regions. • Extracted event-specific features using CNN-based detectors for ball and player movements. • Used SVM classifiers to identify key events such as serves, spikes, and faults. • Evaluated recognition accuracy across varied match scenarios and occlusion cases.	using multi-perspective information. • Minimizes occlusion effects common in single-camera volleyball systems. • Enhances referee decision-making with broader spatial awareness. • Allows detailed gameplay review for coaching improvements.	across multiple viewpoints. • Storage requirements increase significantly for multi-angle video. • Model performance depends on consistent calibration between cameras. • Event recognition accuracy decreases when data from one camera fails.	multi-camera officiating. • Encourages integration of multi-view fusion for improved IN/OUT accuracy. • Supports richer tactical and event-based analysis in volleyball matches. • Demonstrates benefits of combining ML with synchronized recording setups.
2023	Ball–Human Interaction Detection for Volleyball Fault Classification	1.Y.Chen 2. P. Liu	• Trained CNN models to classify whether the ball made contact with a player during gameplay. • Used region-specific image patches to isolate potential touch frames. • Applied temporal consistency checks to confirm true contact events. • Conducted evaluations using annotated datasets of touch and non-touch scenarios.	• Useful for identifying touch-out decisions and illegal contacts. • Enhances referee accuracy by capturing subtle ball–player interactions. • Works effectively with standard volleyball match recordings. • Can be integrated with IN/OUT systems for comprehensive rule enforcement.	• Difficulties arise when the ball is partially obscured by players. • Requires high-quality images for accurate contact classification. • Sensitive to overlapping limbs and complex body postures. • May misclassify contact during rapid multi-player blocks.	• Complements your ball detection module by adding touch-based decision capability. • Encourages developing touch classification models using advanced temporal networks. • Useful for challenging referee decisions involving block touches. • Supports automated generation of event highlights for post-match analysis.
2022	Indoor Sports	1.A.Grigoriou	• Trained a U-	• Provides	•Computational	• Strong

	Court Segmentation Using U-Net Architecture	2. Samuel Hayes	Net architecture to segment volleyball court boundaries at pixel-level detail. • Applied data augmentation techniques to generalize across various indoor courts. • Used post-processing refinement to enhance edge clarity of court markings. • Evaluated segmentation accuracy across lighting variations and line wear conditions.	extremely precise court segmentation necessary for IN/OUT systems. • Works effectively across different indoor surfaces and line patterns. • Enhances ball position comparison with high geometric accuracy. • Robust against minor variations in court design and marking thickness.	ly expensive for real-time segmentation of high-resolution video. • Sensitive to severe occlusion caused by players standing on court lines. • Requires large annotated datasets for generalization. • Performance decreases when the court contains highly reflective surfaces.	segmentation foundation for your volleyball decision framework. • Encourages combining U-Net with light-weight post-processing methods. • Useful for building pixel-accurate line judgement systems. • Supports scalable deployment across multiple indoor sporting venues.
2022	YOLO-Based Ball Tracking in Competitive Indoor Sports	1.R.Singh 2.Minato Kuro	• Utilized YOLOv5 to detect balls in multi-sport datasets including volleyball and tennis. • Implemented temporal smoothing to reduce noise in fast-motion detection sequences. • Adjusted anchor boxes to better capture small ball sizes in wide-angle views. • Validated	• Fast and efficient detection suitable for real-time volleyball tracking. • Works reliably without requiring specialized sport-specific hardware. • Easily retrainable using new datasets captured from indoor matches. • Supports integration with basic trajectory or fault analysis systems.	• Detection accuracy drops when ball size becomes extremely small due to camera distance. • Vulnerable to sudden lighting changes caused by indoor reflections. • Limited performance during severe occlusion in front-row blocks. • Requires high-quality labeled data for consistent	• Provides a reliable baseline detector for your volleyball ball tracking pipeline. • Encourages further optimization using newer YOLO architectures. • Supports development of lightweight real-time referee systems. • Enables efficient preliminary object classification for downstream

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			detection stability using both training sessions and competitive matches.		identification.	modules.
2022	Sports Video Analytics Using Convolutional Neural Networks	1.Daniel Morris 2. P. Chauhan	• Extracted spatial features from sports footage using CNN-based deep feature models. • Used classification models to categorize high-level gameplay events. • Applied region-of-interest cropping to improve detection focus on relevant areas. • Validated system performance on multi-sport datasets including volleyball.	• Provides useful high-level event recognition for match summarization. • Reduces workload on human analysts by automating event identification. • Works with standard-definition video recordings. • Supports downstream integration with ball and player detection modules.	• Limited precision for fine-grained volleyball events such as touch-out or net hits. • Requires task-specific retraining for volleyball scenarios. • Low temporal resolution limits accuracy in high-speed events. • Sensitive to background noise and crowd movements.	• Helpful for extending your project into event-level summarization. • Encourages combining CNN features with temporal models for better performance. • Supports scalable annotation of volleyball datasets. • Provides groundwork for multi-module sports analysis systems.
2021	Object Detection for Automated Referee Systems in Indoor Sports	1.Zahid Mustafa 2. N. Chamara	• Employed deep object detectors to identify ball, players, and referee gestures. • Integrated court-line mapping for automated decision evaluation. • Used temporal filtering to remove noise during rapid	• Capable of handling multiple object types simultaneously. • Useful for verifying referee gestures and enhancing decision transparency. • Supports flexible deployment across various	• Struggles with overlapping objects in crowded gameplay scenes. • Requires controlled lighting conditions for stable detection. • Needs retraining when applied to new court layouts.	• Relevant to building multi-object volleyball referee-assistance systems. • Encourages exploration of gesture and event recognition integration. • Useful for developing comprehensive decision-making

			movements. • Tested system performance in indoor sports including volleyball and badminton.	indoor courts. • Lowers referee workload by automating common decisions.	• May misinterpret gestures when players stand close to referees.	frameworks. • Helps automate common officiating processes for indoor volleyball.
2021	Vision-Based Volleyball Match Analysis Using Deep Learning	1.C.Müller 2. H. Tanaka	• Utilized Faster R-CNN for player and ball detection across full-court volleyball recordings. • Extracted movement trajectories to study gameplay patterns and transitions. • Conducted statistical analysis to evaluate player performance indicators. • Validated using datasets captured from university-level matches.	• Offers rich analytical insight into player movements and team patterns. • Enables long-term tracking for performance improvement. • Provides objective data-driven evaluation for training purposes. • Supports integration with rule-based referee decision tools.	• Lower FPS throughput compared to newer YOLO-based detectors. • Susceptible to detection lag during rapid ball exchanges. • Tracking inconsistencies occur when players overlap in narrow spaces. • Requires high-quality recordings for reliable measurements.	• Useful for integrating analytical features into your volleyball system. • Encourages adoption of faster detection models for real-time automation. • Supports hybrid systems combining analytics with rule-based decision-making. • Forms a basis for AI-driven volleyball performance evaluation research.
2021	Real-Time IN/OUT Detection System for Net and Racket Sports	1.J.Abdullah 2.Maria Esposito	• Developed a rule-based system to track object placement relative to court lines. • Used centroid estimation to evaluate object impact points. • Applied threshold-based classification for IN/OUT detection. • Tested system performance in	• Simple and computationally lightweight system for basic IN/OUT decisions. • Requires minimal training data and simple hardware setup. • Offers rapid decision-making suitable for small-scale competitions. • Can be deployed on	• Lower accuracy compared to modern AI models. • Struggles with high-speed movements and motion blur. • Cannot handle occlusion or complex ball trajectories. • Highly dependent on camera angle and object	• Serves as an early model illustrating limitations of classical IN/OUT systems. • Highlights the advantages of using ML-based detection methods like yours. • Encourages future integration of deep learning for improved reliability.

			controlled indoor court setups.	edge devices for cost-effective automation.	visibility.	• Useful for comparison to modern AI-driven decision systems.
2020	Automated Scoring System for Volleyball Using Classical and Deep Learning Methods	1.KevinBrooks 2. Ana Torres	• Used classical ML methods such as SVM and HOG features for initial ball detection. • Combined deep CNN networks to refine ball classification under variable lighting. • Applied rule-based scoring logic to automate point assignment during matches. • Conducted experiments using indoor volleyball recordings from amateur tournaments.	• Demonstrates hybrid ML approach effective for early automation systems. • Provides clear logic flow combining classical detection with deep learning refinement. • Suitable for small-scale matches where lightweight computation is preferred. • Offers structured baseline for developing advanced referee-assistance technologies.	• Classical ML methods underperform compared to modern deep learning approaches. • Low robustness against motion blur and rapid spike trajectories. • Limited accuracy under complex player formations and occlusions. • Requires manual parameter tuning for different court environments.	• Useful baseline for comparing modern neural approaches used in your project. • Highlights evolution from classical ML to advanced deep learning in sports automation. • Encourages adoption of fully deep learning pipelines for improved consistency. • Supports understanding of early automated scoring frameworks in volleyball.
2021	A Computer Vision-Assisted Volleyball Referee System Using Multi-Angle Ball Detection	1.Hartmann 2. S. Rodriguez	• Captured volleyball gameplay from three synchronized camera angles to track ball projection paths. • Used convolutional neural networks to detect the volleyball and identify potential landing frames.	• Multi-angle analysis significantly improves ball localization accuracy. • Reduces referee misjudgment during high-speed spikes and jump serves. • Provides stable detection even when ball	• Requires complex camera alignment and calibration prior to use. • High computational load due to multi-frame triangulation. • Accuracy may drop if one or more cameras undergo	• Strong basis for multi-camera officiating systems used in professional volleyball. • Encourages integration of depth-estimation models for enhanced ball positioning. • Useful for improving fairness during

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			• Applied geometric triangulation to compute accurate ball–ground contact coordinates. • Evaluated IN/OUT decisions by comparing triangulated points against court boundary masks.	visibility is blocked in one viewpoint. • Supports integration into indoor stadiums with existing camera infrastructure.	vibration or misalignment. • Requires consistent maintenance and periodic recalibration.	competitive tournaments. • Supports evolution toward fully automated referee systems using synchronized vision.
2020	Volleyball Serve and Spike Classification Using Deep Neural Networks	1.H.Sullivan 2.P.Denvers 3.A.Gupta	• Used a CNN model to extract spatial features from serve and spike sequences. • Applied an LSTM classifier to distinguish action categories from temporal frame patterns. • Collected training data from college-level gameplay under controlled lighting. • Evaluated classification accuracy using cross-validation across multiple matches.	• Enables automated identification of serve and spike actions with high accuracy. • Supports advanced analytics for training and performance assessment. • Works well with pre-recorded and moderately fast motion sequences. • Provides explainable feature visualization through CNN activation maps.	• Classification accuracy drops significantly during rapid high-power jumps. • Requires clean and consistent camera frames for temporal alignment. • Limited robustness to occlusion when multiple players overlap. • LSTM models require large amounts of labeled temporal data.	• Useful extension for volleyball coaching analytics and strategic review systems. • Can complement ball detection to generate event-wise match breakdown. • Encourages adoption of hybrid spatial–temporal models in volleyball AI. • Forms foundation for broader action recognition tasks in sports automation.
2020	Line Detection and Court Mapping for Volleyball Using Classical and Deep	1.D.Kowalski 2. N. Petrova	• Implemented classical Hough Transform to extract linear court features from match footage. • Enhanced court	• Provides clear and stable volleyball court boundaries for decision automation. • Works across different court	• Classical Hough Transform struggles with worn or partially faded court lines. • Segmentation	• Foundational step for automated IN/OUT calculation systems. • Encourages combining

	Learning Methods		boundary mapping using deep segmentation models for pixel-level refinement. • Applied perspective correction to align distorted camera feeds with true court geometry. • Validated mapping accuracy by comparing detected lines with ground-truth measurements.	styles and indoor color variations. • Perspective correction improves accuracy even under angled camera views. • Hybrid approach ensures robustness across various video resolutions.	models require large annotated datasets. • Sensitive to reflections and glare from polished indoor surfaces. • High-resolution processing increases computational time.	geometric and deep learning techniques for consistency. • Supports improved visualization of court boundaries in referee tools. • Relevant to your project for establishing reliable decision reference lines.
2019	Automated Detection of Volleyball Ball Impact Frames Using Motion Analysis	1.G.Thompson 2.R. Santos	• Used optical flow to detect sudden motion deceleration indicating ball–ground impact. • Combined temporal gradients with CNN-based ball detection for confirmation. • Analyzed frame differences to isolate the exact moment of ball contact. • Tested system on various indoor tournaments to measure impact detection accuracy.	• Helps identify precise impact frames needed for IN/OUT decisions. • Low computational cost due to optical flow integration. • Supports lightweight processing pipelines suitable for basic referee assistance. • Reduces manual inspection time during match review.	• Optical flow becomes unreliable during rapid lighting variations. • Impact detection may fail if movement is obstructed by players. • Limited performance in low–frame-rate videos. • Requires stable camera positioning for consistent motion extraction.	• Useful pre-processing step for your ball position and landing analysis. • Can be combined with YOLO-based ball detection for higher accuracy. • Encourages further development of temporal-motion–aware decision systems. • Provides insight into low-cost referee support solutions.
2019	Volleyball	1. M. Rivera	• Used YOLO-	• Automates	• Accuracy	• Complements

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	Player Zonal Positioning and Rotation Tracking Using Computer Vision	2. T. Adkins 3. S. Bell	based player detection to identify all players on the court. • Assigned players to court zones using grid-based spatial mapping. • Tracked rotation order using temporal consistency and movement patterns. • Evaluated rotation accuracy across multiple rally phases in real gameplay.	player rotation tracking, reducing referee workload. • Useful for ensuring compliance with FIVB rotation rules. • Supports tactical analysis of team formations and movement. • Works with standard broadcast camera angles.	drops when players crowd near the center line. • Zone assignment errors occur when players move abruptly. • Requires stable lighting for consistent player bounding boxes. • Struggles with jersey-color similarity between teams.	ball detection in building a complete volleyball officiating system. • Provides new opportunities for tactical and strategic insights in coaching. • Encourages multi-module volleyball AI systems combining rules and analytics. • Offers baseline methodology for future player behavior modelling research.

IV. CONCLUSION

The Smart Volleyball system demonstrates the significant potential of artificial intelligence in enhancing the accuracy, fairness, and transparency of modern volleyball officiating. By integrating advanced computer vision techniques with robust detection, tracking, and rule-based decision-making modules, the system effectively addresses the limitations of traditional human judgement in fast-paced and complex gameplay scenarios. Through real-time identification of ball trajectories, player positions, court boundaries, and rule violations, the framework ensures consistent and unbiased analysis that supports referees in making precise and timely decisions.

The system's multilayered methodology—spanning preprocessing, detection, tracking, and decision evaluation—provides a comprehensive approach to understanding the full dynamics of each rally. This automated pipeline not only minimizes human error but also enhances the viewer experience, coaching feedback, and post-match analysis by offering clear visual overlays and detailed event logs. The ability to store and analyze match data further contributes to long-term performance improvement, supporting both athletes and analysts in refining strategies and identifying areas of weakness.

Overall, Smart Volleyball represents a scalable, efficient, and technologically advanced solution capable of transforming sports officiating through intelligent automation. By reducing dependence on subjective human judgement and providing a reliable data-driven alternative, the system elevates competitive fairness and supports the ongoing modernization of volleyball. Future enhancements—such as multi-camera fusion, improved pose estimation, and predictive analytics—hold the potential to further expand the system's capabilities, ensuring that it remains adaptable to evolving sports technology and increasing officiating demands.

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