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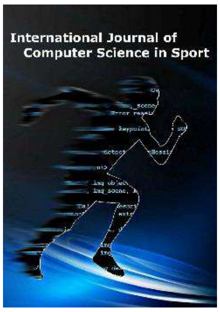

A Review on the Application of Artificial Intelligence in Basketball Sports

*Zhang Chenyi[1], Zhu Weijian[2, *], Li Bo[2, 3], Zhu Zhiyong[1], Zhu Feng[1]*

1 China Basketball College, Beijing Sport University, Beijing 100048, China;

2 School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, China;

3.Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment, Beijing 100044, China

Abstract

Basketball exerts a significant global influence, marked by intense competition and widespread participation, contributing substantially to the global economy. Recent advancements in computer technology and artificial intelligence (AI) have propelled research in basketball, leading to notable achievements in various aspects of the sport. A thorough literature review on the application of computer and AI technologies in basketball reveals four key areas: virtual reality technology, data capture and recognition, performance analysis and prediction, and basketball flight trajectory prediction. These studies enhance player and team training, analyze player characteristics, devise game strategies, recognize on-court data patterns, predict match outcomes, and reduce injury risks. Evidence from most studies indicates that computer and AI technologies have significantly improved player instruction and training, demonstrating remarkable potential for development in analysis and prediction. Nevertheless, this research is still in its infancy; more efforts are needed to translate these findings into practical applications.

KEYWORDS: BASKETBALL; ARTIFICIAL INTELLIGENCE; VIRTUAL REALITY; DATA CAPTURE AND RECOGNITION; PERFORMANCE ANALYSIS.

Introduction

The sport of basketball was initially established in 1891 and has since amassed a rich historical legacy spanning over 130 years. Presently, basketball stands as one of the most widely embraced sports globally, with a substantial number of participants and serving as a significant catalyst for global economic development. Basketball is renowned for its intense competitiveness and has given rise to numerous professional leagues worldwide, with the most prominent being the National Basketball Association (NBA) in the United States.

Basketball demands exceptional physical fitness, fundamental skills, and close teamwork from players, making their technical and tactical abilities crucial. Traditionally, coaches rely on past experience for training, with most research focusing on biological principles, such as enhancing physical fitness (Greco, Memmert, & Morales, 2010; Gao, Zhao, & Zhang, 2014; Ramirez-Campillo et al., 2022; Luo et al., 2023; Pechlivanos et al., 2024), honing technical and tactical skills (Kumar, 2014; Savas, Yüksel, & Uzun, 2018; Pratama et al., 2022), and exploring their interrelationship. Physical fitness includes speed, strength, explosive power, coordination, and endurance, essential for performance. Skills encompass dribbling, passing, shooting, blocking, stealing, and executing team tactics. Traditional studies typically involve comparative experiments to determine the effectiveness of methods, often requiring significant time.

Recent advances in computer technology, particularly AI, have revolutionized basketball research. Computer science serves as the foundation for AI, a subfield within this broader discipline. In contemporary life, AI pervades every aspect. AI is a broad concept encompassing a wide array of research domains, such as machine learning, computer vision, natural language processing, and robotics, among others. Nevertheless, given that the application of AI in the domain of basketball remains in its nascent stage, the AI mentioned in this article specifically pertains to the technologies that have already found application in the field of basketball, although this may still not be comprehensive enough. The technologies discussed in this article primarily involve computer hardware and computational programs and software used for simulation, such as MATLAB and Computational Fluid Dynamics (CFD). AI mentioned in this article focuses on the research and development of theories, methods, technologies, and application systems aimed at simulating, extending, and augmenting human intelligence. Leveraging advanced computational programs and algorithms, AI and computer technology have become significant in basketball. AI and computer-based research methods, such as trajectory prediction (Carré et al., 2002; Seo, Murakami, & Yoshida, 2004; Lissaman & Hubbard, 2010; Seo et al., 2014; Jung, Staat, & Müller, 2014; Ward et al., 2019; Che & Keir, 2021;), data collection, and analysis (Rein & Memmert, 2016; Brock & Ohgi, 2017; Khaustov & Mozgovoy, 2020), have been successfully applied to sports like football, flying disc, and ski jumping. Compared to traditional methods, intelligent computers and devices excel in collecting, analyzing, and predicting big data, enabling a comprehensive analysis of players' skills and tactics. This broader perspective facilitates an in-depth assessment of strengths and weaknesses and provides targeted training. Additionally, this research extends beyond player and match analysis, enhancing referee call quality, predicting game outcomes, and forecasting player injuries. These applications have significant implications for basketball matches.

Currently, the application of computer technology and AI in basketball is still in its nascent stages. This literature review categorizes emerging fields of basketball research into four main areas: virtual reality technology, data capture and recognition, performance analysis and prediction, and prediction of basketball flight trajectory. The primary goal of this review is to provide a clear classification of existing research methods for novice researchers and offer new insights for current researchers. The following sections will provide a comprehensive overview of the applications and methodologies of basketball intelligence across these four dimensions.

Methods for the Review

In order to conduct a comprehensive review of the application of AI in basketball sports, this review obeys the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009). Adhering to PRISMA guidance ensures that this review maintains a systematic and thorough approach.

Search Strategy

Prior to conducting the literature review, we initially conducted searches for relevant articles using keywords such as "AI" and "basketball" in ‘Google Scholar’, ‘Baidu Scholar’, ‘IEEE Explore’, and ‘ScienceDirect’. Based on the varying research content, we preliminarily categorized the application of AI in basketball sports into three aspects: virtual reality technology, data capture and recognition, and performance analysis and prediction. Furthermore, we employed more detailed keywords such as ‘VR’ , ‘data’, and ‘senor’ for article retrieval based on various applications of AI in basketball sports to broaden the scope of research content. Articles written in English are our top choice. During the search process, it was noted that the trajectory of basketball flight is pertinent to all three aforementioned research fields. Consequently, we have incorporated the prediction of basketball flight trajectory within the purview of this review. The search keywords for relevant articles in each research domain are delineated in Table 1. The materials procured through our search encompass research articles, review articles, conference articles and books. We also augmented the breadth of our literature search by employing a ‘snowballing’ methodology, which involved expanding our search range through citation and reference expansion to bolster the comprehensiveness of this review.

Table 1. Literature search details

Time	Literature Database	Research Domain	Key Words	Type of research work
March 2024 to May 2024	Google Scholar Baidu Scholar IEEE Explore ScienceDirect	Virtual Reality Technology Data Capture and Recognition Performance Analysis and Prediction Prediction of Basketball flight Trajectory	Artificial intelligence (AI) Basketball Virtual reality (VR) Senor Video Data Prediction Trajectory	Research articles Review articles Conference articles Books

Selection Process

The literature search commenced in March 2024 and concluded in May 2024. In light of the recent widespread application of AI and its appeal to researchers across various disciplines, the majority of collected articles are publications from 2010 onwards, with only a minority predating 2010. Based on the keywords presented in Table 1, we initially undertake the first round of literature search and acquire relevant new keywords, references, and cited references via the ‘snowballing’ methodology. This methodology is implemented in the four research domains (Table 1) within this paper, and its merit lies in the capacity to promptly obtain a substantial amount of articles within a short time span and comprehend in which fields the corresponding technologies have been applied. The articles encompassed within the review are primarily evaluated in light of their pertinence to the review topic, the count of citations they have garnered, and the quality of their content. Similar articles will be eliminated, thereby 112 articles during the initial literature search was obtained. From an initial pool of 112 articles, we further delineated the four research domains into multiple subfields, as depicted in Figure 1. Taking the performance analysis of player and team module within performance analysis and prediction as an example, our focus on selected articles centered around: 1) methods and algorithms for predicting player and team performance; 2) accuracy of such predictions; and 3) strategies for leveraging predictions to enhance player or team performance. Consequently, additional refinement is necessary when sifting through the acquired articles.

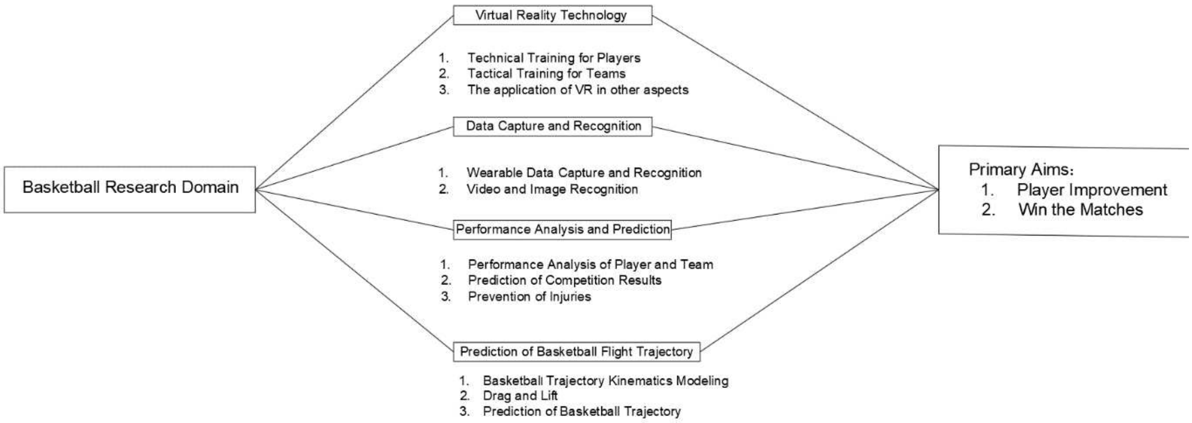

Figure 1. Relationship among four basketball research domains

Due to the presence of overlapping content in the retrieved literature, 27 articles were excluded, leaving a final selection of 85 articles. Additionally, 24 relevant research papers from other fields were considered as crucial supporting factors for the argument. Although these 24 articles are not pertinent to basketball, the research approach employed in the articles is universal and can even offer enlightenment for the application of AI in basketball. These papers encompass not only sports such as soccer and ski jumping but also research from the domain of aerospace. Beyond the mentioned articles, despite the fact that certain articles were not encompassed within the review, they are nonetheless intimately associated with AI and basketball, such as the operation of the team, player trades, the automatic generation of videos featuring exciting game moments, and the influence of fan participation on the game, among others. The material selection process and methods were based on PRISMA guidelines, with Figure 2 depicting the relevant screening process.

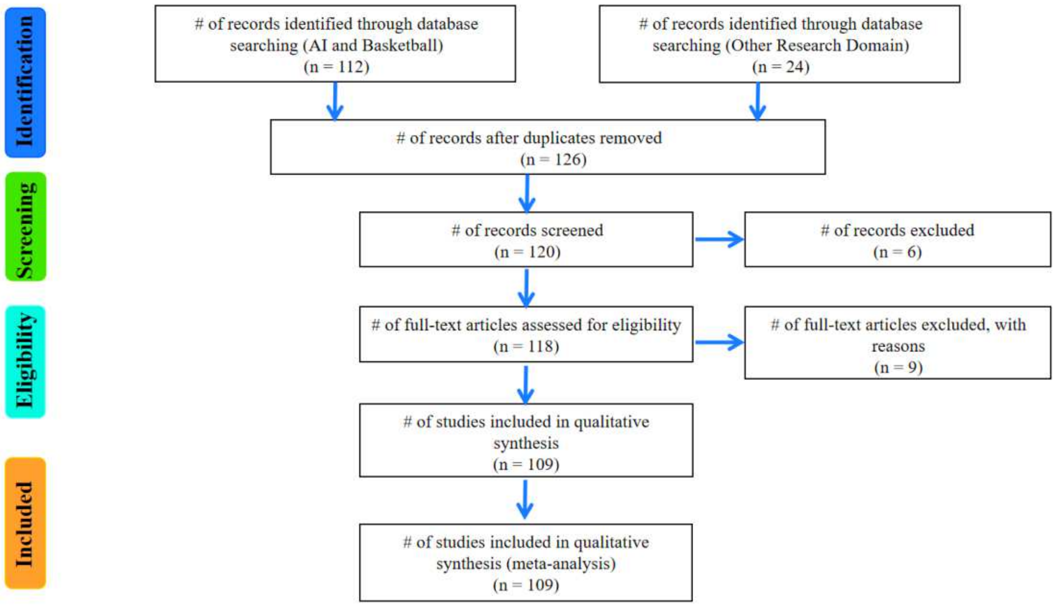

Figure 2. Flow of information through the different phases of a review based on the PRISMA

Virtual Reality Technology (VR)

Theoretically, VR constitutes a computer-simulated system capable of creating and experiencing a virtual world. It employs computer-generated simulations to establish an immersive environment for users. The origins of VR technology can be traced back to the 1980s, but it only began to gain widespread popularity in the 2010s. VR technology is characterized by its immersive experience, interactivity, perceptiveness, and innovation, which have propelled advancements in numerous fields (Jerald, 2015). Currently, VR is gradually being applied in various areas of sports, particularly playing a significant role in learning and teaching (Abulrub, Attridge, & Williams, 2011). Neumann et al. (2017) conducted a comprehensive review of the application of interactive virtual reality in sports training. They defined virtual reality within sports and proposed an application framework and system for its use. In basketball training specifically, VR represents an innovative method that can enhance the efficiency of training processes (Ma, Wang, & Liu, 2020), although the manner in which VR is worn may present a significant obstacle to advancing this training technology. At present, VR has been implemented across multiple domains within basketball.

Technical Training for Players

A player's proficient technical expertise is crucial in winning basketball games, encompassing both offensive and defensive skills. Shooting, as the primary scoring method, requires a solid technique, which is essential for every outstanding player. Beyond traditional coaching, VR technology offers a promising approach to learning shooting techniques. Li (2018) highlighted that virtual reality-based basketball technical training can help athletes quickly grasp key actions and significantly enhance training efficiency.

For effective VR-based shooting training, precise simulation of the basketball flight trajectory is necessary to provide accurate shooting feedback. This also requires capturing the hand shape and shooting conditions of the player (Covaci et al., 2012; Zindulka, Bachynskyi, & Müller, 2020). As various technologies advance, the role and effectiveness of VR in basketball training are becoming increasingly evident. Research has shown positive results regarding VR's performance in basketball training, particularly in instructional applications. Zamzami's (2020) study involved 45 novices divided into three groups: real training, VR training, and a control group. Shooting tests conducted before and after training, evaluated using One-Way ANOVA, indicated significant improvements in the shooting skills of both the real and VR training groups, with minimal differences between them. This suggests that VR technology is a feasible and effective method for learning shooting. Soltani & Morice (2023) analyzed VR-based shooting training across various scales, including instrument construction, biomechanics, and psychological fidelity. In virtual training, a basketball fitted with MarkerDriveBoxes and batteries simulates shooting, with software calculating the ball's trajectory for accuracy. Using an actual basketball enhances sensory perception and psychological immersion. The study also measured players' expertise and sensitivity to basket distance perception, finding that kinematic characteristics did not affect distance adjustments. Furthermore, the study tracked and identified players' professional skills and gender, offering tailored measurement devices for different skill levels.

In VR training, the design of the virtual environment (VE) is a crucial consideration, as different VEs can introduce perceptual biases. While a first-person perspective is typically employed in conventional VR training, research indicates that scenarios like free throws may benefit from a third-person perspective due to potential underestimation of shooting distance in the first-person view (Covaci, Olivier, & Multon, 2014). Identifying VR training modes that are both suitable and immersive is therefore essential.

In basketball training, players must enhance not only their technical skills, such as passing, shooting, and dribbling, but also their reactive abilities and agility, which are equally significant in competitive play. Players need to process dynamic information swiftly and make decisions based on this input. Offensive players must decipher defensive tactics, necessitating the simultaneous monitoring of both defenders and teammates. Consequently, visual training for movement is critical. A comprehensive review of sports visual training literature underscores the importance of visual training in competitive sports and discusses historical perspectives and methodologies (Appelbaum & Erickson, 2018). BetterSight, a VR-based immersive basketball visual training system, includes an interaction module (IM), a Training Content Generation Module (TCGM), and an Analysis Module (AM). This system facilitates direct interaction between players and the VR environment while requiring the use of a real basketball during simulated training scenarios. Figure 3 illustrates the BetterSight framework. Throughout training sessions, player eye movements are tracked and analyzed, with insights used to assess training efficacy (Liu et al., 2022).

Currently, most VR basketball training research focuses on shooting techniques, with comparatively less attention given to actions like dribbling and layups due to technical challenges. Future research should explore VR's potential in training areas such as dribbling, passing, situational awareness, and individual defensive skills to enhance players' overall capabilities and technical proficiency.

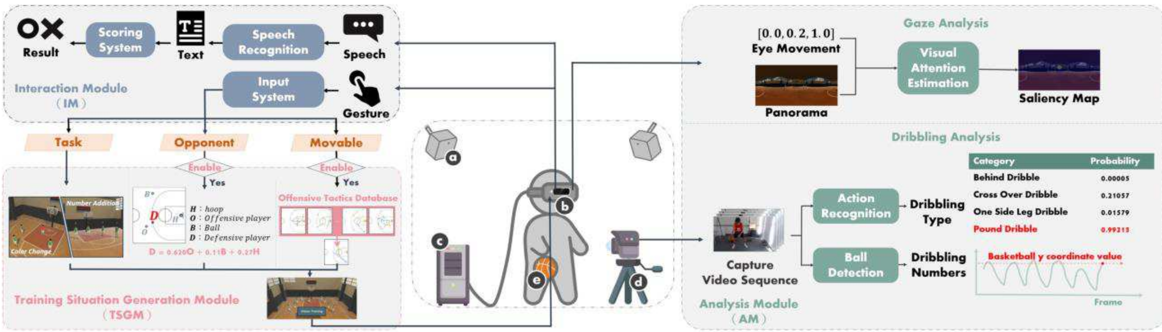

Figure 3. System framework of BetterSight (Liu et al., 2022)

Tactical Training for Teams

In a competitive setting, team tactical coordination is recognized as a critical determinant of game dynamics, often surpassing individual player capabilities. Effective tactical coordination facilitates smoother ball movement and enhances opportunities for favorable shooting spaces. Given basketball's nature as a team sport, the significance of team coordination can outweigh individual abilities. VR technology has shown potential in enhancing players' comprehension and interpretation of game tactics compared to traditional training methods. Tsai et al. (2017; 2018; 2020) developed a VR-based tool for basketball tactical training, offering both 2D and 3D modalities. This technology utilizes a wireless VR interaction system with motion capture, allowing players to move swiftly. Figure 4 illustrates the VR device used in the experiment. The system includes a computer server to generate 3D virtual players for training purposes and uses tactic input devices to predetermine target tactics during practice sessions. This ensures comprehensive coverage of various tactical categories while effectively augmenting players' situational awareness through immersive training experiences. Additionally, by eliminating the need for physical movement on a virtual court during these sessions, there is potential to mitigate injury risks.

Outstanding tactical thinking is essential for the accurate execution of basketball tactics. In team offense, the ball carrier must observe teammates' movements and assess the rationality of the next ball transfer. Enhancing players' on-field decision-making abilities significantly improves tactical execution. Research shows that VR-related training effectively enhances players' game decision-making capabilities. Using control groups and actual training and game footage, subjects viewed clips in VR and answered tactical decision questions. The findings indicate that VR provides a more realistic perceptual environment, closely resembling real-game scenarios, thus yielding greater benefits in analyzing game videos (Pagé, Bernier, & Trempe, 2019). Tsai et al. (2019) investigated VR's impact on decision-making abilities using ANCOVA. Participants wore motion capture devices and engaged in interactive VR defensive scenarios, receiving alerts and advice when making incorrect offensive choices. Testing 45 participants divided into control and VR groups (with subdivisions using 360° panoramic video and computer-generated environments), the study found that while VR training did not enhance decision-making abilities, it reduced decision-making time. Given the nearly identical effectiveness of 360° panoramic videos and computer-rendered environments, and considering the production cost of 360° videos, computer-generated virtual environments may be a preferable training choice.

To make VR basketball training more convenient for academic purposes, Honma et al. (2021) introduced a VR-based training system designed to enhance decision-making abilities through a simulation environment closely mirroring real-world conditions. This system suits players who cannot engage in normal games. They assessed perceptual errors in the vertical, horizontal, and depth directions between trainers and VR objects to refine system accuracy. Additionally, Honma et al. developed a VR game application to enhance decision-making skills and shooting awareness, providing convenient accessibility for trainers.

Recently, a large-scale basketball tactical training environment based on mixed reality (MR) has been introduced. Unlike traditional computer-rendered virtual environments, this method integrates virtual players with real-world scenarios using transparent head-mounted displays and motion capture technology to track the positions of individuals and balls. This seamless integration of virtual and real elements significantly enhances the immersive nature of the training experience (Figure 5). Research suggests that this approach is more effective than conventional tactical training methods and holds promise for multi-person tactical training (Saiki et al., 2024).

Figure 4. VR for basketball training (Tsai et al., 2020)

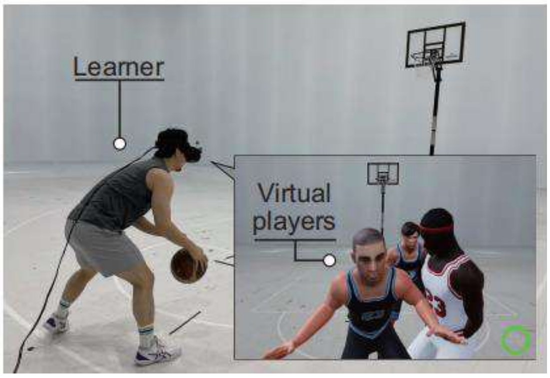

Figure 5. Applications of MR (Saiki et al., 2024)

The application of VR in other aspects

In addition to being effective in player training, VR can also be utilized to enhance the competitive level of other aspects of sports competitions. In the context of basketball games, referees are pivotal in upholding fairness and impartiality, constituting an essential component of the sport. Particularly within high-level professional leagues, the proficiency and integrity of referees' decisions are indispensable. Instances of erroneous calls and overlooked infractions during actual gameplay necessitate a heightened focus on refining referees' adjudicative capabilities. VR technology has shown potential not only in player training but also in facilitating effective training for referees. Iskurniawan, Sugiharto, & Mukarromah (2020) developed a VR-based instructional product that significantly aids referees in honing their decision-making skills during training sessions. This product has received commendation from both refereeing experts and media professionals, with referees giving it a "very good" rating 97% of the time in a small-scale experiment. Despite its relevance to basketball refereeing, VR's application remains relatively limited, with scant scholarly literature available on the subject.

Current VR training presents challenges, as it requires a high degree of immersion and fidelity in user perception. Feedback from trainers indicates that most individuals initially struggle to integrate training outcomes with real-world perceptions during VR training. Perceptual errors, such as misjudging distances, can directly impact the efficacy of player training (Covaci, Olivier, & Multon, 2015). Enhancing feedback mechanisms in VR is crucial for improving immersion experiences. For instance, integrating vibration tactile gloves into a VR basketball training system can heighten immersion through tactile feedback (Tsai, Pan, & Hu, 2022), as illustrated in Figure 6. However, current methods for enhancing immersion through tactile feedback still have limitations. Additionally, visual perception may be an even more critical factor in improving training effectiveness

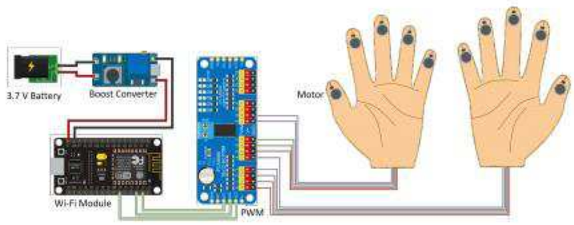

Figure 6. Vibrotactile gloves (Tsai et al., 2022)

Research on basketball VR training indicates that the dimensions of VR wearable devices may limit trainers' ability to fully optimize their capabilities (CannavòLi et al., 2018). For example, the substantial size of VR goggles could potentially influence shooting movement. Therefore, miniaturization and lightweight design of VR equipment represent promising directions for the advancement of basketball VR training.

In conclusion, research in numerous basketball VR training-related studies has primarily focused on novices. While significant effects have been observed in beginner training, the effectiveness of such training for professional players remains to be determined. The professionalization of basketball VR training requires further exploration. VR-based training modalities allow trainers to engage in multiple repetitions across a broader range of scenarios and receive automatic evaluation after each trial. However, the transfer of skills from virtual training to real-world practice remains an unresolved issue and warrants further investigation.

Data Capture and Recognition

In the training and competition of athletes, acquiring their movement data is crucial. The detection of physiological and kinematic characteristics serves as the foundation for performance analysis and prediction, which can effectively assist athletes in optimizing their training, enhancing athletic performance, and mitigating injury risks. In addition to recognizing video and images captured by cameras, there has been a recent emergence of wearable data capture and recognition devices that can be utilized to differentiate athletes' movement patterns and record various physiological parameters.

Wearable Data Capture and Recognition

Wearable devices primarily include motion and physiological sensors. Generally speaking, a sensor is a kind of detection apparatus that is capable of sensing the measured information and converting it into electrical signals or other requisite forms of information output in accordance with a specific rule, so as to fulfill the demands of information transmission, processing, storage, display, recording, and control. In the sport of basketball, motion sensors, such as pedometers, accelerometers/gyroscopes, and GPS trackers, and physiological sensors, including heart rate monitors, sleep monitors, temperature sensors, and integrated systems (Li et al., 2016), collect athlete data during training and competitions, offering timely feedback to coaches. This feedback helps refine training regimens and identify optimization opportunities.

Accelerometers are the most widely used motion sensors in basketball, crucial for enhancing training effectiveness by identifying different movement patterns. Nguyen et al. (2015) introduced the BSK board, a wearable data detection device with multiple inertial measurement unit sensors to capture movement data (Figure 7). The compact BSK board (62x35x24 mm3) minimally impacts players. Comparisons between video recordings and sensor signals identified acceleration signal features in specific movements, enabling recognition of fundamental basketball actions like walking, jogging, running, sprinting, jumping, shooting, layups, and pivoting. The recognition accuracy for distinguishing between standing and moving is 92%, although variations in physical characteristics among players can reduce the accuracy of identifying movement patterns related to steps and jumps. Recognition of basketball footwork can also be achieved using smart insoles embedded with multiple motion sensors. While identifying most basketball actions is costly, smart insoles with integrated three-axis acceleration and angular velocity sensors reduce costs. Data from these insoles, combined with algorithms (K-Nearest Neighbors (KNN), Support Vector Machines (SVM), and Convolutional Neural Networks (CNN)), enables recognition of five fundamental basketball footwork movements: sideslip step, backward step, cross step, jab step, and jump step. Analysis of test data from three college basketball players revealed the CNN algorithm had the highest accuracy rate at 98.51%, followed by the SVM algorithm at 98.51%, and the KNN algorithm at 80.70% (Peng, Zhong, & Zhou, 2020).

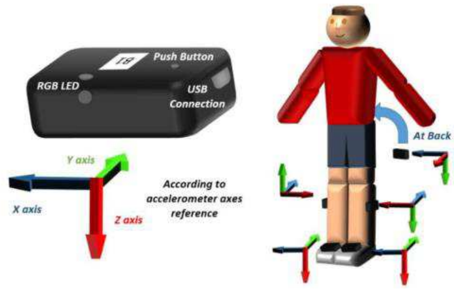

Figure 7. BSK board model and positions of sensor setup (Nguyen et al., 2015)

In basketball competitions, shooting is the primary method for scoring. Research on recognizing and detecting shooting actions using wearable sensor devices is still in its early stages. Unlike identifying various basketball movement patterns, the main utility of wearable sensors lies in recognizing a player's shooting posture. This recognition helps develop proper shooting form and habits, providing comprehensive guidance on shooting technique. Previous studies have shown that collecting shooting signals is feasible by installing devices with integrated 3D acceleration and gyroscope sensors on the dorsum of the shooting hand (Figure 8). Accurate identification of shooting action features through waveform recognition enables real-time guidance on shooting techniques and alerts about potential errors (Taniguch, Watanabe, & Kurihara, 2012). To enhance the precision of identifying shooting actions, Fan et al. (2021) developed a basketball shooting posture recognition system using a deep learning model (VGG16) based on a CNN fused with an inertial measurement unit sensor. The training data for the deep learning model came from 13 untrained adult males aged 18-40, with 12,210 shooting data points, including five basic and five composite shooting postures, collected using wireless sensors on the dominant hand and foot. This data was then categorized and analyzed. Subsequent research by Fan et al. (2022) introduced a new deep learning model (SCGA) to identify shooting postures, demonstrating that the SCGA model outperformed the VGG16 model. Kuhlman (2021) utilized the Mbient Lab's MetaMotion R wearable system, positioning it on participants' wrists to collect shooting signals in a research setting. The data was then used to develop a machine-learning application in MATLAB for analyzing shooting features. Among the methods tested—Quadratic SVM (QSVM), Decision Tree, KNN, and SVM—the QSVM proved to be the most effective, achieving an accuracy rate of 85% in identifying four types of shooting.

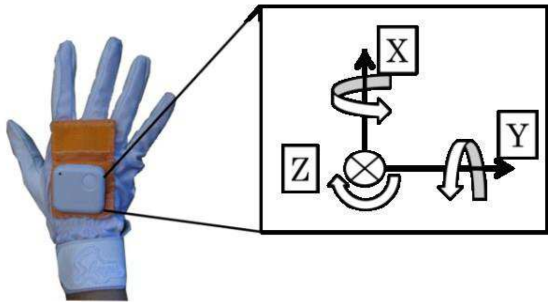

Figure 8. Wearable sensor for shooting posture recognition (Taniguchi et al., 2012)

The Global Positioning System (GPS) plays a significant role in data capture and recognition. Besides collecting movement data, GPS can gather players' movement trajectories, studying the relationship between player positions and actions during games and team performance (Metulini, 2016). Metulini, Manisera, & Zuccolotto (2017) affixed GPS microchips to athletes' clothing, using the system to capture movement and position data during matches. Their analysis of spatial structure, relative distances, and offensive and defensive characteristics at different intervals provides valuable insights for coaches to enhance team performance.

Sports sensors can also be integrated into equipment like tennis rackets, basketballs, and soccer balls. Abdelrasoul et al. (2015) highlighted the 94Fifty instrumented basketball, which offers real-time data on shot trajectory, speed, and dribbling frequency via a smartphone or tablet. Comparing player-measured data with video analysis showed the 94Fifty's excellent data acquisition accuracy. This shooting and dribbling data can provide precise, timely feedback for players and coaches, guiding training effectively.

In physiological data monitoring, players' physiological parameters serve as benchmarks for assessing their condition and identifying areas for improvement in physical fitness (Montgomery, Pyne, & Minahan, 2010). Sensor devices track heart rate, body temperature, EEG, and energy expenditure during games, determining physiological indicators and health status (Taylor, Nagle, Goss, Rubinstein, & Simonson, 2018). Many smartwatches, like the Apple Watch, offer this functionality, providing real-time physiological data and providing real-time physiological data for athletes, facilitating the monitoring and analysis of their physical health status. Their convenient wearability allows easy integration into basketball training sessions.

Although wearable sensors are still not permitted to be worn during official competitions, they provide a rapid and accurate method for obtaining sports data due to their portability and minimal impact on training and competition. The miniaturization, precision, and data recognition methods of sensors will be the primary focus of future development in this field. The identification of collected data is a crucial step, as accurate analysis is essential for guiding player training and facilitating player improvement. Most contemporary data analysis methods are AI-based and closely integrated with big data, with the precision of the analysis method determining the accuracy of conclusions.

Video and Image Recognition

In the traditional sense, basketball data is primarily captured from video and images taken by cameras installed in the court environment. Video and images offer the most intuitive records, and their cost is lower and application range wider compared to wearable devices. With the advancement of computer technology, these methods are now mostly integrated with AI, achieving promising results based on computer vision applications.

Video and image recognition significantly enhance the analysis of basketball movements, particularly shooting, contributing to scientific training advancements. Ji’s (2020) feature extraction from images provided multi-dimensional movement data in both time and frequency domains. Precise shooting posture identification was achieved through feature selection and Gaussian hidden variables. Four classification methods—random forest, SVM, SOM neural network, and Bayesian network—identified upper and lower limb movements. Comparative analysis revealed the Bayesian algorithm’s superiority for upper limb movements and the random forest algorithm’s effectiveness for lower limb movements. Shooting efficiency, determined by action effectiveness, directly impacts stability and accuracy. Shooting trajectory, a critical indicator of efficiency, requires isolating the small-sized basketball from complex backgrounds. Background objects complicate trajectory extraction. Chakraborty & Meher (2013) proposed a method for detecting and tracking the trajectory of a basketball, which effectively reproduces the basketball’s path in videos under complex backgrounds. Using the three-frame difference technique, It isolates the object from the background and utilizes interpolation methods to determine its position when occluded, aiding in shooting technique analysis and improvement. Traditional trajectory methods often yield inaccurate results. Cao, Yu, & Liu (2021) introduced an automatic trajectory tracking method based on data fusion and sparse representation models. They extracted target features and established an appearance model using sparse representation. Combining data fusion with particle filtering algorithms enabled automatic basketball flight path tracking. A shooting robot captured images, successfully extracting the trajectory (Figure 9). Identifying players’ shooting form and trajectory through video and image recognition is a prominent research area. Simulating basketball flight trajectories often complicates shooting posture identification. Integrating video and image-based posture recognition allows more accurate identification of shooting issues and informed recommendations. Camera angle constraints must be carefully considered during video and image-based trajectory recognition.

Figure 9. Extracting the trajectory of a basketball in flight using a robot (Cao et al., 2021)

Team performance is crucial for victory in sports competitions, with effective tactical execution being a primary concern for coaches. Consequently, automatic player detection and tracking in team sports have become increasingly significant in academic discourse (Petilla, Yap, Zheng, Yuson, & Ilao, 2018). Image recognition technology, particularly body motion tracking, has emerged as an invaluable tool for tactical deployment. Yoon et al. (2019) proposed a real-time object detection system designed to classify and track players’ movements in videos automatically. The system’s core, YOLO (You Only Look Once), leverages the Darknet framework implementing CNN for object detection, allowing autonomous player identification on the field. To address suboptimal recognition under adverse conditions (e.g., players out of the video frame or overlapping), the authors enhanced YOLO and incorporated machine learning to mitigate these issues. Additionally, the system provides a framework of pass networks from different perspectives, helping teams uncover decisive performance factors. In video recordings, a player's movement trajectory is crucial for tactical analysis. Chen, Chang, & Hsiao (2017) introduced a technique to reconstruct player trajectories from basketball broadcast videos by detecting the court boundary using mosaic methods and determining player positions based on visual information such as shape and color. These trajectories are visualized on a field model using homography transformation, providing coaches with detailed player movement information. Computational analysis and verification on NBA video recordings demonstrated the method's reliability, achieving an accuracy rate of 88.31%. Santhosh & Kaarthick (2019) developed an algorithm to track individual player movements during a game and project their positional data onto a 2D plane. The detection procedure includes court detection, pedestrian detection, player classification, player tracking, and mapping via homography. This provides basketball coaches with extensive real-time defensive and offensive information, aiding in team tactics analysis. The method has undergone rigorous testing on datasets for football, basketball, ice hockey, and pedestrian movement, proving its lightweight and efficient nature.

Video image recognition holds promising applications in the technical and tactical analysis of players and teams and extends to field data recognition, specifically for identifying player scoring and other court statistics. An intelligent basketball analysis system based on a basketball scoring detection (BSD) method using cameras has been deployed in multiple basketball courts in Beijing, China. This method leverages CNN and frame difference to analyze video input from the court and determine object movement near the basket, thus ascertaining if a score has been made. The framework, depicted in Figure 10, shows that detecting the basketball hoop is a prerequisite for scoring recognition. Pixel analysis determined that an input image size of 544×544 pixels achieved optimal recognition performance. An analysis of 44 scoring instances from five basketball game videos revealed an average accuracy rate of 88.64% in detecting basketball scores (Fu, Yue, & Pan, 2021). Additionally, video image recognition can be utilized for real-time identification of referee signals. Žemgulys et al. (2020) proposed an image segmentation technique based on directional gradient histogram and local binary pattern (LBP) features combined with SVM/RF classifiers to recognize referee gestures in videos with an accuracy as high as 95.6%. However, this analysis currently applies solely to isolated referee gestures; more complex scenarios involving sequences of referee gestures still require further development.

Video image recognition is crucial for analyzing the technical and tactical aspects of basketball players and non-player contexts. The accuracy of this method depends on the precision of the computational approach utilized. Currently, the primary challenges in video and image recognition are the influence of complex backgrounds and the visual range of videos. Most proposed methods in research studies still fail to guarantee an accuracy rate of over 90%, which may be related to computational methods and the scope and quantity of datasets used for AI training. With the rapid advancement of AI, an increasing number of sophisticated and intelligent recognition technologies based on neural networks and machine learning are being developed. In future research, we aim to expand the application of video and image recognition in basketball, particularly in areas such as data statistics and real-time motion signal identification.

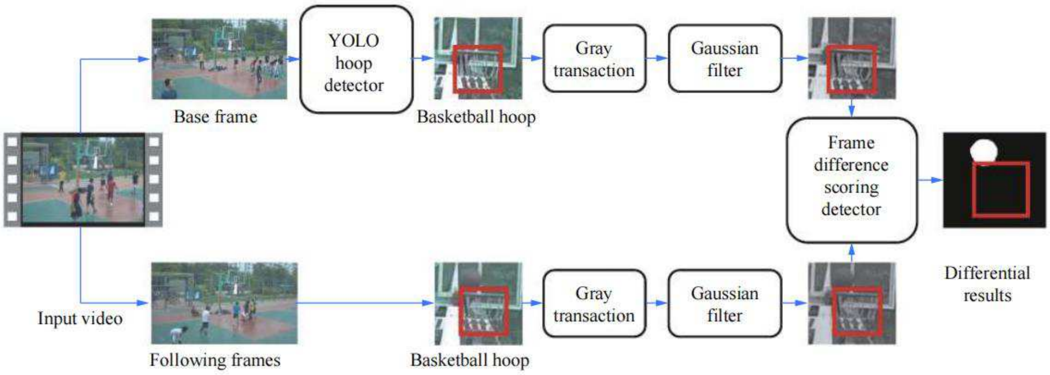

Figure 10. Framework of the BSD method (Fu et al., 2021)

1. Performance Analysis and Prediction

The analysis and prediction of basketball performance serve as critical foundations for teams in formulating strategies, primarily relying on extensive data sets for their analytical and predictive processes. The analysis of vast amounts of data constitutes a crucial characteristic of the information era. The processing and mining of data based on AI (including machine learning and deep learning) to fulfill the functions of analysis and prediction is emerging as the dominant trend (Sagiroglu & Sinanc, 2013). The sources of data are extensive and closely tied to data capture and recognition. Through extensive data collection and recognition, it is possible to construct a vast database for feature analysis. Currently, professional basketball leagues have extensive game databases that enable in-depth analyses of players and teams. This allows for the identification of performance trends among players and teams, leading to predictions about their future trajectories. Additionally, leveraging sports injury data can help predict and mitigate injury risks for players. This section will primarily focus on three aspects: analyzing player and team, predicting match results, and forecasting sports injuries.

Performance Analysis of Player and Team

Performance analysis and prediction significantly enhances the comprehensive evaluation of player and team performance by constructing robust data models from specific databases to discern multifaceted influences. These datasets, derived from empirical game statistics, ensure reliability. The acquisition of such data often leverages wearable devices and image recognition methods, particularly for capturing shooting actions and accuracy. Feature analysis on the collected data informs player training and development. Hao (2021) developed an advanced basketball assistant training system focused on refining shooting posture and optimizing shooting accuracy. This innovative system utilizes Kinect 3D sensors to capture extensive image information and employs the Vibe background modeling method to analyze image features. This enables precise human posture estimation and extraction of critical shooting parameters based on contour features and image processing. Rigorous experimentation with 100 trials revealed that boys' shooting accuracy improved significantly to 63.33%, while girls' accuracy increased to 62.15% under the system's guidance. Zhong (2022) introduced BSTARNet, a basketball action recognition mechanism based on artificial intelligence neural networks (ANN) and trained using basketball data for precise action recognition. The author gathered 1,086 videos from the internet, encompassing six distinct training actions, to train and test the data-driven model. The BSTARNet system achieved a satisfactory accuracy rate of 95.4% in movement recognition, assisting coaches in monitoring training quality and improving training programs. The application of performance analysis and prediction in basketball player training typically involves combining data capture and recognition technology to train identification models. From another perspective, video and image recognition intersects with data analysis, as many studies leverage data analysis methods for such recognition, highlighting their complementary relationship.

Assessing player performance in games is a primary application of performance analysis and prediction in basketball. Unlike training, game scenarios involve high-intensity defense, causing players to experience significant pressure when shooting. To analyze the impact of this high-pressure state on shooting performance, Zuccolotto, Manisera, & Sandri (2018) conducted data modeling on match data from the 2015-2016 "Serie A2" championship in Italy. They defined "high-pressure state" in four scenarios and used univariate and multivariate analyses with classification and regression trees. The analysis revealed that scoring probability was most affected when the offensive time was nearing its end. Additionally, a missed first free throw influenced the likelihood of scoring on subsequent attempts. The data model was validated with match data from the 2016 Rio Olympics, confirming that "high-pressure state" impacts shooting performance across different competition levels. These conclusions allow for a deeper analysis of players' in-game states through specific shooting performance evaluation indicators. Lee & Page (2021) analyzed player performance curves, peak periods, and optimal ages in Europe's premier basketball leagues using the Aryuna data platform, which includes over 37,000 games and data for more than 20,000 players. The study considered rating correction factors between different leagues and variables influencing the future development of basketball athletes. Analysis of extensive player data from Aryuna revealed that the peak period for players in top European leagues generally occurs within 7-11 years of their careers, with the optimal age range being 26-29 years. These findings have significant implications for strategic team development, emphasizing the importance of focusing on players at their peak. Teams can strategically cultivate and capitalize on the peak performance of players based on these predicted outcomes.

In recent years, scholars have focused on forecasting potential emerging stars in the NBA. Mahmood, Daud, & Abbasi (2021) assert that player rankings become effective once a player has accumulated sufficient game experience; however, during the early stages of a player's career, limited game data is insufficient to indicate their development prospects. Machine learning serves as a potent tool for predicting whether a player has potential. The researchers utilized game data from co-players (categorized into three types) as features for machine learning models and evaluated the relationship between co-players and basketball prospects using various machine learning models. The prediction results, based on NBA game data from 2004-2009, indicate that most of the top 20 basketball prospects became top 100 players in the league over the following six seasons, while the top 5 basketball prospects exhibited significantly higher game efficiency than the top 5 fastest-progressing NBA players. Such conclusions are crucial for informing team player selection strategies.

In addition to individual player factors, the composition of a team's lineup significantly influences match outcomes. Optimizing lineup composition is a primary concern for coaches, and performance analysis and prediction offers a thorough exploration of this aspect. Xu, Zhang, & Yi (2022) analyzed the top 16 teams in the 2019 FIFA Basketball World Cup, differentiating players based on their average height, weight, and BMI. Using Schwartz's Bayesian criterion, they classified lineups into four types according to these physical attributes. By examining game data from 67 matches involving 104 teams and analyzing 525 lineups, they found that lineups with low average height, low weight, and medium BMI had shorter playing times and lower offensive performance but better turnover control and faster game pace. Research on team lineup combinations provides valuable recommendations for coaches' tactical decisions and team rotation strategies, enhancing scoring efficiency and defensive capabilities at different stages of play. In lineup analysis, physical fitness is just one of many evaluation elements; thus, judiciously arranging existing players into effective lineups is crucial. Kolias et al. (2022)

analyzed 1131 possession phase samples from the Greek Basket League, evaluating the offensive and defensive performances of lineups using a scoring function. They also employed a Markov chain model (Figure 11) to assess the long-term performance probability of various lineups, distinguishing between those with excellent and poor performance. Their calculations indicated that the most effective offensive lineup was point guard-point guard-small forward-power forward-center, while the most effective defensive lineup was point guard - shooting guard - small forward - center - center. Teams have different objectives at various stages of games, necessitating rotation adjustments based on opponents' lineup changes. Nevertheless, the findings from these studies provide supplementary evidence for coaches' decision-making processes by offering rotation strategies based on extensive data analysis.

The advantage of performance analysis and prediction lies in its capacity to thoroughly extract valuable insights from a substantial volume of internationally sourced data, thereby aiding players and teams in optimizing their performance during training and competitions. In the realm of training, it can assist players in identifying areas for improvement and devising targeted training regimens; during competitions, it can support coaches in making informed decisions. The aforementioned research reveals that performance analysis and prediction has extensive applications for both players and teams, offering valuable reference points and guiding significance.

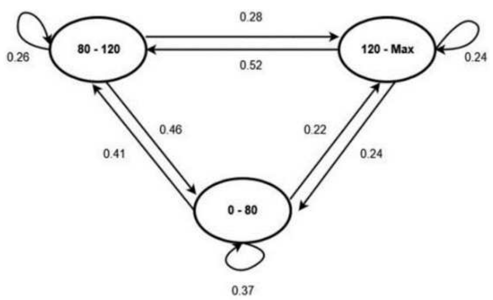

Figure 11. An application example of Markov chains in basketball performance evaluation (Kolias et al., 2022)

Prediction of Competition Results

Analyzing and mining big data consistently reveals patterns and trends from past data, enabling well-founded predictions about the specifics of basketball games. Game outcomes interest both players and spectators, who are equally invested in the results. The rise of sports betting further heightens the need for accurate game predictions. Thus, exploring performance analysis and prediction in basketball is crucial for fully utilizing its predictive capabilities.

With the advancement of AI technology, machine learning and deep learning are increasingly applied in basketball. Miljković et al. (2010) developed a prediction system using data mining technology to forecast basketball game outcomes. This system employs classification methods including decision trees, K-nearest neighbors, Naive Bayes, SVM, and multiple linear regression to predict NBA match results. Among these, Naive Bayes demonstrated superior efficacy, achieving an accuracy rate of 67% when evaluating 778 regular season games from the 2009-2010 NBA season. This system can also be adapted for predicting outcomes in other sports such as football and American football. Pai, ChangLiao, & Lin (2017) enhanced prediction accuracy by integrating the SVM technique with a decision tree approach (HSVMDT), avoiding the rule generation limitations of SVM. Using NBA data from 2008-2010, they achieved a prediction accuracy of 85.25%. This model not only forecasts match outcomes but also assists coaches in making strategic adjustments. Jain & Kaur (2017) addressed SVM limitations by employing a hybrid fuzzy SVM (HFSVM) model, which demonstrated a test precision of 88.26%, outperforming both the HSVMDT model (85.25%) and traditional SVM model (86.21%). The HFSVM model also showed faster computation speed and higher efficiency. Ozkan (2020) developed a prediction model based on artificial neural networks (ANN) and enhanced it with a concurrent neuro-fuzzy system (CNFS), combining ANN and fuzzy logic. Using data from 240 games in the Turkish League's 2015-2016 season, the CNFS model achieved an accuracy rate of 79.2%, compared to 70.8% for the ANN model, demonstrating higher accuracy than previous ANN studies (Loeffelholz, Bednar, & Bauer, 2009; Zdravevski & Kulakov, 2012). However, the CNFS method focuses on team data and does not consider individual player performance. Chen & Su (2022) proposed a basketball game prediction system based on fuzzy theory, utilizing variations in game parameters (such as scores and rebounds) over specific periods to predict outcomes. This system used fuzzy theory to assess the significance of these parameters, achieving a prediction accuracy of 61% with data from the NBA 2018-2019 season. This surpasses the 47% accuracy of crowd predictions on sports websites and the 53% accuracy of expert predictions. AI plays a pivotal role and offers significant advantages in the analysis and prediction of data, serving as the primary tool for data prediction functions and holding strong potential for future development.

Currently, there is a wealth of research focused on predicting game outcomes, and readers can readily access relevant literature in academic databases. Predicting the outcome of basketball games holds significant implications for guiding coaches' strategic planning and decision-making. The accuracy of predictions hinges primarily on the size of the dataset and the precision of computational methods. While advancements in AI are gradually enhancing prediction model accuracy, most models still fall short of achieving a high standard (e.g., 90%) in accurately forecasting game outcomes. Consequently, further progress in this area necessitates the development of new algorithms and expanded datasets.

Prevention of Injuries

Injuries are a critical determinant of a team's season performance and significantly impact the career trajectory of individual players. Although injury occurrences within a team are inherently uncertain, performance analysis and prediction reveals a discernible correlation between injuries and games. Leveraging AI can help identify nodes with higher probabilities of injury occurrence, facilitating the formulation of injury prevention recommendations. Wu (2020) analyzed data from 277 players who logged at least 20 minutes per game during the 2015-2016 NBA season, encompassing 824 injuries (27 occurring on-court). Using the random forest method, potential factors associated with injuries were identified. The findings revealed that increased player activity during games correlated positively with a higher risk of subsequent game-related injuries, as more shots taken increased this risk. However, high-intensity training did not necessarily elevate this risk. Due to inherent limitations in game data, further research requires additional datasets. Deep learning holds promise for mitigating these limitations. Cohan, Schuster, & Fernandez (2021) used NBA injury data from 2010-2020 to develop a deep learning model, METIC, to predict potential future injuries. The model's computational performance was evaluated using an imbalanced data metric, highlighting injury risk probabilities for different body parts based on provided data features. Sarlis et al. (2021) conducted a statistical analysis of injuries among 1298 NBA players during the same period, totaling 11,225 injuries. Applying machine learning algorithms, the study revealed that musculoskeletal system injuries were most prevalent, with lower limb, trunk, and upper limb injuries being both common and severe. They also identified a weak positive correlation between player performance and injury occurrence, suggesting that other factors influence player performance. Tedesco et al. (2022) provided an in-depth overview of AI applications in sports injury prediction.

Injury prediction enables timely identification of injury likelihood, reducing injury probability through methods such as rotation and maintenance. This approach ensures sustained high performance from players, brings long-term benefits to the team, and minimizes injury-related expenses. Currently, the accuracy of injury prediction and other data analytics applications in basketball is constrained by factors such as sample size and computational methodologies. Addressing these limitations is a primary focus for future advancements in applications of performance analysis and prediction within basketball.

Prediction of Basketball Flight Trajectory

The trajectory of basketball is a research focus that encompasses the use of VR, data capture and recognition, and performance analysis and prediction. Data capture and recognition, along with performance analysis and prediction, serve as reference points for reconstructing basketball trajectories, which are essential for maintaining fidelity and creating an immersive experience in VR training. In a basketball game, the airborne trajectory of the basketball constitutes a substantial portion of the overall game duration. Currently, the methods for predicting basketball trajectories primarily involve solving physical models through numerical integration or utilizing Computational Fluid Dynamics (CFD). Consequently, it is imperative to simulate the basketball’s trajectory to facilitate an understanding for players and coaches on how to execute shots that ensure adherence to a reasonable flight path. Taking shooting as an example, through modeling the basketball trajectory and configuring initial release conditions, it becomes feasible to simulate various release scenarios and their impact on shooting accuracy. Analysis of these shooting parameters enables determination of optimal conditions tailored to individual players, thereby facilitating targeted training during practical sessions. The accuracy of trajectory simulation lies in comprehensive consideration of all influencing factors and ensuring that calculation methods meet precision requirements. The issue regarding whether air drag should be factored into basketball flight remains subject to ongoing debate within current research perspectives in this domain.

Basketball Trajectory Kinematics Modeling

Directly extracting the trajectory of a basketball through video and image recognition effectively determines the ball’s flight path. However, parameterizing this trajectory provides better player training assistance. Therefore, a physical model based on basketball kinematic equations plays a crucial role in guiding training efforts. Simulating basketball trajectories involves modeling the paths of shots, passes, and other movements using kinematic equations. Numerically solving Newton’s second law and angular momentum equations based on initial conditions can simulate any airborne object’s flight. This method has been widely applied in various sports, including football (Carré et al., 2002; Ward et al., 2019; Che & Keir, 2021), ski jumping (Seo et al., 2004; Jung et al., 2014), and flying disc and discus (Lissaman & Hubbard, 2010; Seo et al., 2014). Although modeling formulas may vary slightly among researchers, the fundamental principles remain consistent.

In basketball trajectory modeling, the shot trajectory (Figure 12) is a focal point of considerable academic interest. Huston & Grau (2003) conducted kinematic modeling of various shots, including free throws, direct shots, bank shots, and layups, analyzing factors such as friction, ball rotation, inertia, and impact restitution. His analysis determined optimal conditions for direct and bank shots, suggesting that close-range shots or layups have distinct advantages. Hamilton & Reinschmidt (1997), one of the early scholars in this field, hypothesized that the center of mass trajectory of a basketball approximates a parabolic arc during free flight, controlled by a fourth-degree polynomial parameter "u." He investigated how release speed, angle, and ball rotation affect shooting, considering the interaction between the ball and the hoop, and determined the optimal trajectory for successful shots. He acknowledged that while air drag can be ignored in most scenarios, it cannot be disregarded in high-speed motions. Silverberg, Tran, & Adcock (2003) proposed a shooting trajectory control equation using Newton's second law and the angular momentum formula, factoring in the ball's interaction with the backboard and hoop. They used the fourth-order Runge-Kutta method to numerically integrate the motion equations, analyzing kinematic parameters and shooting positions affecting shooting performance. They presented a model of the flight trajectory of a basketball shot from release to either scoring or missing and utilized the shooter's proficiency level to forecast the shooting accuracy at specific locations on the court. However, this method does not account for aerodynamic effects, deemed minimal and not exploited by shooters. Neglecting lift and drag forces during a basketball's flight can lead to deviations in predicted outcomes, despite the short flight time. Building on Silverberg et al.'s shooting trajectory prediction program, Tran & Silverberg (2008) conducted simulations with different combinations of five variables: release height, release speed, launch angle, side angle, and angular velocity. The results suggest that a backspin frequency of 3 Hz is optimal for shooting accuracy, and a launch angle of 52° is the ideal release angle. Few researchers have considered wind speed's impact on basketball trajectory. Zhiwen et al. (2017) incorporated wind speed and direction into their trajectory analysis using mechanical theory under various shooting conditions. Their study found that as wind speed increased from 2 to 3 stages, shooting accuracy dropped from 90.3% to 78.6%, highlighting wind's significant impact on outdoor games. Different wind directions also affected shooting performance variably. They validated their model with NBA and CAB game data, and self-produced shooting videos, and analyzed shooting angles and speeds. While indoor games are less affected by wind, outdoor games can be significantly impacted. Zhiwen et al. included air drag in their analysis but did not consider lift effects.

Figure 12. Shot trajectories (ZhiWen et al. , 2017).

Few scholars have fully considered aerodynamic forces such as drag and lift in basketball trajectory calculations, often deeming their impact on shooting and the flight of the basketball minimal (Hamilton & Reinschmidt, 1997; Huston & Grau, 2003; Silverberg et al., 2003). Inaba, Hakamada, & Murata (2017), however, incorporated drag and lift forces using kinematic equations derived from Yasuda, Tsuboi, Tanaka, & Miyazaki (2014) to analyze various shot types and parameters. He found that players should increase their release height and angle for close-range shots but avoid excessively elevating the release angle for long-range shots. Additionally, increasing the ball's rotation rate may improve shooting stability.

Most kinematic simulations focus on shooting, but trajectory simulation also encompasses passing and rebounding. Passing is similar to shooting in trajectory analysis while studying rebound trajectories presents a more complex challenge. Okubo's (2012; 2015) analysis of basketball trajectories considered potential landing areas for missed close-range, mid-range, and long-range shots using dynamic models and Gaussian probability density functions for random initial conditions. The probability distribution of rebound landing locations indicated that the distance from the basket for long-range rebounds is roughly proportional to the shooting distance, while close-range rebounds land near the basket. Rebounds from bank shots typically land farther away than those from direct shots. These findings enhance players' ability to anticipate rebounds during training and improve their success rate in securing rebounds. Despite its importance, research on rebounding remains relatively limited.

Current shooting trajectory models primarily consider the basketball's flight path under fixed parameters, meaning that when these parameters remain constant, the flight trajectory is also fixed. These deterministic models do not account for environmental and psychological factors affecting players. In actual training or competition, players experience various influences that cause fluctuations in shooting parameters. In such cases, a stochastic model may be more suitable for representing a player's shooting. The Monte Carlo simulation method is ideal for this purpose, and Huang et al. (2016) successfully applied it to model the flight trajectory of wind-borne debris with favorable outcomes. Conducting numerous simulated shots can yield a dataset of basketball trajectory distributions, allowing for the proposal of optimal ranges for various shooting parameters, thus enhancing shooting skills. This process aligns with the principles of performance analysis and prediction. A current hot research area involves using big data mining to establish a database of shooting parameters and creating a big data model for shot prediction. By collecting extensive shooting data through sensors (Hao, 2021) and video recognition (Zhong, 2022) and integrating it with the shooting model, a comprehensive big data shooting model can be developed to more accurately reflect players' shooting characteristics.

In general, the integration of basketball trajectory models with AI still requires further advancement and is considered a primary direction for future research in the academic domain. Currently, prediction of basketball trajectory is based on the principles of mechanics. Analyzing the impact of shooting parameters on trajectory can help players find suitable release parameters to improve their shooting accuracy. The precision of trajectory modeling depends on the accuracy of kinematic equations and related parameters.

Drag and Lift

In aerodynamic analysis, drag and lift significantly impact the flight trajectory of a flying object. Studies using video analysis methods have estimated the air drag, friction, and damping coefficients of a basketball, with the air drag coefficient CD approximated at 0.54 (Okubo & Hubbard, 2010). However, obtaining precise aerodynamic coefficients through video analysis requires a more extensive dataset. Nikhilesh & Kulkarni (2015) incorporated empirical formulas for lift and drag into the motion equation of a basketball's flight trajectory, using lift formulas derived from Baek and Kim's (2013) findings. This formula accounts for the basketball's angular velocity, considering the Magnus effect. Results suggest that the optimal release angle for a basketball is 45°. Accounting for lift changes the basketball's vertical trajectory by approximately 5-15 cm, indicating a significant impact. Inaba, Hakamada, & Murata (2019) analyzed and reconstructed free throw trajectories of ten college basketball players, finding that considering both drag and lift aligns the flight trajectory more closely with actual paths. Ball rotation's effect on air drag and lift is crucial for accurate relationships between throwing parameters and final trajectories when calculating optimal shooting parameters.

The most direct method for obtaining aerodynamic lift and drag of a basketball is through wind tunnel testing. Due to the high cost of wind tunnel testing, CFD numerical simulation is a viable alternative. Pan (2014) used FLUENT's fluid-solid coupling mechanism to examine basketball flight trajectories, calculating velocity fields and deformation curves through numerical simulation. As the basketball's speed increases, its deformation in flight also increases. CFD simulates trajectories by determining drag and lift without physical experimentation, automatically obtaining these values at each calculation step. The aforementioned CFD calculations were based on structured grid computation, not accounting for the influence of angular velocity on lift and drag. Future research could explore computational methods from other fields, such as dynamic grid applications, which can effectively replicate the effects of a spinning basketball during its flight (Kakimpa et al., 2012).

In addition to physical experiments and CFD, AI algorithms offer a more efficient and convenient approach for calculating aerodynamic forces in basketball. The release speed of a basketball varies with different shooting positions (Miller & Bartlett, 1996), and due to air drag, the flight speed and spin rate change over time. Consequently, the aerodynamic forces acting on the basketball are variable throughout a single shot. Richards' (2010) studies on plate flight trajectories involved wind tunnel tests to measure aerodynamic forces in various flight attitudes, updating the aerodynamic state at each computational step. However, wind tunnel testing demands substantial human and material resources. While the aerodynamic coefficients of a basketball are more stable than those of plates, they are still influenced by flight speed and rotation. Therefore, employing machine learning or deep learning to forecast aerodynamic forces at various stages of a basketball's flight is a promising approach that can refine sports motion models. The aerospace industry has made notable advancements in optimizing and forecasting aerodynamic forces for aircraft through machine learning and deep learning methodologies (Barnhart, Narayanan, & Gunasekaran, 2021; Li, Du, & Martins, 2022). Applying similar techniques to basketball can significantly enhance the accuracy and efficiency of aerodynamic predictions.

While some researchers argue that air drag in enclosed spaces has a negligible impact on a basketball's trajectory, aerodynamic effects during the free flight phase can be significant, particularly in outdoor games. Fundamental aerodynamic literature suggests that for most two-point shots, dribbling, and short-distance passes with relatively low speeds, lift and drag effects are minor. However, for longer distance shots, the initial drag force on the basketball can reach 50% of its weight, while the lift force could approach 10%, making these forces substantial (Fontanella, 2006). Advancements in basketball gameplay and changing player strategies have led to expanded shooting ranges, as evidenced by NBA players like Stephen Curry and Damian Lillard, who frequently take long-range shots. Accurately simulating the shooting model for longer distances necessitates considering air drag and lift on the basketball's free-flight trajectory. Increased shooting distances require higher release velocities, which in turn increase the angular velocity of backspin. The resulting Magnus effect, particularly when the basketball's rotation plane is not perpendicular to the ground, significantly influences the trajectory, a phenomenon also observed in long-distance soccer shots (Okazaki & Rodacki, 2012). Considering all factors, the force situation during the basketball's flight includes drag, lift, gravity, and the Magnus effect, as illustrated in Figure 13. The force dynamics become more intricate when the basketball interacts with the backboard or hoop.

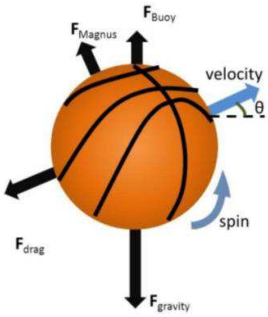

Figure 13. Force situation during the flight of the basketball

Prediction of Basketball Trajectory

Given a set of initial conditions, a basketball's flight trajectory can be determined using the appropriate calculation method. Key initial factors influencing the flight trajectory include release speed, angle, and height, which directly impact the entry angle and shooting accuracy of the ball. Figure 14 illustrates the correlation between a basketball's entry angle into the hoop and its shooting accuracy (Miller & Bartlett, 1993; Miller & Bartlett, 1996). Adjustments to release speed, angle, height, and backspin during shooting can be made through training, while release height is closely related to a player's physical attributes and height. This review will focus solely on the ball's flight trajectory after release, excluding considerations of a player's shooting technique and physical attributes.

Individual differences among players, such as height, arm span, and vertical jump, result in variations in shooting techniques, leading to differences in release height, speed, and angle. Basketball shooting models can identify parameters that align with each player's unique characteristics and analyze their shooting attributes. This analysis can help enhance shooting precision and increase a player's success rate. Currently, this approach is not widely integrated into basketball training programs, but it holds potential for broader applications in realistic basketball computer games. Notably, substantial research has been conducted on designing basketball shooting robots with promising outcomes (Cheng, Chen, & Lin, 2005; Rochim, Eridani, & Rustam, 2023).

The current physical model for basketball flight trajectories remains in the developmental stage and lacks robust integration with AI. AI algorithms can effectively optimize shooting models by transforming existing deterministic models into stochastic ones, thus achieving exceptional training outcomes. Enhanced precision in basketball trajectory modeling will directly improve the effectiveness of VR training, thereby enhancing players' abilities from multiple perspectives. Additionally, integrating data recognition with performance analysis and prediction can create a synergistic effect, representing a significant research direction for future studies.

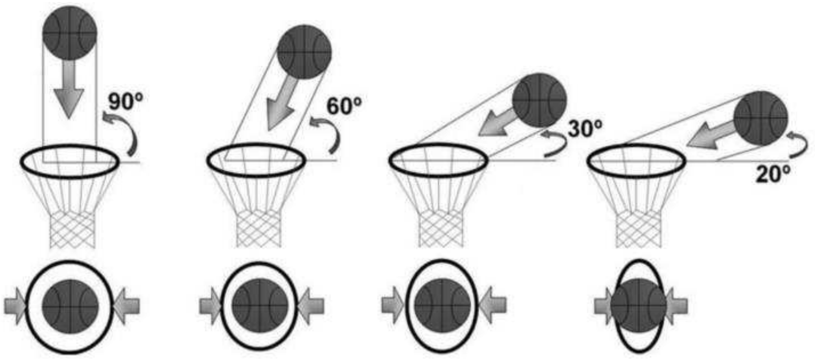

Figure 14. Correlation between the entry angle of a basketball into the hoop and its shooting accuracy (Miller, 1993).

Summary and Conclusion

Advancements in computer and AI technology have revolutionized basketball research, transforming traditional training paradigms and analysis methodologies. These innovations offer promising prospects for the field. Studies involving virtual reality technology, data capture and recognition, performance analysis and prediction, and basketball flight trajectory prediction reveal the substantial potential of computer and AI technology in basketball. Applications include assisted training and teaching, comprehensive player and team analysis, tactical guidance, match prediction, and injury prevention. The broad applicability of computer and AI technology in basketball is well-supported by their effectiveness and significance, particularly in educational contexts. Despite this potential, the integration of computer and AI technology in basketball remains in its early stages. The coverage of AI presented in this article remains incomplete, and numerous other technologies encompassed within the domain of AI are yet to be developed and implemented in the domain of basketball. Smart training techniques show significant improvements for beginners, but their efficacy for professional players requires further investigation. Enhancing the precision of computational predictions across various basketball aspects is also necessary. The core challenge lies in translating theoretical concepts into practical outcomes to effectively enhance player performance.

As computer and AI technologies evolve alongside algorithmic advancements, higher computing efficiency and improved accuracy can be anticipated. Categorizing existing research through thorough analysis provides valuable insights, aiding new researchers in rapidly understanding current trends and identifying suitable research directions. Concurrently, stakeholders in the sports industry are encouraged to recognize the benefits of computer and AI technologies alongside traditional training methods. Active engagement in relevant studies will drive progress in this domain.

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