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TOPICAL REVIEW

A Review of Basketball Shooting Analysis Based on Artificial Intelligence

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ABSTRACT Artificial Intelligence (AI) has promising applications in basketball shooting analysis, as it can help basketball athletes improve their shooting techniques and accuracy, thereby enhancing the effectiveness of both games and training sessions. This article provides a systematic review of the latest developments in AI-based basketball shooting analysis, covering four main research topics: Basketball Shooting Posture / Training Type Recognition, Analysis of Basketball Shooting Posture/Trajectory, Prediction / Analysis of Basketball Free Throw, and Intelligent Method of Correcting the Basketball Shooting Motion / Direction. From the perspective of AI methodology, this article elaborates on the application process of AI in basketball shooting research, including Data Collection and Preparation, Feature Engineering, Algorithm/Model Selection and Training, Dataset, and Evaluation Metric. Additionally, the advantages and limitations of AI technology in basketball shooting analysis are analyzed. Finally, this article presents future trends and research directions for AI in basketball shooting analysis, such as combining computer vision and biomechanics for analyzing the rationality of shooting actions, developing real-time AI systems adaptable to training and game scenarios, and constructing personalized shooting analysis and training systems. The aim of this article is to provide a comprehensive overview and discuss the current status of research and applications of AI in the field of basketball shooting. It holds significant theoretical significance and practical value for promoting the cross-development of AI and basketball sports, improving the level and popularity of basketball, and advancing the understanding and utilization of AI technology in sports.

INDEX TERMS Basketball shooting, sports, artificial intelligence, computer vision, machine learning, artificial neural networks, research topic.

I. INTRODUCTION

Shooting is the only way to score in basketball game. Broadly defined, basketball shooting encompasses all actions involved in propelling the basketball towards the hoop and is considered one of the most complex technical movements in basketball. Consequently, the analysis of shooting techniques has become a focal point in basketball research.

In recent years, AI technology has become widely used in basketball shooting, it can analyze both technical and tactical aspects of basketball. Technical analysis looks at individual player skills, movement patterns, and physical attributes, while tactical analysis focuses on strategies and methods used during games. AI is particularly valuable for studying shooting in basketball and helps overcome various challenges in this area.

This review aims to explore the current state of AI application in basketball shooting, along with research achievements, and propose potential future directions. To achieve this, the paper applies an AI methodology to discuss the application of AI in basketball shooting, encompassing key steps such as data collection and preparation, feature engineering, algorithm/model selection and training, datasets, and evaluation metrics.

As shown in figure 1, this study follows the following structure: Section II introduces the methods used to search relevant literature and presents the search results. Section III summarizes the current state of AI application in the sports domain, the development of basketball games, and research themes in AI-based basketball shooting analysis, along with their advantages and limitations. Section IV explores the

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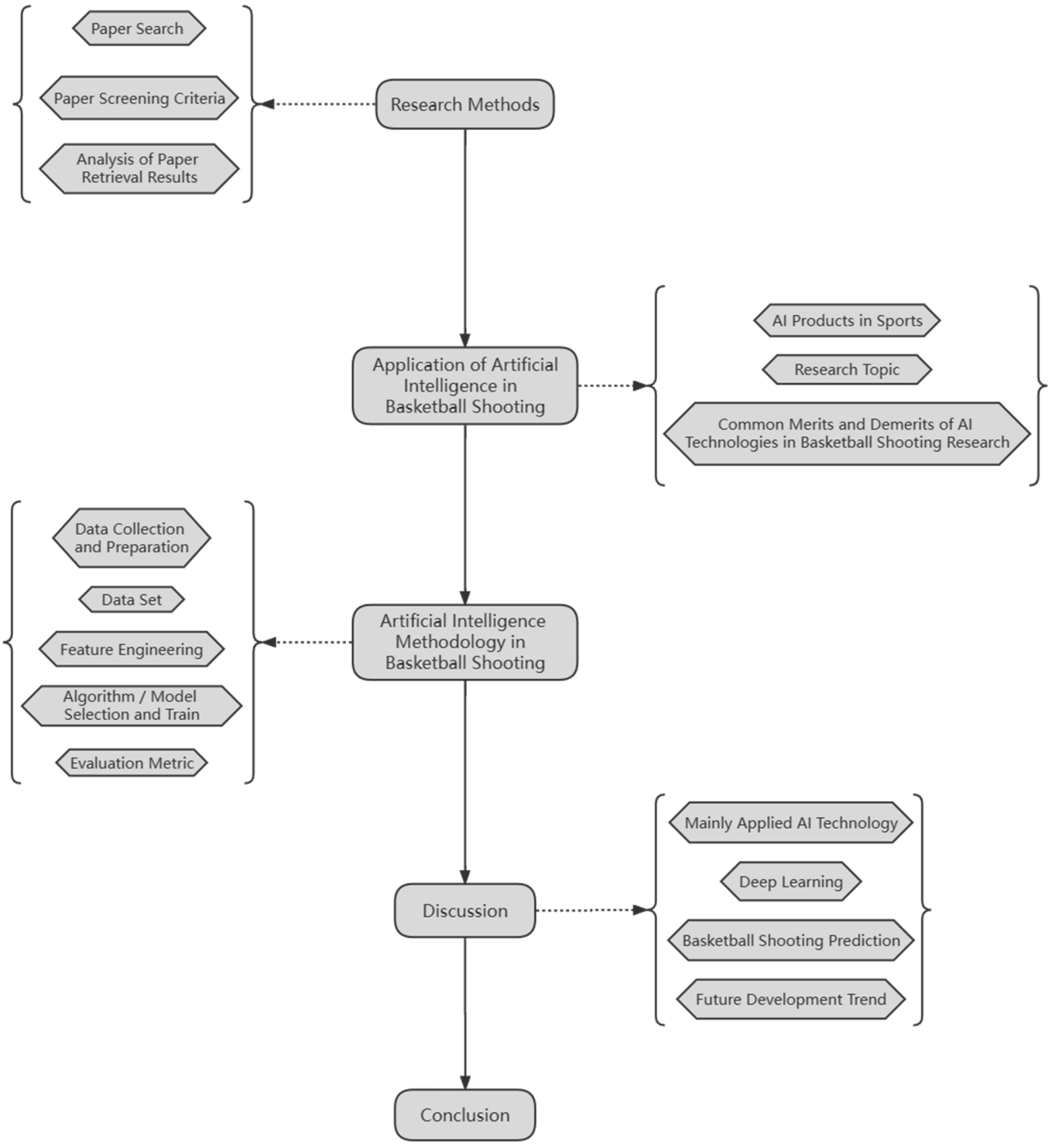

FIGURE 1. The structure of paper.

application of AI in basketball shooting from the perspective of AI methodology. Section V investigates the reasons for using AI in basketball shooting, elucidates the fundamental steps in employing AI technology to predict shooting accuracy, discusses the challenges faced in its application, explores the advantages and limitations of various deep learning models in basketball shooting analysis, and delves into future development trends. Finally, Section VI provides a comprehensive summary of the entire paper, emphasizing its main contributions and innovations.

II. RESEARCH METHODS

A. PAPER SEARCH

Using the core collection journals in the Web of Science database as the data source to retrieve foreign papers, to comprehensively study the application of artificial intelligence in the field of basketball shooting, ''Basketball Shooting'' is used as the keyword. For the interpretation of artificial intelligence, in addition to ''Artificial Intelligence'', through the analysis of the top ten hot research topics in the list of the world's most influential scholars in artificial intelligence

- AI2000 released on April 8, 2021, selects deep learning, machine Learning, computer vision, data mining, and feature extraction serve as common subject terms. Therefore, set the advanced search expression as TS = (Basketball Shooting) AND (Artificial Intelligence OR Machine Learning OR Deep Learning OR Computer Vision OR Data Mining OR Feature Extraction), the period is 2013-2023, and the search time is January 5, 2023. Using ''article'' as the type of document condensed, and select the language as ''English''.

B. PAPER SCREENING CRITERIA

A total of 89 English papers were retrieved. The author checked the title, abstract and full text of the paper to ensure that at least one of the full text contained the above keywords. 48 papers were eliminated through repetitive screening, and 26 papers were eliminated through title and abstract review. The author refers to the following screening criteria to further screen and exclude foreign language papers obtained by keywords and repeated reviews: (1) Unpublished papers, conference abstracts, dissertations, monographs, etc. (2) Review papers. (3) The selected perspective is not in the field of basketball shooting. (4) Papers that are not related to the discipline. (5) Papers that have not been peer-reviewed. A total of 15 relevant papers were finally selected.

C. ANALYSIS OF PAPER RETRIEVAL RESULTS

Based on 15 selected English research papers, this study categorized the research topics into four categories from the perspective of applying artificial intelligence technology to basketball shooting analysis. The first category is the intelligent correction method of basketball shooting motion/direction, the second category is the prediction/analysis of basketball free throws, the third category is the analysis of basketball shooting posture/trajectory, and the fourth category is the recognition of basketball shooting posture/training type. The author independently read and summarized the full text of the 15 English research papers, extracting key research information. The study found that current research on basketball shooting analysis based on artificial intelligence technology mainly focuses on the application of artificial intelligence to identify and analyze shooting postures, helping coaches and athletes find factors that affect shooting accuracy, and ultimately improving shooting accuracy.

III. APPLICATION OF AI IN BASKETBALL SHOOTING

This section is divided into three parts. The first part provides an overview of the current application of artificial intelligence in the field of sports, as well as a summary of the development of basketball. The second part explores the application of artificial intelligence in the domain of basketball shooting, and the main research topics in the field of artificial intelligence in basketball shooting are analyzed. The third part summarizes the merits and demerits of different artificial intelligence techniques in basketball shooting. It also explores their application background, objectives, limitations, and core questions.

A. ARTIFICIAL INTELLIGENCE PRODUCTS IN SPORTS

As shown in **Table 1.** In recent years, with the rapid development of information technology, artificial intelligence is no longer regarded as a separate research field that develops independently but frequently intersects with various fields, including the field of sports. The intersecting development of sports and artificial intelligence can help solve many problems in various competitive sports, especially basketball. At present, the interdisciplinary research between artificial intelligence and basketball is in its infancy. Li et al. [1] conducted a comprehensive review of the application research of artificial intelligence in basketball through paper retrieval. The application of artificial intelligence in basketball includes Analysis of Basketball Team Performance, Analysis of Individual Performance of Basketball Team Players, Analysis and Prediction of Basketball Shooting, Prediction of Game Results, Basketball Coaching System, Basketball Training Machine, Smart Stadium, Prevention of Sports Injuries, Application of wearable Devices.

Li [2] believes that in modern basketball games, due to the change of rules and the development of players' basketball skills, the rhythm of basketball games is getting faster and faster, and the proportion of three-pointers in the game is getting larger and larger. Therefore, professional athletes will attach great importance to the training of their shooting ability, especially the training of three-point shooting ability. However, the amount of three-point shooting training for professional athletes is very large. Under such circumstances, the shooting coach cannot take into account the quality of each athlete's shooting training, so the improvement of the athlete's shooting ability will be slow. To quickly and efficiently improve the quality of athletes' shooting training, experts have begun to turn their attention to artificial intelligence. The application of artificial intelligence in the field of basketball is constantly developing, and companies with mature products mainly include Sports VU, Second Spectrum, Athos Sportswear, and Catapult Sports.

Among them, the artificial intelligence technology mainly used by Sports VU and Second Spectrum is computer vision. Sports VU reveals new insights about individual players, teams, and opponents, changing the way professional players play basketball and the way fans watch games. It can Track, quantify, and ultimately archive every tiny motion on the pitch. Coaches, their assistants, and data processing support staff now know more than ever about player attributes and how certain groups of players work together. However, due to the large amount of data generated by the NBA, Sports VU can't handle so much data. Second Spectrum uses spatiotemporal pattern recognition to identify and enhance data extracted from videos, generating new types of statistics for visualization. The main AI technology used by Athos Sportswear and Catapult Sports is machine learning. Among them, Athos sportswear can monitor heart rate, muscle activity, and breathing rate, it can summarize the data of the user's exercise test into one device, according to the data, give a reasonable improvement plan in time, provide users with

TABLE 1. Artificial intelligence products in sports.

Company	Way of working	Effect
Sport VU	Sports VU is realized through six 3D high-definition cameras hanging above the ceiling of each arena connected to computer data analysis, and then import the processed data into the NBA's huge database.	Sports VU makes coaches, their assistants, and data processing back office staff now know more than ever about player tendencies and how certain groups of players work together, it has led to a rethinking of basketball and changed the way players are evaluated.
Athos Sportswear	The 20 EMG sensors and 6 heart rate sensors in the Athos sportswear will collect the user's data, and then these data will be aggregated into a device called Athos Core, finally transmitted to the Athos App on the mobile phone.	Based on the user's exercise test data, Athos will give reasonable improvement plans in time, provide professional suggestions to users, improve movements, and guide users to exercise correctly.
Catapult Sports	Catapult developed Inertial Motion Analysis (IMA) to measure the biomechanical effects of motions that cannot be detected by traditional GPS technology.	Catapult Sports has two main products: Vector and Matchchecker. ①Vector utilizes GPS and inertial sensor data to help athletes and teams fully prepare for competition, ensure the body meets the physical demands of the game, and support athletes in their recovery process. ②Matchchecker as a video solution provides teams with comprehensive and detailed on-field insights for tactical decision-making, player feedback, and player selection.
Second Spectrum	With the help of video tracking technology, 3D spatial data including basketball/player/referee positions, movements, and other dynamic statistics/visual functions are collected through cameras installed in NBA arenas.	Second Spectrum uses spatiotemporal pattern recognition to identify and enhance data extracted from video to generate insights and visualize new types of statistics.

professional suggestions, improve motions, and guide users to exercise correctly. Catapult Sports has two main products: Vector and Matchchecker. (1) Vector uses the data of GPS and inertial sensors to help athletes and teams fully prepare for the game, ensure that the body meets the physical requirements of the game, and supports the recovery process of athletes; (2) Matchchecker, as a video solution, provides the team with comprehensive and detailed on-court information insights for tactical decision-making, player feedback, and player selection. It does not only focus on a certain aspect of video analysis work but provides a comprehensive overall solution for analysts, coaches, and sports scientists.

Currently, artificial intelligence (AI) has found its application in various aspects of basketball. Specifically, it is employed in the following fields:

1. Basketball team performance analysis.

AI algorithms can collect and analyze game data to provide a comprehensive assessment of the team's performance. The insights gained through this process can aid coaches and players to devise effective game strategies and training plans.

2. Personal performance analysis of basketball players.

By tracking and analyzing a player's movement trajectory, shooting percentage, number of steals, rebounds, and other indicators, AI algorithms can conduct a thorough evaluation of a player's performance. This can assist coaches and players in identifying areas of improvement and developing strategies to enhance player performance.

3. Basketball shooting analysis and prediction.

AI algorithms can collect and analyze shooting data to predict the player's shooting percentage and offer more scientific shooting training programs, thereby improving shooting skills.

4. Game result prediction.

By analyzing and learning from a team's historical game data and player performance data, AI can predict the game result and help teams and fans better forecast the game outcome.

5. Basketball coaching system.

By integrating basketball players' performance data and game data, AI can help coaches formulate effective training

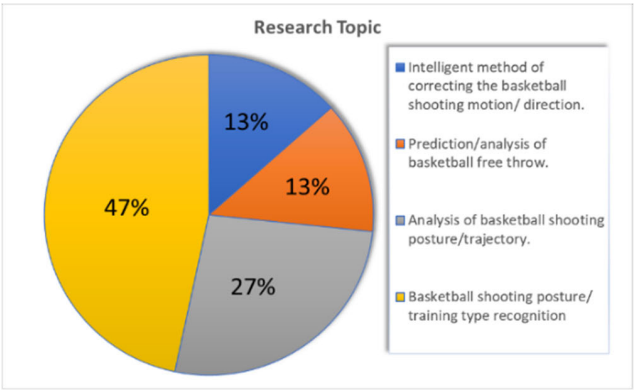

FIGURE 2. The proportion of papers contained in each research topic to the total number of papers.

plans and game strategies, leading to enhanced team competitiveness.

B. RESEARCH TOPIC

As shown in Figure 2, when applying artificial intelligence to study basketball shooting, it focuses on the following four research topics: Intelligent Method of Correcting the Basketball Shooting Motion/Direction, Prediction/Analysis of Basketball Free Throw, Analysis of Basketball Shooting Posture/Trajectory, Basketball Shooting Posture/Training Type Recognition.

According to the current state of the application of artificial intelligence in basketball shooting shows that all aspects of basketball shooting can benefit from the application of AI technology. Among them, the recognition of shooting posture/training type is the most popular topic in current research, accounting for 47% of the total research topics. This indicates that identifying and analyzing shooting movements is critical because shooting is the only way for players to score in basketball games, and it is a highly variable motion with no fixed routine. It is necessary to continuously use images or videos of various shooting motions to train the model for accurate recognition and analysis.

1) BASKETBALL SHOOTING POSTURE / TRAINING TYPE RECOGNITION

As shown in **Table 2**, "Basketball shooting posture/training type recognition" is the topic that has the most papers. Basketball shooting posture/training type recognition refers to the process of identifying and analyzing the shooting posture and training type of basketball players, typically using artificial intelligence techniques such as feature selection, data analysis, computer vision, and machine learning algorithms.

In this research topic, a variety of algorithms are applied to identify and analyze different types of basketball shooting motions or training contents.

1. Image Feature Extraction Algorithms. Refer to **Figure 3**.

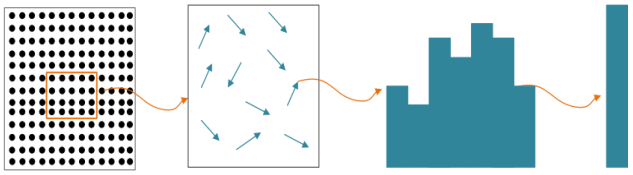

FIGURE 3. Schematic diagram of statistical feature extraction methods such as SIFT and HOG [3].

Histogram of Oriented Gradients (HOG): The HOG algorithm describes texture and shape features of an image by computing the gradient orientation histograms of local regions. In basketball shooting motion's recognition, the HOG algorithm can extract texture and shape features of basketball shooting postures from images, distinguishing different shooting actions [3].

Scale-Invariant Feature Transform (SIFT): The SIFT algorithm is a scale-invariant image feature extraction method that detects key points and describes them. In basketball shooting recognition, the SIFT algorithm can detect the basketball's position and key points of shooting postures in images, providing feature descriptions for subsequent classification and recognition [3].

2. Gaussian Hidden Variable Models and Improvements.

Variational Inference and Expectation-Maximization (EM) Algorithm: These methods are used to estimate parameters of Gaussian mixture models, including the category of shooting postures and posterior probabilities of latent variables. Through iterative optimization steps, accurate classification and recognition of basketball shooting postures can be achieved [3], [5].

Random Initialization and K-means Clustering: These methods are used to initialize Gaussian mixture models by setting initial parameters as random values and clustering based on data similarity to determine shooting posture categories. They can be employed in basketball shooting recognition for rapid model initialization and accurate classification and recognition [3], [4], [5].

Locality Preserving Projections (LPP): The LPP algorithm maps high-dimensional data to a lower-dimensional space by preserving the local neighborhood relationships of the data to better retain local structure. In basketball shooting recognition, the LPP algorithm can reduce data dimensionality and extract the most representative shooting posture features to achieve more accurate classification and recognition [3].

3. Principal Component Analysis (PCA) Methods.

Singular Value Decomposition (SVD) or Eigenvalue Decomposition: These methods are commonly used in PCA to transform data from the original feature space to a new feature space. In basketball shooting recognition, PCA can extract the most representative principal components of shooting postures, leading to more accurate classification and recognition. The eigenvectors represent the principal components, while the eigenvalues indicate the importance of the corresponding principal components [3], [9].

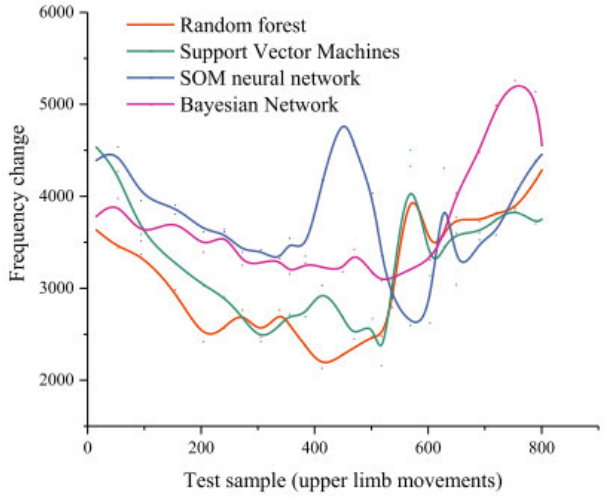

FIGURE 4. Comparison of basketball shooting motion recognition effect (upper limb movement) [3].

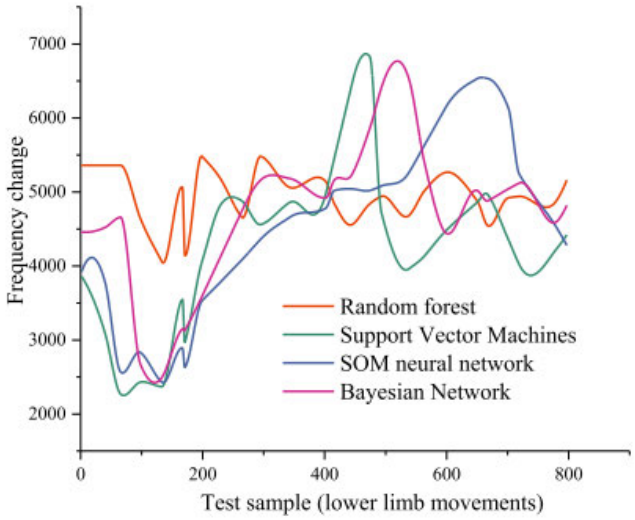

FIGURE 5. Comparison of basketball shooting motion recognition effect (lower limb movement) [3].

4. Classifiers. Refer to **Figure 4** and **Figure 5**.

Random Forest: Random forest is an ensemble learning method that combines multiple decision trees and uses voting for classification or regression tasks. In basketball shooting recognition, random forests can learn decision rules for basketball shooting postures, achieving accurate action classification and recognition [3].

Support Vector Machines (SVM): SVM is a binary classification model that finds the optimal hyperplane to separate data points of different classes. In basketball shooting recognition, SVM can learn decision boundaries of shooting postures, enabling accurate classification and recognition with strong generalization capabilities [3], [5], [8].

Self-Organizing Maps (SOM) Neural Network: SOM is an unsupervised learning method that maps input data onto a low-dimensional topological structure while preserving the topological relationships between the inputs. In basketball shooting recognition, SOM neural networks can cluster and classify shooting actions by learning the topological structure of basketball shooting postures [3].

Bayesian Networks: Bayesian networks are probabilistic graphical models used to represent dependencies among variables and can be employed for inference and probabilistic reasoning. In basketball shooting recognition, Bayesian networks can model the probability distribution of shooting postures and dependencies among variables, enabling accurate classification and recognition [3].

5. Machine Learning/Deep Learning

Convolutional Neural Networks (CNN): CNN is a deep learning model used for image processing tasks and recognition, extracting image features through operations like convolution and pooling for classification. In basketball shooting recognition, CNN can learn feature representations of basketball shooting postures, achieving accurate classification and recognition with strong image feature extraction capabilities [4], [6], [7], [9].

Recurrent Neural Networks (RNN): RNN is a deep learning model suitable for sequential data, processing time-series information in sequences through recurrent connections. In basketball shooting recognition, RNN can model the time-series data of basketball shooting, enabling recognition and analysis of action sequences, suitable for handling continuous frame images or time series data [4].

Hough Circle Transform: The Hough Circle Transform is a technique for detecting circular shapes in images, searching for combinations of circle centers and radii in a parameter space. In basketball shooting recognition, the Hough Circle Transform can be used to detect the circular shape of the basketball hoop, providing crucial information for shooting analysis and determining if a shot is successful [4].

Background Subtraction: Background subtraction is a method for detecting moving objects in a sequence of video frames by comparing the current frame with a background model. In basketball shooting recognition, background subtraction can be used to detect the basketball's motion trajectory and position changes, aiding in the analysis of shooting action paths and parameters such as speed [4].

Three-Frame Difference: Three-frame difference is a background subtraction method that compares the current frame with the two preceding frames to extract the foreground objects. In basketball shooting recognition, three-frame difference can be used to detect the basketball's motion status and trajectory, assisting in analyzing shooting actions and paths [4].

Double-core Extreme Learning Machine (ELM): Used to combine Dense Trajectory Features (DTF) and deep learning features (DLF) to improve the accuracy and efficiency of human motion recognition in videos [9].

Long Short-Term Memory (LSTM) Networks: Used to handle spatiotemporal information in videos, combining the outputs of CNN for action classification [9].

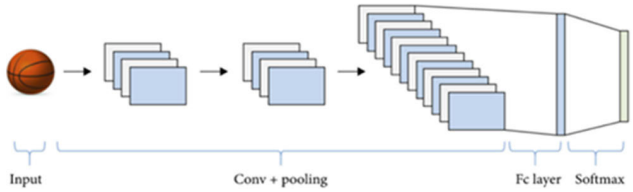

FIGURE 6. Pipeline of basketball shooting motion recognition framework [10].

2) ANALYSIS OF BASKETBALL SHOOTING POSTURE/TRAJECTORY

As shown in Table 2, "Analysis of basketball shooting posture/trajectory" refers to the study of the body posture and movement patterns of basketball players during shooting, as well as the trajectory of the basketball. The goal is to understand and improve basketball shooting performance, accuracy, and consistency. In this research topic, various algorithms are extensively applied to analyze basketball shooting postures and trajectories, aiming to further comprehend and enhance basketball shooting performance.

1. Feature extraction and dimensionality reduction algorithms. Refer to **Figure 6**.

Algorithms such as Singular Value Decomposition (SVD) enable the analysis of variations in shooting angles and extraction of key features. Additionally, Convolutional Neural.

Networks (CNNs) capture local features in images, facilitating the recognition of different shooting poses and trajectories. Trajectory Pooling Networks (TPNs) are utilized to fuse information from different feature sources, providing comprehensive and accurate analysis results of basketball shooting postures and trajectories [10].

2. Video processing and analysis algorithms.

The Double-core Extreme Learning Machine, combining deep learning and handcrafted features, accurately recognizes and classifies human motion in videos. Image Color Segmentation (ICS) divides video frames into RGB channels, extracting color and positional information for analyzing spatial locations and motion trajectories in shooting actions. Moreover, preprocessing and feature extraction techniques applied to video frames, such as median filtering, binarization, region opening, and bounding box detection, effectively eliminate noise, extract crucial features, and further optimize analysis outcomes [10], [11].

3. Time series analysis and prediction algorithms.

Recurrent Neural Networks (RNNs) handle the time-series information of video frames, offering valuable insights into the temporal evolution and dynamic changes of shooting actions. Kalman filtering, on the other hand, can be employed for trajectory prediction and correction, providing more accurate trajectory analysis and prediction results [10], [11].

4. Machine learning and optimization algorithms.

Support Vector Machines (SVMs) are utilized for classification and regression tasks, enabling the classification and

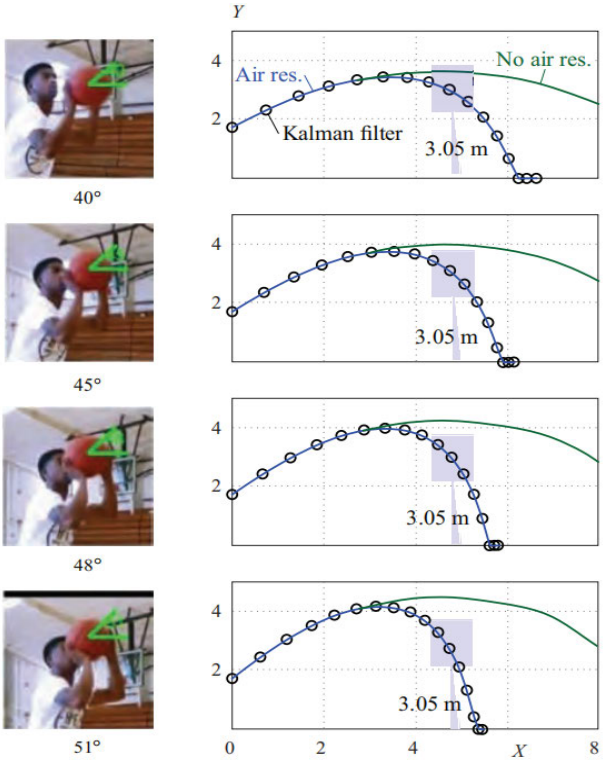

FIGURE 7. Best possible projectile trajectories [11].

recognition of different types of shooting postures to further optimize training and guidance strategies. Genetic algorithms can search for optimal solutions through the optimization process, assisting in the optimization of shooting postures and trajectories, and enhancing shooting accuracy and consistency [10], [12], [13].

3) PREDICTION / ANALYSIS OF BASKETBALL FREE THROW

As shown in **Table 2**, "Prediction / Analysis of Basketball Free Throw" refers to the use of various methods, such as computer vision, machine learning, and statistical analysis, to predict or analyze the accuracy of a basketball player's free throw. The analysis may involve factors such as the player's shooting posture, release angles, velocity, and trajectory of the ball, which can help coaches and players identify areas for improvement and enhance their performance. The main algorithms used in the topic are as follows.

1. Generating Skeleton Data using OpenPose.

OpenPose is a deep learning-based real-time multi-person 2D pose estimation method that captures the skeletal keypoint coordinates of the human body from basketball free-throw videos. These keypoint coordinates can be utilized for analyzing shooting postures and movements [14]. Refer to **Figure 8**.

2. Logistic Regression Model.

The study employs a logistic regression model as the predictive model for basketball free-throw prediction. Logistic regression is a commonly used classification algorithm that can be employed for predicting binary outcomes, such as whether a shot is successful or not. By considering the shot

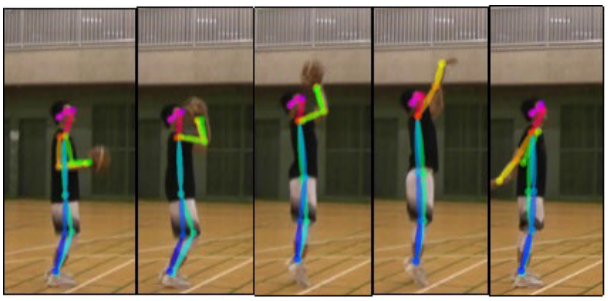

FIGURE 8. The use of openpose in basketball shooting [14].

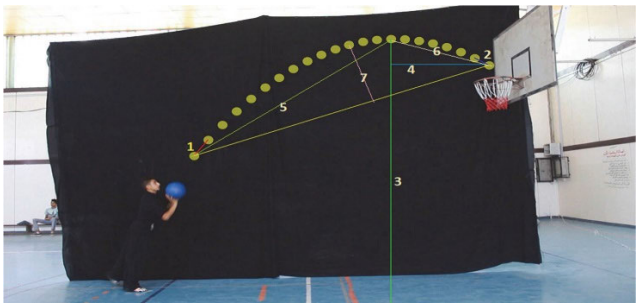

FIGURE 9. The extracted information after image processing [15].

outcome as the target variable (''0'' indicating a miss and ''1'' indicating a success) and the selected features as the explanatory variables, the logistic regression model learns the relationship between the features and the shot outcome, enabling prediction and diagnostics [14].

3. Image Processing Techniques.

The method involves utilizing image processing techniques, including binarization, filtering, and edge detection, to create a biomechanical training model for basketball free-throw. These techniques are employed to identify and track the trajectory of the basketball. By processing video frames, the motion trajectory information of the basketball can be extracted, facilitating subsequent data analysis and modeling [15]. Refer to **Figure 9**

4. Classification Learning Algorithms.

The study employs the WEKA data mining software and utilizes various classification learning algorithms such as REP Tree, Simple CART, and Random Tree to learn and analyze the extracted variables that influence free-throw success. These algorithms can discover relationships and assess the importance among variables, aiding in the understanding of factors influencing basketball free-throws [15].

5. Physical and Monte Carlo Simulation Models.

The study employs physical models and Monte Carlo simulation methods to predict and evaluate the optimal shooting angle and velocity for free-throws. By establishing a physical model and conducting extensive random simulation experiments, the optimal parameters for free-throw shooting can be determined, providing guidance for practical free-throw training and skill improvement [15].

4) INTELLIGENT METHOD OF CORRECTING THE BASKETBALL SHOOTING MOTION / DIRECTION

As shown in **Table 2**, ''Intelligent Method of Correcting the Basketball Shooting Motion / Direction'' refers to a technique or process that uses advanced technology or machine learning algorithms to analyze a basketball player's shooting motion and direction, identify any errors or inconsistencies, and provide feedback or guidance to correct those mistakes. This method typically involves using sensors, cameras, or other data collection devices to capture information about the player's shooting technique and then using machine learning models to process that information and generate insights on how to improve their shooting form or direction. The goal of this method is to help basketball players improve their accuracy and consistency when shooting the ball, ultimately leading to better performance on the court. There are several categories of algorithms utilized in this topic:

1. Image preprocessing and enhancement algorithms.

Image processing algorithms: These methods, such as median filtering and Sobel edge detection, are employed during the image acquisition process to preprocess the images. They eliminate noise, enhance the edges and features of the images, providing clearer and more accurate input data for subsequent basketball shooting analysis. This improves the quality of the images and enhances the efficiency of feature extraction [17].

Background modeling algorithms: By utilizing codebook techniques, these algorithms model the time-series changes of each pixel or pixel block, effectively distinguishing the background from foreground objects. This distinction aids in the identification and tracking of crucial elements in shooting actions, such as the basketball, players, and the hoop [17].

2. Feature extraction and matching algorithms.

Object detection algorithm (Yolov3): This algorithm is used to obtain the bounding box regions of players from basketball shooting videos [16].

Human pose estimation algorithm (Alpha Pose): Keypoint information is extracted from the detected players, enabling the analysis of shooting postures and angles [16].

Feature point detection and matching techniques: These techniques extract and match feature points from multi-view images, facilitating further analysis of detailed shooting motion features [16].

3. 3D modeling and reconstruction algorithms.

3D reconstruction technology: Based on the extracted keypoint information, these algorithms construct three-dimensional structural models of the shooting process, obtaining more accurate posture and spatial information [16].

Point cloud registration and meshing techniques: Point cloud data is transformed into three-dimensional models and texture mapping is applied, resulting in visually appealing representations of shooting postures [16].

4. Motion analysis and correction algorithms.

Edge contour detection and adaptive feature segmentation techniques: These techniques visually segment shooting

TABLE 2. The application of artificial intelligence in the field of basketball shooting.

Research Topic	Paper	Subject Information			Methods	
		Sample Size (person)	Gender	Athlete Level	Feature	Algorithm
Intelligent method of correcting the basketball shooting motion/direction.	Li B et al.[16] (2022)	40	M	NR	Joint point information.	Yolov3 target detection; Alphapose attitude estimation; Joint similarity calculation.
	Huang Y et al. [17] (2022)	NR	NR	NR	Trajectory information of the basketball shooting.	Tracking method based on improved Harris corner point extraction.
Prediction/analysis of basketball free throw.	Nakai M et al. [14] (2018)	23	M	①High-school basketball team ②Exchange student basketball circle	OpenPose skeletal recognition data.	Logistic regression model.
	Saraireh S et al. [15] (2018)	8	NR	NR	Parameters of a Basketball Shot: 1.RA 2.LA 3.HAB 4.HDHB 5.AFHB 6.ALHB 7.DFTC 8.IVB 9.HVB 10.FVB	REP Tree and Random Tree.
	Wang Y et al. [10] (2021)	NR	NR	NR	Optical flow data.	Double-core extreme learning machine and deep learning technology.
Analysis of basketball shooting posture/trajectory.	Egi Y. [11] (2022)	NR	NR	NR	Releasing angle; Player posture.	Image color segmentation (Median filtering; RGB color channelization; Area opening)
	Pan H et al. [12] (2021)	10	M/F	Non-basketball specialty	Three-dimensional skeleton information.	Kinect Azure; Euclidean dot product formula; Inverse trigonometric formula; Second-order double exponential smoothing.
	Chen H et al. [13] (2013)	20	M/F	NR	Basketball shooting's curve, height, and angle.	Back Propagation (BP) neural network and a genetic algorithm.
Basketball shooting posture/training type recognition.	Ji R. [3] (2020)	NR	NR	NR	Time domain and frequency domain.	Feature selection; Gaussian hidden variables.
	Pengyu W et al.[4](2021)	10	NR	NR	Feature joint points.	Fast skeleton extraction; Model segmentation.
	Zhao B et al.[5](2021)	20	NR	NR	Spatial features; time-series features.	Support Vector Machine (SVM) and Gaussian mixture.

TABLE 2. *(Continued.)* **The application of artificial intelligence in the field of basketball shooting.**

Basketball shooting posture/training type recognition.	Fan J et al.[6] (2021)	13	M	No professional basketball training.	Basketball shooting posture data of the players' main force hand and main force foot.	Visual geometry group network 16 deep learning model(VGG16).
	Liu R et al.[7](2021)	8	M	NR	Upper limb and lower limb movement data.	The convolutional neural network combines with prior knowledge.
	Acikmese Y et al.[8] (2017)	NR	NR	NR	Accelerometer, gyroscope, and orientation sensor signals are recorded in the X, Y, and Z axes.	Support Vector Machine (SVM) with Gaussian Kernel model.
	Fan J et al.[9](2022)	13	NR	NR	Basketball shooting posture's features (spatial feature and time-series feature).	Squeeze convolutional gated attention (SCGA) deep-learning model.

aNR = Not Reported; M = Male; F = Female; RA = Release angle; LA = Landing angle; AFHB = Angle between the first ball and the highest ball; ALHB = Angle between the last ball and the highest ball; HAB = Highest altitude of the ball; HDHB = Horizontal distance between the last ball and the highest ball; DFTC = Distance of the furthest ball from the chord of the track; IVB = Initial Velocity of the ball; HVB = Horizontal Velocity of the ball; FVB = Final Velocity of the ball.

images and identify non-standard shooting motions and abnormal postures [16].

Intelligent correction models: Based on the deviation angles and similarity measures of shooting motions, these models provide corrective recommendations and restore standard shooting form [16].

5. Visual localization and tracking algorithms.

Visual localization algorithm: By utilizing techniques such as corner detection, optical flow tracking, and Kalman filtering, this algorithm achieves the localization and tracking of basketball trajectories using stereo vision cameras [17]. Refer to **Figure 10**.

In conclusion, artificial intelligence (AI) has the following advantages in the field of basketball shooting.

(1) The non-contact, automated, and real-time data collection and analysis of AI significantly enhance the efficiency and accuracy of sports analysis.
(2) The diverse, personalized, and quantitative recognition and evaluation of shooting postures and trajectories offered by AI provide comprehensive and accurate motion feedback and guidance.
(3) The efficient, reliable, and explainable prediction and intelligent correction of shooting accuracy provided by AI offer scientific and effective solutions for sports training and optimization.

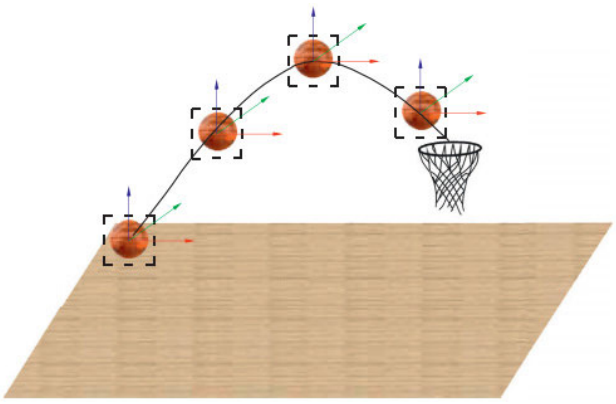

FIGURE 10. **Basketball movement and actual movement predicted by the system [17].**

However, AI also faces some limitations in this field

(1) High requirements for data quality and quantity, necessitating extensive data collection and annotation work.
(2) High technical demands for data processing and analysis, requiring the selection of appropriate algorithms and models, as well as multiple iterations and parameter adjustments.
(3) Challenges related to real-time performance and practicality, demanding the development of efficient and

TABLE 3. Datasets used in the papers.

Research Topic	Data Sets	Details
Intelligent method of correcting the basketball shooting motion/direction. Li B et al.[16] (2022) Huang Y et al. [17] (2022)	Unpublished	Three-dimensional posture data of basketball shooting techniques of elite basketball players. Basketball shooting movements' data in the shooting process.
Prediction/analysis of basketball free throw. Nakai M et al. [14] (2018) Saraireh S et al. [15] (2018)	MS COCO (a part of data)	Features: Object segmentation; Recognition in context; Superpixel stuff segmentation 330K images (>200K labeled); 1.5 million object instances; 80 object categories; 91 stuff categories; 5 captions per image; 250,000 people with key points.
	Unpublished	11 different variables that affect free-throw in the basketball game.
Analysis of basketball shooting posture/trajectory. Wang Y et al. [10] (2021) Egi Y. [11] (2022) Pan H et al. [12] (2021) Chen H et al. [13] (2013)	UCF101; NATOPS (a part of data)	UCF101: low resolution; the big amount of data; test the recognition performance of the algorithm for large-scale data sets. NATOPS: high resolution; including 24 movements; test the recognition effect of the algorithm on small amplitude movements.
		Perfect shooting motion video
	Unpublished	Basketball shooting movement's data in the shooting process.
		Basketball shooting movement's data in the shooting process.
Basketball shooting posture/training type recognition Ji R. [3] (2020) Pengyu W et al. [4] (2021) Zhao B et al. [5] (2021) Fan J et al. [6] (2021) Liu R et al. [7] (2021) Acikmese Y et al. [8] (2017) Fan J et al. [9] (2022)	Human Eva database (a part of data)	Including jogging, gesture, walking, and boxing.
	/	/
	Unpublished	Basketball shooting movement's data in the shooting process. 10 types of sensor fusion basketball shooting posture.
Basketball shooting posture/training type recognition Fan J et al. [6] (2021) Liu R et al. [7] (2021) Acikmese Y et al. [8] (2017) Fan J et al. [9] (2022)	Unpublished	Including walking, running, jumping, without the ball and standing dribble, walking dribble, running dribble, shooting, passing, and receiving. Including different types of basketball training features. 10 types of sensor-fusion basketball shooting-posture datasets.

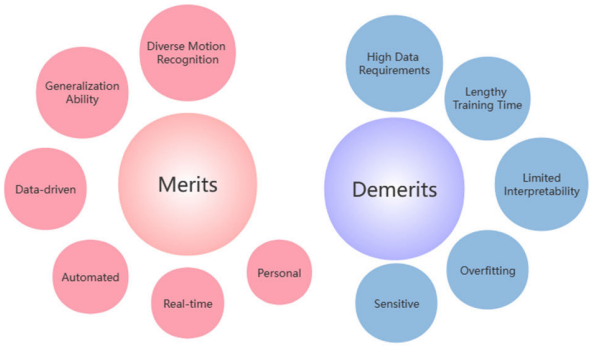

FIGURE 11. Merits and demerits of computer vision technology [3], [4], [5], [6], [7], [8], [10], [11].

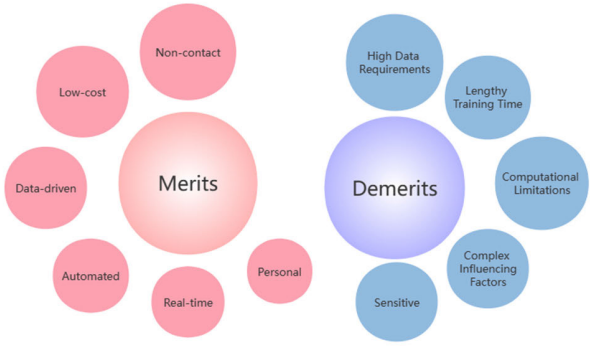

FIGURE 12. Merits and demerits of machine learning and artificial neural networks [9], [12], [13], [14], [15], [16], [17].

real-time AI systems to adapt to actual basketball game and training scenarios.

(4) Lack of biomechanical knowledge support in analyzing shooting rationality, limiting comprehensive analysis from a mechanical perspective.

C. COMMON MERITS AND DEMERITS OF AI TECHNOLOGIES IN BASKETBALL SHOOTING RESEARCH

As shown in **Figure 11 and Figure 12**, when it comes to the research on basketball shooting, the applications of two artificial intelligence (AI) technologies are not mutually exclusive but rather complementary, each with its focus. The following are their common merits and demerits.

1) MERITS.

1. Data-driven.

Both computer vision technology and machine learning/artificial neural networks rely on extensive datasets for training and analysis. Data plays a crucial role in enhancing the accuracy, performance, and quantitative research of basketball shooting models.

2. Real-time and automated analysis.

Both approaches possess the capability to capture, extract, and evaluate sports data in real-time, reducing the need for manual intervention and improving the efficiency and precision of sports analysis.

3. Personalized guidance.

Both technologies can adapt models based on individualized data, offering tailored sports analysis and training programs that cater to the unique characteristics and requirements of individuals, facilitating improved performance.

1) DEMERITS.

1. High data requirements.

Both computer vision and machine learning/artificial neural networks demand substantial amounts of data for training, necessitating time and resource-intensive efforts in acquiring and annotating large-scale datasets. Moreover, the quality and diversity of the dataset significantly impact model performance.

2. Lengthy training time.

Training complex models requires considerable time, involving multiple iterations and parameter adjustments to achieve higher accuracy and performance.

3. Sensitivity to noise and outlier data.

Both techniques are sensitive to data quality and accuracy. Noise, outliers, or erroneous labels in the dataset may adversely affect model training and performance, necessitating data cleansing and processing to enhance model robustness.

As shown in figure 10 and 11, computer vision and machine learning/artificial neural networks offer several common merits and demerits in the context of basketball shooting research. Leveraging these technologies can provide data-driven approaches, real-time and automated analysis, and personalized guidance, thereby facilitating accurate, efficient, and personalized training and guidance for basketball players. However, it is essential to address challenges such as data requirements, lengthy training time, and the need for high-quality data to maximize the potential of these technologies in advancing basketball shooting techniques.

In addition, the background, objectives, limitations, and core questions of applying artificial intelligence in the field of basketball shooting can be deduced from the contents of these two figures.

1. Background.

The technical aspects of basketball shooting involve various factors such as the player's posture, movement trajectory, and the trajectory of the ball. Traditional analysis methods have certain limitations, while the application of artificial intelligence (AI) technology can provide more comprehensive and accurate analysis and predictions

2. Objective.

The objective of applying AI technology in basketball shooting is to achieve intelligent correction and prediction of shooting motion and direction. By analyzing data such as the player's posture, ball trajectory, and velocity, personalized guidance, and training suggestions can be provided to improve shooting accuracy and consistency.

1) Limitation

(1) Data collection

Accurate analysis and prediction require a large amount of basketball shooting data, including videos, images, and sensor data. The quality and accuracy of the data are crucial for the reliability of the research results

(2) Data processing and analysis

Processing and analyzing basketball shooting data require complex techniques such as computer vision, machine learning, and statistical analysis. Selecting suitable algorithms, training and optimizing models require specialized technical knowledge and skills.

(3) Real-time and practicality.

In basketball games and training, evaluating and correcting shooting performance requires real-time and practical solutions. Developing efficient and real-time AI systems is a challenging task.

(4) Core question.

Based on the above background, objectives, and limitations, the core questions in applying AI technology in basketball shooting include:

How to accurately capture relevant data in basketball shooting, such as the player's posture, ball trajectory, and velocity, through combining computer vision with sensor technologies?

How to analyze and model basketball shooting data using machine learning and statistical analysis methods to achieve evaluation and prediction of shooting accuracy?

How to design an intelligent correction system that utilizes AI to provide real-time guidance and feedback to athletes, helping them improve shooting posture?

By researching these questions, the research on the application of AI technology in basketball shooting can make significant advancements. This can lead to the establishment of an intelligent analysis and correction system for basketball shooting, which holds immense significance for professional sports, physical education, and mass participation sports.

And the following content is discussed following the methodology of artificial intelligence.

IV. ARTIFICIAL INTELLIGENCE (AI) METHODOLOGY IN BASKETBALL SHOOTING

Based on the principles of artificial intelligence methodology, this discussion delves into the application of AI technology in the research of basketball shooting. **Figure 13** depicts the key components of artificial intelligence methodology, encompassing five essential stages: Data Collection and Preparation, Feature Engineering, Algorithm/Model Selection and Training, Dataset, and Evaluation Metric. Notably, machine learning and deep learning techniques permeate each stage of the methodology, contributing to their overarching significance in advancing the field of basketball shooting research. Each of these stages will now be examined in detail, elucidating their significance in the field of basketball shooting research.

A. DATA COLLECTION AND PREPARATION

From the selected articles, the following main methods of data collection and processing can be summarized:

1. Image feature extraction.

Using image processing techniques such as edge contours, adaptive feature segmentation, color channelization, median filtering, region opening, etc. to extract feature information from basketball shooting images [3], [5], [7], [11], [12], [16], [17].

2. Time series data calculation features.

By calculating time series data, including the position of bone points, moving speed, acceleration, etc., to obtain the motion features of basketball players [14], [15].

3. Machine learning.

Using the improved dense trajectory (IDT) descriptor to extract the features of the video, and also using the CNN to design deep learning features [4], [10], [13].

4. Sensor data analysis.

Extract statistical features from wearable devices equipped with motion sensors, including maximum value, minimum value, average value, median, standard deviation, variance, etc., and calculate the features within a specific time interval through window technology [6], [8], [9].

In summary, the main data collection and processing methods used include image feature extraction, time series data calculation features, machine learning, sensor data analysis, and feature selection and weighting calculations. These methods include computer vision, machine learning, and sensor technology to extract relevant feature information of basketball shooting motions.

B. DATA SET

Table 3 illustrates that the 15 studies included in this paper utilized diverse datasets for training and testing their models. Among them, 12 studies [4], [5], [6], [7], [8], [9], [11], [12], [13], [15], [16], [17] employed self-built and unpublished datasets. The remaining three studies [3], [10], [14] utilized publicly available datasets: Human Eva database, UCF101&NATOPS, and COCO2016, respectively. As no publicly accessible dataset specifically focused on basketball motions exists, these three studies [3], [10], [14] divided basketball shooting postures into distinct motions for analysis during model training and testing. Conversely, the other 12 studies [4], [5], [6], [7], [8], [9], [11], [12], [13], [15], [16], [17] collected basketball shooting motions to create their own datasets for model training and testing purposes.

The scarcity of specialized basketball motion datasets presents a significant challenge in contemporary basketball shooting research. Due to the wide array of basketball motions and the unique characteristics exhibited by each player, it becomes exceedingly challenging to establish a standardized dataset that encompasses various shooting motions. Consequently, machine learning models developed using these datasets often only capture a subset of basketball motion data, limiting their applicability. For example, if a dataset solely focuses on specific shooting motions, the model may struggle to comprehend other types of shooting motions. This complexity further hinders model training as the model must possess the ability to understand and differentiate between various basketball motions to effectively apply them in practical scenarios.

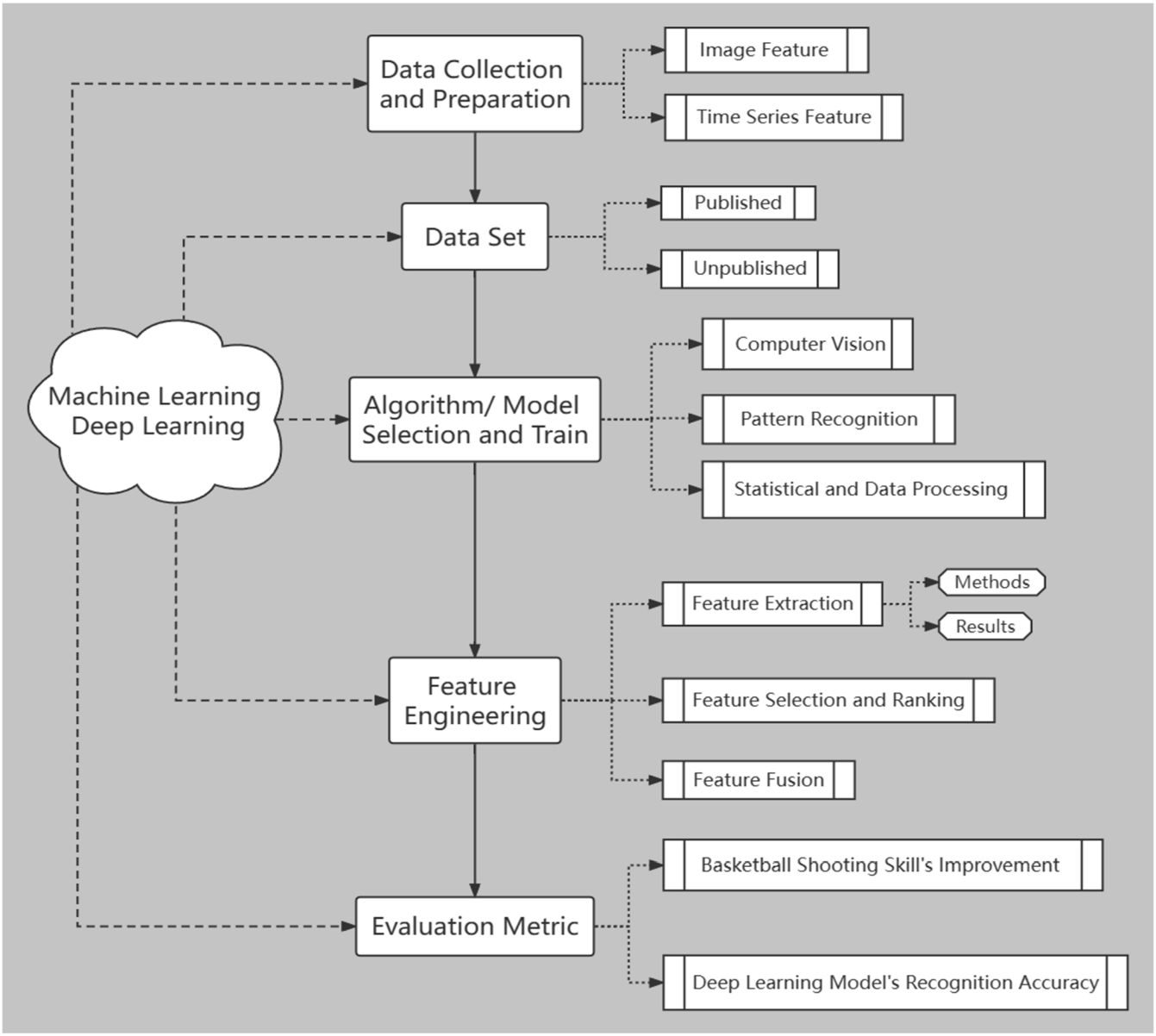

FIGURE 13. Flow chart of artificial intelligence methodology in the field of basketball shooting.

Furthermore, individual variances among basketball players make it difficult to encompass all motion characteristics within datasets that incorporate multiple types of basketball motions. Therefore, to enhance the generalization ability and robustness of machine learning models, it is imperative to employ more comprehensive datasets that cover diverse types and difficulty levels of shooting motions. Achieving this necessitates considering different types and difficulty levels of basketball motions during the data collection and annotation process, ensuring dataset comprehensiveness and representativeness. Only through these means can more accurate and comprehensive basketball shooting models be trained, offering enhanced training and guidance for basketball players.

Establishing a dedicated dataset for basketball shooting movements becomes an urgent requirement to foster research and development in this field. This dataset should aim to capture the shooting motions of exceptional basketball players while ensuring the quality of motions and data accuracy. The collected data will undergo preprocessing, including cleaning and normalization, to guarantee consistency and accuracy. Storing the data in a database can facilitate efficient data storage, querying, updating, and management. Additionally, stringent measures will be implemented to safeguard the privacy and security of the data, thereby preventing unauthorized access and misuse. The objective of this data resource is to provide reliable and secure data to professional basketball players and sports researchers, thereby promoting the

application of artificial intelligence technology in basketball shooting research.

C. FEATURE ENGINEERING

This section presents the most important methods and results of feature extraction in feature engineering, and discusses their characteristics.

1) FEATURE EXTRACTION METHODS

Feature extraction methods vary widely, and the following methods have been primarily selected in the research.

1. Multidimensional feature extraction.

These studies employ multidimensional feature extraction methods to obtain rich information from different data sources. For instance, spatial features are extracted from images, statistical features are extracted from sensor data and time-series and frequency domain features are extracted from videos. This multidimensional feature extraction allows for a more comprehensive description of basketball motions and postures, thereby enhancing the accuracy of classification and recognition [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17].

2. Time series feature extraction.

Many studies focus on extracting features from time series data, which can include the position of skeletal points, movement speed, acceleration, and more. By analyzing time series data, dynamic changes and motion patterns in basketball movements can be captured, enabling better differentiation of different basketball postures and motions [3], [14].

3. Deep learning feature extraction.

Some studies employ deep learning techniques for feature extraction. For example, convolutional neural networks (CNNs) are used to extract spatial features from images, and gated recurrent units (GRUs) are utilized to extract time-series features from time series data. Deep learning models possess powerful feature extraction capabilities, allowing them to automatically learn and represent high-level features in the data [9], [10].

4. Feature selection and ranking.

Certain studies employ feature selection and ranking methods to choose features that contribute significantly to classification. This can be achieved through statistical methods, feature importance evaluation, feature ranking techniques, and others. By selecting and utilizing the most relevant features, classification and recognition performance can be improved, while reducing computational complexity [8], [12].

5. Feature fusion.

Some studies utilize feature fusion by combining multiple data sources or employing various feature extraction methods. For example, fusion can be performed between image features and sensor data features or by combining the results of different feature extraction methods. Feature fusion enables the comprehensive integration of diverse information sources, thereby enhancing the accuracy and robustness of recognizing basketball motions and postures [9].

These common characteristics indicate that these studies emphasize the extraction of rich features from different perspectives and data sources to describe basketball movements and postures. The application of multidimensional feature extraction, time series feature extraction, deep learning feature extraction, feature selection, and fusion methods aims to improve the classification and recognition performance of basketball motions and postures.

2) FEATURE EXTRACTION RESULTS

During feature extraction, the choice between analyzing the shooting motion in different stages or analyzing the complete shooting motion depends on the specific task requirements and research objectives.

1. Complete shooting motion analysis.

If one is interested in the overall process and performance of the entire shooting motion, analyzing the complete shooting motion is recommended. In this case, global features related to the entire shooting motion can be extracted, such as velocity, acceleration, trajectory, and time-series continuity. This approach provides a comprehensive understanding of the entire motion and helps evaluate shooting techniques, motion fluency, and overall performance [4], [5], [6], [7], [8], [9], [11], [12], [13], [14], [15], [16], [17].

2. Stage-wise analysis.

For a comprehensive analysis of the shooting motion in basketball, it is recommended to divide it into different stages, allowing for a detailed examination of specific parts and motion patterns. By breaking down the shooting motion into stages like takeoff, arm lift, and release, individual features can be extracted and studied for each stage. This approach enhances the understanding of the shooting motion by identifying key points and time-series intervals unique to each stage, shedding light on the underlying motion mechanisms [3], [10].

Feature engineering in basketball shooting research lacks a standardized approach. The choice of feature extraction methods depends on specific research goals, data types, available tools, algorithms, and the researcher's expertise. Different aspects of basketball shooting research, such as posture recognition, motion analysis, and motion classification, require distinct feature extraction approaches. Posture recognition involves extracting spatial features, motion trajectories, and keypoint positions from images or videos. Motion analysis focuses on velocity, acceleration, and angle changes. Time-series or frequency domain features and statistical features are commonly used for motion classification. Feature extraction methods in basketball shooting research include image processing, motion analysis, signal processing, and machine learning. Researchers select methods based on feasibility, effectiveness, and practical needs, taking into account their domain knowledge. They may also refer to previous studies and classical techniques to ensure comparability and interpretability. Consequently, feature extraction remains an active research area in basketball shooting, with ongoing

exploration, optimization, and improvement of various methods.

D. ALGORITHM/MODEL SELECTION AND TRAIN

According to the existing literature, basketball shooting research incorporates a variety of models and algorithms. These can be categorized as follows.

1. Machine learning and deep learning [6], [7], [8], [9], [10], [13].

Machine learning models such as Logistic regression, REP Tree, Random Tree, BP neural networks, and genetic algorithms. Deep learning techniques including VGG16, dual-kernel extreme learning machines, and Squeeze convolutional gating attention.

The combination of different machine learning algorithms or models, for example, integrating support vector machines (SVM) with Gaussian mixture models, convolutional neural networks with prior knowledge, and SVM with Gaussian kernel models.

2. Computer vision and pattern recognition [3], [4], [5], [11], [12], [14], [15], [16], [17].

Computer vision-related approaches such as Yolov3 for object detection, Alphapose for pose estimation, tracking methods based on improved Harris corner detection, and image color segmentation techniques.

Pattern recognition and feature extraction techniques such as Joint similarity calculation, fast skeleton extraction, and model segmentation are used to extract meaningful features from data and perform relevant computations.

3. Statistical and data processing methods [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17].

Statistical and probability models (e.g., Gaussian latent variable models, Gaussian mixture models), dual-kernel extreme learning machines, and deep learning techniques are employed. Data processing and filtering methods (e.g., median filtering, RGB color channelization, area opening operations) are utilized to enhance image quality or extract specific information.

In summary, the given content illustrates the three main categories of algorithms/models used to conduct basketball shooting research, each category contains a series of techniques and algorithms for improving image quality, extracting data features, and analyzing the motion of basketball shooting.

E. EVALUATION METRIC

As shown in **Table 4**. The 15 studies selected in this paper have two different categories of evaluation metrics. The two categories of metrics can exist at the same time in a study, but there is a distinction between primary and secondary. The first category of evaluation metrics is the change in the basketball shooting technique of the subjects after the artificial intelligence technology assists the training. The second category of evaluation metrics is the recognition accuracy (including accuracy, recall, and precision) of basketball shooting motions by the deep learning model used in this study. Among the 15 studies selected in this paper, there are 4 studies [4], [12], [13], [14] whose main evaluation metrics are the first category, and 11 studies [3], [5], [6], [7], [8], [9], [10], [11], [15], [16], [17] whose main evaluation metrics are the second category.

When evaluating a basketball shooting model, it is necessary to consider different evaluation metrics comprehensively. On the one hand, metrics such as accuracy, precision, and recall should be taken into account to evaluate the overall performance of the model. These metrics can help understand the model's performance in predicting basketball shooting motions and determine its reliability and usability.

On the other hand, important basketball shooting parameters should also be compared and analyzed to determine the model's performance in specific areas, such as shooting angle and release point height. By analyzing these parameters, a deeper understanding of the model's performance and limitations can be gained, and improvements and optimizations can be made as needed. It should be noted that different evaluation metrics may have a trade-off between them. For example, the cost of improving the model's accuracy and precision may reduce its speed and practicality. Therefore, it is necessary to balance and weigh different metrics to find the best solution.

V. DISCUSSION

A. MAINLY APPLIED AI TECHNOLOGY

Among the 15 articles selected in this paper, machine learning is the most frequently used artificial intelligence technology in the field of basketball shooting. All studies are using machine learning, followed by computer vision technology, and artificial neural network is the lowest. The three technologies work in conjunction with each other for the main reasons:

1) THE AMOUNT OF DATA IS LARGE

There are many kinds of basketball shooting motions, such as jump shots, hook shots, teardrop shots, etc. Shooting motion is a process of synergistic force exerted by multiple joints of the upper and lower limbs, mainly composed of ankles, knees, hips, shoulders, elbows, wrists and knuckles work together to throw the basketball, and under different body postures, the shooting posture will also change. Therefore, whether basketball shooting is analyzed by computer vision technology or wearable devices, it is necessary to use machine learning to process a huge amount of data and predict the success rate of shooting.

2) THE METHOD OF BASKETBALL SHOOTING MOTION RESEARCH

Humans observe basketball shooting motions directly with their eyes, and experienced basketball players will judge whether a certain shot is successful or not according to the feeling of the shooter. Therefore, when computer vision technology matures, sports scientists will tend to use it to analyze

TABLE 4. Evaluation metrics used in the papers.

Research Topic	Evaluation Metrics	Details
Intelligent method of correcting the basketball shooting motion/direction. Li B et al. [7] (2022) Huang Y et al. [8] (2022)	Accuracy of the basketball shooting motion transformation judgment.	The computer vision analysis process of 20 basketball shooting movements is averaged, and the adaptive correction and motion standardization judgment are carried out in the three-dimensional space of basketball shooting movements.
	The tracking effect of the basketball shooting direction correction method.	Basketball movement and actual movement predicted by the system.
Prediction/analysis of basketball free throw. Nakai M et al. [5] (2018) Saraireh S et al. [13] (2018)	①Accuracy of Predicting Basketball Free Throws. ②Relation for shooting probability and features.	①Accuracy of Logistic Regression Model. ②Sensitivity analysis, the relationship between basketball shooting probability increment and features of the shooter.
	The accuracy of the system in extracting the information.	The accuracy of this system in extracting the information equal to 96.55%.
Analysis of basketball shooting posture/trajectory. Wang Y et al. [6] (2021) Egi Y. [4] (2022) Pan H et al. [9] (2021) Chen H et al. [14] (2013)	Accuracy of the algorithm.	Compared with other motion recognition algorithms. ①Recognition accuracy of the baseline recognition algorithms. ②Accuracy of the baseline recognition models.
	The trajectory of a basketball shooting from different angles with or without air resistance.	Trajectory of different angles for: h-projectile = 1.73m, v0 = 8 m/s, l = 4.6 m and h = 3.05 m.
	Movement of human joints during basketball shooting.	①The degree of bending of the lower limbs. ②The tilt of the torso. ③The stretch of the upper limbs. ④The coordination of upper and lower limbs.
Basketball shooting posture/training type recognition Ji R. [3] (2020) Pengyu W et al. [10] (2021) Zhao B et al. [11] (2021) Fan J et al. [12] (2021) Liu R et al. [15] (2021) Acikmese Y et al. [16] (2017) Fan J et al. [17] (2022)	The shooting-hit ratio of male and female basketball players at the free-throw line and the three-point line.	The shooting hit ratio of male and female basketball players at the free throw line and three-point line improved continuously with cycle and by the same amount.
	The accuracy of classifiers in recognizing basketball shooting motions.	Basketball shooting recognition effect. ①Upper limbs. 91.2% (the Bayesian algorithm's average recognition accuracy rate). ②Lower limbs. 94.1% (the Random forest algorithm's average recognition accuracy rate).
	The accuracy of the model's classification and recognition of basketball shooting motions.	The average accuracy rate of motion capture results for computer vision recognition using the support vector machine model is 95.9%, and the average accuracy rate of motion capture results for computer vision recognition using the Gaussian mixture model is 82.9%.
	①The compactness and quantity of bounding boxes. ②The actual goal and the goal judged by the method in this paper.	①Using ellipsoid as the primitive bounding box to design a fast-fitting method of dynamic human model based on template frame information labeling. ②The data of the basketball shooting posture in the three directions of left, middle, and right.
	①The intratest's average recall rate and precision rate. ②The intertest's average recall rate and precision rate.	①The intratest achieved a 98.6% average recall rate, 98.6% average precision rate, and 98.6% accuracy rate. ②The intertest achieved an average recall rate of 89.8%, an average precision rate of 91.1%, and an accuracy rate of 89.9%.

shooting techniques, allowing computers to observe and learn correct basketball shooting motions, to help athletes achieve the goal of efficient and scientific training.

3) THE CHARACTERISTICS OF BASKETBALL SHOOTING

The pace of modern basketball games is very fast, and the time for offensive and defensive transitions is extremely short. Therefore, athletes need to shoot at a very fast speed on the field. However, because it is difficult for human eyes to capture many important details of the shooting, artificial intelligence is needed to assist in analysis and find out the problems existing in the shooting process, it will help the athletes to solve them one by one in future shooting training.

B. DEEP LEARNING

As shown in **Table 5**, when CNN and RNN are used in the research of basketball shooting, they can provide deeper analysis and insights. Here is their specific role in basketball shooting research [18].

1. Spatial feature analysis.

CNN plays a role in extracting spatial features from basketball shooting images. Through multiple convolutional and pooling layers, CNN can capture features of different scales and levels, such as the basketball, court, and players. For example, it can identify the position of the basketball, players' postures, and the location of the shooting point. These spatial features are crucial for analyzing the accuracy, angles, and body posture of shooting motions.

2. Time-series modeling.

RNN plays a role in modeling the time-series relationship of motions in basketball shooting. With the structure of recurrent neural networks, RNN can process consecutive time steps and capture the time-series dependencies between shooting motions. This allows the model to understand the development and evolution of shooting motions, as well as the causal relationships between motions. For example, it can analyze the initiation of shooting motions, adjustments and corrections during the middle process, and the final shooting outcome.

3. Context modeling and attention mechanism.

Combining CNN and RNN can better model the contextual information of basketball shooting. The spatial features extracted by CNN can be used to understand the shooting environment, such as the layout of the court and the distribution of players. By modeling the motion sequences, RNN can pay attention to and weight key motions during the shooting process. This attention mechanism enables the model to focus more on important motions during shooting and factors related to the final shooting outcome [19].

4. Motion prediction and improvement.

By combining CNN and RNN, basketball shooting motions can be predicted and improved. The model can predict the next possible shooting motion by learning from historical shooting data. This is helpful for players' technical improvement and training. Additionally, the model can generate new basketball shooting sequences to evaluate the impact of specific motions on shooting outcomes, thereby assisting in designing better shooting strategies and training programs [20].

Compared to other deep learning techniques, CNN and RNN have distinct advantages in basketball shooting research.

1) CNNs ADVANTAGES

1. Spatial Feature Extraction.

CNN effectively extracts spatial features from images, which is crucial in basketball shooting research. Visual sensors, such as cameras, capture image or video data of the shooting process, containing valuable spatial information, including the shooter's motions and posture, basketball position, and trajectory. By extracting spatial features, key information related to shooting can be obtained from these image or video data, such as:

(1) Shooter's posture and motions.

Extraction of the shooter's body posture, arm and hand positions, as well as motions during the shooting process, such as jumping and shooting motions.

(2) Basketball position and trajectory.

Extraction of the basketball's position and trajectory during the shooting process, including the initial position, movement trajectory, and final landing point.

(3) Shooting environment and court information.

Extraction of environmental information during the shooting, such as the position and height of the basketball hoop, and the court background.

These spatial features are vital for understanding and analyzing shooting techniques. Researchers can utilize these features to analyze the correctness of the shooter's posture and motions, the conformity of the basketball trajectory to expectations, and the impact of environmental factors on the shooting outcome.

2. Hierarchical feature learning.

Through the deep structure of convolutional neural networks, CNN can learn abstract feature representations at different levels, ranging from low-level edges and textures to high-level shapes and semantic information. This is crucial for understanding the details and semantic meanings of basketball shooting motions. In basketball shooting research, hierarchical feature learning helps extract meaningful features related to shooting from video or image data. By learning hierarchical features, we can progressively capture higher-level abstract features, such as shapes, postures, and motions, starting from low-level image features like edges and textures. These abstract features better capture key information in basketball shooting, such as player postures, basketball positions, and trajectories.

3. Parameter sharing and local connectivity.

CNN's parameter sharing and local connectivity enable efficient and robust image data processing in basketball shooting

TABLE 5. Deep learning techniques mainly used in basketball shooting research.

Characteristics	CNN	RNN	Overall Analysis
Structure	Composed of multiple convolutional and pooling layers for feature extraction	Composed of recurrent connections for modeling time-series relationships	CNN extracts spatial features from basketball shooting images, while RNN models the time series relationships of shooting motions
Applications	Image processing, computer vision tasks	Time-series data processing	CNN analyzes spatial features in basketball shooting images, while RNN analyzes the time features of shooting motions
Input Data	2D images	1D sequence data	CNN processes basketball shooting images, while RNN processes shooting motion sequences
Output Data	Feature vectors	Probability distributions	CNN provides quantitative information about the player's posture and position, and RNN provides information about the player's shooting trend and stability
Principles	Local perception and weight sharing	Time dependency and handling of historical information	CNN captures spatial features through local perception, while RNN models motion sequences by considering time dependencies
Parameter Sharing	Weight sharing to reduce parameter count	No parameter sharing, larger parameter count	CNN reduces parameter count through weight sharing, suitable for large-scale image data processing; RNN does not share parameters, suitable for time series data
Network Connections	Local connections with convolutional operations	Previous time step's output serves as input for the current time step	CNN extracts spatial features through local connections, while RNN models time-series relationships through recurrent connections
Challenges	Sensitivity to input dimensions and sizes	Handling long-term dependencies, vanishing gradients, and exploding gradients	RNN needs to address long-term dependencies, vanishing gradients, and exploding gradients
Advantages	Powerful spatial feature extraction ability for image data processing	Capturing time dependencies for sequence data processing	CNN can extract spatial features from basketball shooting images, while RNN models the time-series relationships of shooting motion
	Parameter sharing reduces parameter count for large-scale image data processing	Dynamic input length accommodates varying lengths and time intervals of shooting motions.	The combined use of CNN and RNN enables comprehensive analysis of the spatio-temporal features and dynamics of basketball shooting

research. Parameter sharing reduces model complexity and storage needs by reusing weight parameters across the network, while also preventing overfitting. This sharing allows CNNs to effectively extract local features for motion recognition and pose estimation tasks. Regardless of their positions, these features receive the same response, capturing crucial patterns like the shooter's arm position or head posture. Local connectivity further reduces complexity and aligns with image and spatial data structures. It enables the network to capture local spatial relationships, such as the shooter's arm position relative to the body or joint angles. By extracting features in local regions and preserving spatial relationships, local connectivity enhances the understanding and analysis of basketball motions and poses.

2) RNNs ADVANTAGES

1. Time-series modeling.

Time-series modeling involves analyzing data in a sequential manner, considering time-series relationships and dependencies. It plays a crucial role in basketball shooting research, where shooting motions unfold as continuous sequences over time. Through the application of time-series modeling, insights can be obtained regarding the dynamic changes and trends within basketball shooting motion sequences, thereby revealing the factors that impact shooting outcomes. Critical moments and motions, such as jumping, arm extension, and ball release, can be identified through this analysis. By examining the sequence and time-series relationships of these key elements, researchers uncover patterns and regularities in shooting techniques. This understanding contributes to the optimization of motion sequences, improvements in shooting accuracy, and enhanced effectiveness. Time-series modeling also facilitates outcome prediction. By establishing predictive models using historical shooting motion data, researchers can forecast future shooting results. This assessment of skill level provides real-time feedback, guidance, and a foundation for training and refining shooting techniques.

2. Long-term dependencies.

Long-term dependencies are crucial relationships between current and distant past time steps in sequential data. In basketball shooting research, they play a significant role. Shooting motions in basketball form continuous time series, where past time steps provide essential information for predicting the current motion and outcome. By modeling these dependencies, researchers can analyze and predict shooting outcomes more effectively. For example, recurrent neural networks (RNNs) can capture important patterns and evolution processes in motion sequences, aiding in motion classification and analysis. Considering long-term dependencies helps the model maintain contextual understanding by memorizing and updating information from the past. This evaluation contributes to the improvement of shooting techniques by identifying critical time points, motions, or postures that affect accuracy and effectiveness.

3. Dynamic input length.

Dynamic input length handling is essential in basketball shooting research as it enables the adaptation to varying lengths and time intervals of different shooting motions. Recurrent Neural Networks (RNNs), such as Long Short-Term Memory (LSTM) or Gated Recurrent Units (GRU), provide flexibility by handling variable-length input sequences. This allows researchers to process shooting motions of different durations and effectively analyze them. Additionally, attention mechanisms allocate weights to different parts of the input sequence, enabling the model to focus on crucial time steps. These techniques facilitate the accurate modeling and analysis of the basketball shooting process. By considering the complete time sequence of shooting motions, the models can capture dynamic features and patterns more accurately. This leads to improved recognition and classification accuracy of shooting motions, enabling further analysis and enhancement of shooting techniques.

In contrast, other deep learning techniques, such as feedforward neural networks (FFNN), may have the following limitations in handling basketball shooting research [21].

1. Limited modeling capability for spatial features.

Feedforward neural networks (FFNN) may struggle to effectively capture spatial features in basketball shooting research due to structural constraints and parameter sharing strategies. This limitation could result in the model's inability to accurately differentiate between different shooting postures, basketball positions, and other crucial spatial information.

2. Neglect of time-series dependencies.

Other deep learning techniques, like traditional feedforward neural networks, often lack the ability to handle time-series data. In basketball shooting research, the time-series dependencies of motions are essential for motion analysis and prediction. If the model fails to capture these dependencies, it may lead to inaccurate recognition and analysis of motions.

3. Difficulty in handling dynamic input length.

Traditional feedforward neural networks typically require inputs with fixed sizes or lengths. However, in the basketball shooting process, the length of motions can vary, such as the duration of shooting or the timing of jumping and releasing the ball. This makes it challenging for traditional feedforward neural networks to accommodate different lengths of input sequences, potentially hindering the model's ability to flexibly handle variations in different shooting motions.

In summary, the combination of CNN and RNN plays vital roles in various research topics related to basketball shooting. Specifically, in the fields of ''ANALYSIS OF BASKETBALL SHOOTING POSTURE/TRAJECTORY'' and ''PREDICTION/ANALYSIS OF BASKETBALL FREE THROW'' RNNs have a greater impact as they focus on capturing the time-series relationships and rhythmical aspects of shooting motions, which are essential for accurate analysis.

On the other hand, in ''BASKETBALL SHOOTING POSTURE/TRAINING TYPE RECOGNITION'', CNNs play a more prominent role due to their ability to recognize distinct

spatial characteristics of different shooting motions. Lastly, the ''INTELLIGENT METHOD OF CORRECTING THE BASKETBALL SHOOTING MOTION/DIRECTION'' represents a comprehensive integration of both CNN and RNN, emphasizing the development of a complete system for analyzing and improving shooting techniques.

C. BASKETBALL SHOOTING PREDICTION

The method of applying artificial intelligence technology to predict the accuracy of basketball shooting is as follows:

1. Data Collection and Preparation.

Collect a diverse data of basketball players' shooting videos, encompassing various shooting motions and players of different skill levels, maintaining high-resolution and clear video data.

2. Human Pose Estimation.

Utilize computer vision techniques like OpenPose to estimate the poses of basketball players. Analyze the positional and movement data of key body points extracted from the video data.

3. Feature Extraction.

Analyze and process the dataset to extract features that are relevant to shooting accuracy. Carefully select and design features that accurately capture the factors influencing shot accuracy, while avoiding redundancy or repetitive information.

4. Dataset Construction.

Based on previously collected basketball player motion data, a dataset is constructed that encompasses various shooting motions and basketball skill levels. It is ensured that the video data in the dataset maintains a high resolution and accuracy.

5. Machine Learning Model.

Select an appropriate machine learning algorithm and model architecture. Utilize the extracted features as inputs to predict the accuracy of basketball shots. Train and optimize the model to improve its predictive performance.

6. Model Validation and Optimization.

Validate the model's performance using an independent test dataset. Evaluate its accuracy and generalization abilities. Adjust and optimize the model based on the evaluation results to enhance its predictive capabilities.

7. Model Application.

Apply the optimized model in practical scenarios to assist basketball coaches and players in identifying areas that require improvement in shooting technique, thereby enhancing shooting accuracy.

In conclusion, the application of artificial intelligence technology can assist in identifying areas for improvement in shooting technique, benefiting both coaches and players. However, it is important to note that predicting basketball field goal percentage is a complex task influenced by numerous factors. Therefore, the system should be used as an auxiliary tool, complementing human expertise and experience for comprehensive evaluation.

D. FUTURE DEVELOPMENT TREND

The application of artificial intelligence in the field of basketball is becoming more and more common and in-depth, and the concept of ''artificial intelligence empowering sports'' is also gradually popularizing. Regarding its future development trend, there are roughly three directions as follows:

1. Combination of computer vision and biomechanics.

Based on the 15 studies examined in this paper, it can be concluded that computer vision can recognize basketball shooting motions without physical contact. However, the accuracy of this method is poor and insufficient for studying the dynamics of shooting. On the other hand, wearable devices utilized in biomechanics can extract more precise mechanical parameters. However, wearing such devices may potentially affect the quality of basketball shooting motions. Therefore, future research should focus on minimizing the negative impact of wearable devices while ensuring accurate parameter measurement. For instance, the accuracy of computer vision technology can be enhanced through upgrades, or wearable devices can be developed with minimal impact on human motion, such as devices that are extremely lightweight or implanted under the skin.

2. Improve the efficiency of basketball technical and tactical analysis.

Basketball skills and tactics refer to the techniques and tactics used in the basketball game. In terms of basketball tactics, artificial intelligence technology can automatically and intelligently help coaches analyze the content of the game and the technical characteristics of athletes, and formulate a game plan. In terms of basketball technology, among the 15 studies selected in this paper, the research focus is on the classification and recognition of basketball shooting movements. There is no in-depth research on the specific principles of basketball shooting, and basketball shooting skills are constantly changing with the changes in basketball games, research on this aspect should also keep pace with the times to be valuable.

VI. CONCLUSION

This article provides an overview of the current application status of artificial intelligence (AI) technology in basketball shooting analysis and discusses the main research topics in this field. These topics include: Basketball Shooting Posture / Training Type Recognition, Analysis of Basketball Shooting Posture/Trajectory, Prediction / Analysis of Basketball Free Throw, and Intelligent Method of Correcting the Basketball Shooting Motion / Direction. In addition, this article also elaborates on the application of key processes in basketball shooting research from the perspective of AI methodology, including Data Collection and Preparation, Feature Engineering, Algorithm/Model Selection and Training, Dataset, and Evaluation Metric. The advantages and limitations of AI technology in the field of basketball shooting are also analyzed.

Finally, this article proposes possible future trends and research directions for AI in basketball shooting. These

include integrating computer vision and biomechanics to support rationality analysis of shooting, developing efficient real-time AI systems to adapt to actual game and training scenarios, and building personalized shooting training systems. These development directions aim to provide basketball players, coaches, and enthusiasts with scientifically effective analysis and optimization solutions for shooting techniques, thereby promoting the development and popularization of basketball.

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