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Article

AI Visual Recognition Technology in Action Difficulty Grading and Referee Assistant System for Freestyle Roller Skating

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Abstract: With the rapid development and increasing global popularity of freestyle roller skating, the traditional difficulty grading and judging model, which relies predominantly on subjective human judgment, is no longer able to meet the stringent needs of the standardized development of the sport. Subjective evaluations often lead to inconsistencies during high-stakes competitions. Consequently, this paper focuses on the innovative application of artificial intelligence (AI) visual recognition technology within this athletic field, aiming to significantly improve the objectivity, accuracy, and fairness of judging by constructing a robust difficulty grading model and an intelligent referee assistant system. First, this study comprehensively explains the underlying AI visual recognition technology architecture and details the freestyle roller skating action judging rules. It designs a comprehensive motion data collection scheme and an advanced feature engineering process to capture the intricate dynamics of the skaters. Furthermore, it constructs and optimizes a sophisticated difficulty grading model based on deep learning algorithms, specifically tailored for complex spatial-temporal movements. On this foundational basis, a comprehensive referee assistant system equipped with real-time monitoring and automated referee assistance functions is developed. Its practical application effectiveness is rigorously evaluated through both computer simulation and actual live competition tests. The empirical results demonstrate that this proposed technical solution will effectively improve the accuracy of complex motion recognition and ensure the high consistency of grading. Ultimately, this research provides a highly feasible approach for the intelligent development of freestyle roller skating. In addition, corresponding strategic solutions are proposed to address the potential technical challenges encountered in the real-world application.

Keywords: artificial intelligence; visual recognition; deep learning; sports technology; motion analysis; referee system

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1. Introduction

Freestyle roller skating, an emerging sport that combines skill and entertainment, has experienced rapid global growth in recent years. However, the current methods for grading difficulty rely on subjective human judgment, which makes the judging process prone to interference and hinders the standardized development of the sport. AI visual recognition technology, with its efficient data processing capabilities and precise feature extraction, offers significant potential for application in sports event analysis and quantitative movement evaluation. Addressing the practical needs of freestyle roller skating and leveraging innovative trends in AI technology, this paper aims to develop a movement difficulty grading model and referee assistant system based on AI visual recognition technology. This approach enhances the objectivity of difficulty grading and the fairness of refereeing. A review of existing research on roller skating movement evaluation systems and sports AI refereeing systems highlights limitations such as insufficient quantification of movement features and weak real-time processing capabilities [1]. Therefore, this paper employs literature research and experimental verification to focus on key technologies, including movement feature extraction in complex sports scenarios and dynamic difficulty quantification algorithms, aiming to provide theoretical support and technical reference for the intelligent development of freestyle roller skating.

2. Core Technology and Theoretical Basis of Research Objects

2.1. AI Visual Recognition Technology Architecture

AI visual recognition technology represents a multidisciplinary system that combines principles from computer science, pattern recognition, and machine learning. Its primary objective is to enable computers to achieve perception and understanding capabilities akin to human vision [1, 2]. Within the domain of dynamic motion analysis, this technology employs image acquisition devices to capture visual data from target scenes. Through a series of processing and analytical steps, it can identify, track, and extract features of moving objects.

Image acquisition and preprocessing techniques form the foundation of AI visual recognition. The selection of image acquisition equipment significantly influences subsequent processing stages. For capturing freestyle roller skating movements, high-speed cameras are commonly utilized, typically operating at a frame rate of no less than 120 frames per second. This ensures the clear capture of intricate details in fast-moving actions. Preprocessing methods, such as image denoising, enhancement, and distortion correction, are employed to mitigate external interference and enhance image quality [3, 4].

Feature extraction algorithms play a pivotal role in AI visual recognition by extracting representative feature information from preprocessed images. The SIFT (Scale-Invariant Feature Transform) algorithm, which is both scale-invariant and rotation-invariant, facilitates stable feature point extraction across varying scales and angles, making it suitable for identifying key limb components in roller skating. The HOG (Histogram of Oriented Gradients) algorithm characterizes features by analyzing the distribution of gradient directions within localized image regions [5]. This approach is particularly effective for describing human contours and postures, enabling the analysis of changes in athletes' body positions during roller skating.

The advent of deep learning models has markedly enhanced the performance of AI visual recognition. Convolutional neural networks (CNNs) autonomously learn image features through structures such as convolutional and pooling layers, circumventing the constraints of traditional manual feature extraction. These networks excel in tasks like image classification and object detection. In the context of motion recognition for freestyle roller skating, CNNs can extract and classify features from sequences of motion images. Pose estimation models, specifically designed for detecting human key points, accurately identify joint positions, providing critical data for analyzing motion kinematics [6]. For instance, by detecting key points such as the hip and knee joints, it becomes possible to calculate limb movement angles and displacements.

Despite its advancements, AI visual recognition technology faces certain limitations in practical applications [7]. Its accuracy can be compromised by complex backgrounds, significant lighting variations, or severe object occlusions. Additionally, the real-time processing of rapidly changing dynamic movements presents challenges, necessitating a careful balance between algorithmic complexity and processing speed.

2.2. Freestyle Roller Skating Operation System and Judging Rules

Freestyle roller skating encompasses a variety of events, including speed slalom and classic slalom. Speed slalom is judged primarily on the speed at which athletes navigate the slalom, emphasizing the speed and consistency of the movements. Classic slalom, on the other hand, emphasizes the technical skill and visual appeal of the movements, requiring athletes to perform complex combinations of jumps, spins, and glides throughout the slalom. While the movement systems vary across different events, they all adhere to certain principles of movement composition, typically consisting of three phases: the launch, the execution of the core movements, and the final glide.

The competition rules established by international skating organizations serve as a crucial basis for judging freestyle roller skating, including clear criteria for evaluating the difficulty of maneuvers. The complexity of maneuvers is determined by three primary factors: technical complexity, execution difficulty, and risk [8]. The establishment of a robust evaluation index system is imperative for the scientific assessment of maneuver complexity. In the classic slalom, artistic performance is one of the core dimensions of the referee evaluation system. Athletes need to design movements in accordance with the rhythm of music, echoing the melody through smooth body posture (such as arm stretches and body coordination), and integrate these movements into technical actions like jumps and rotations, thereby forming a linkage between movements and music. The artistic performance score comprehensively considers the fit between the action and the music, the appeal of the body expression, and the creativity of the overall arrangement. The demonstration of artistic expression can significantly improve the score and become a key indicator to distinguish the level of athletes.

Movement continuity reflects an athlete's ability to control their movements and refers to the smooth transitions between movements. In the freestyle event, athletes must complete a series of movement transitions between different positions [9]. A smooth transition between movements demonstrates a higher level of technical proficiency.

In addition, the quality of the movement will also affect the difficulty rating, including landing stability and posture standardization. It has been demonstrated that superior body posture at the moment of landing is associated with a higher level of completion quality, resulting in the allocation of additional points to the difficulty rating [8].

3. AI Implementation Path for Difficulty Grading in Freestyle Skating

3.1. Motion Data Collection and Feature Engineering

To develop a comprehensive freestyle roller skating dataset, a multi-view high-speed camera setup was implemented [10]. Four high-speed cameras were positioned at the collection site to capture athletes' movements from the front, back, left, and right perspectives. The cameras operated at a frame rate of 240 frames per second, ensuring detailed capture of rapid movements. The recorded movements spanned various difficulty levels, including basic movements (such as single-leg straight skating and double-leg turns), advanced movements (such as crossover skating and single-foot slalom), and complex movements. Each movement was performed ten times by five athletes with different skill levels to ensure the dataset's diversity and representativeness.

During the data collection process, basic athlete information, such as height, weight, and years of experience, along with performance details, was documented to support subsequent data analysis [11]. After collection, the raw video data underwent preprocessing steps, including image cropping and format conversion. The resulting images were standardized to a uniform size and resolution to facilitate feature extraction and model training.

Feature engineering plays a pivotal role in transforming raw image data into meaningful features. Preprocessed images were analyzed using skeletal key point detection technology [10]. This deep learning-based approach automatically identifies and locates key joints in the human body, such as the head and neck. By tracking the positional changes of these key points across consecutive frames, kinematic parameters such as joint angles, limb displacement, movement speeds, and acceleration were extracted.

The extracted kinematic parameters were subjected to quantization and normalization. Quantization converted continuous kinematic parameters into discrete numerical features, simplifying model processing [12]. Simultaneously, normalization mitigated the impact of variations in athlete size by mapping feature values to a consistent numerical range.

3.2. Construction and Optimization of Difficulty Grading Model

A freestyle roller skating maneuver classification model was developed using a deep learning framework, with a convolutional neural network (CNN) serving as the foundational architecture. To account for the temporal nature of freestyle roller skating maneuvers, a long short-term memory (LSTM) network was integrated with the CNN, forming a hybrid CNN-LSTM model. The CNN extracts spatial features from individual frames, capturing static pose information, while the LSTM processes temporal sequence features from consecutive frames, capturing dynamic movement changes. The model's input consists of feature-engineered image data representing the action sequence, and its output is a classification of the movement's difficulty level, such as basic, advanced, or high difficulty. Figure 1 illustrates the structure of the hybrid CNN-LSTM model.

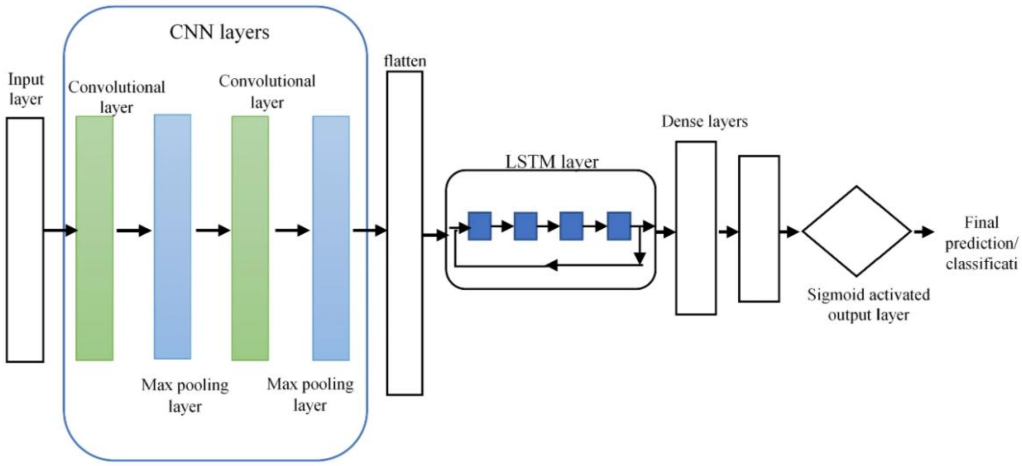

Figure 1. Structure of Hybrid Cnn-lstm Model

To address the challenge of limited freestyle skating datasets, a transfer learning approach was implemented. Initially, the model was pre-trained on a large, publicly available human motion recognition dataset, allowing it to learn generalized human motion feature representations. Subsequently, the pre-trained model parameters were fine-tuned using the constructed freestyle skating dataset, enabling the model to adapt to the specific motion recognition task [10]. This approach effectively enhanced the model's generalization capabilities and mitigated overfitting.

A difficulty assessment algorithm was developed by incorporating expert scoring criteria. Scores were collected from a dataset of maneuvers evaluated by experienced freestyle roller skating referees [13]. The relationship between the scores and the characteristics of the maneuvers was analyzed, leading to the creation of a mathematical model for difficulty assessment. This model utilizes extracted kinematic parameters as input and calculates a difficulty score through a weighted computation. The weights are assigned based on the significance of the expert ratings, with greater emphasis placed on key features such as takeoff height and rotation angle.

The model's accuracy was refined through iterative optimization using confusion matrix analysis. The confusion matrix provided performance metrics, such as accuracy and recall, for each difficulty level. By examining the confusion matrix, specific action types prone to misclassification were identified, along with the underlying reasons for these errors. For actions with lower recognition accuracy, additional training samples were incorporated, and adjustments were made to the model's network structure and parameter settings [14]. Through multiple iterations of optimization, the model achieved significant improvements in action recognition accuracy and consistency in difficulty grading, establishing a comprehensive technical framework from action recognition to difficulty assessment.

4. Design and Development of Referee Assistant System

4.1. System Requirements Analysis and Architecture Design

Based on the practical needs of freestyle roller skating referees, three core functional requirements for the referee assistant system were identified. The real-time monitoring function enables the system to capture and analyze athlete movements during competitions, promptly obtaining key information such as movement type, completion time, and location [2]. This provides referees with immediate visual feedback on the athletes' actions.

The officiating assistance function is designed to help referees accurately identify athlete violations [15]. The system is required to automatically detect common violation scenarios and issue timely alerts to minimize errors caused by manual oversight. Additionally, the data backtracking function ensures that all action data and video information from the competition are recorded, allowing referees to replay and reassess controversial actions post-event, thereby enhancing the traceability and fairness of officiating outcomes.

To meet these requirements, the referee assistant system was developed with a three-layer architecture: data acquisition layer, feature processing layer, and decision support layer. The data acquisition layer collects on-site video and motion data using high-speed cameras and sensors, transmitting this information to the system for storage and preprocessing. The feature processing layer analyzes the collected data using AI visual recognition technology to identify movement types, extract kinematic parameters, and detect violations [9]. The decision support layer utilizes the results from the feature processing layer to generate reference scores for movement difficulty, issue violation warnings, and produce statistical reports to assist referees in decision-making.

This three-tier architecture ensures the system's stability and adaptability. Data exchange between layers is facilitated through standardized interfaces, which support future functional enhancements and updates. Additionally, the integration of distributed computing and storage technologies improves the system's data processing efficiency and responsiveness.

4.2. Implementation of Core Functional Modules

The real-time action recognition module serves as a pivotal component of the referee assistant system, designed to identify and label athlete movements during competitions in real time. Utilizing a constructed difficulty grading model, this module processes video frames transmitted from the data acquisition layer. Through the application of a CNN-LSTM hybrid model, it efficiently identifies action types and determines the start and end times of each movement. During recognition, the module automatically marks critical moments, such as the take-off and landing points of jumps and the initial angle of rotations. These details are visualized on the system interface, enabling referees to assess athletes' performance instantaneously.

The violation detection module defines recognition rules for common infractions in freestyle roller skating competitions. By analyzing competition regulations and historical violation cases, it identifies characteristic patterns associated with violations such as slalom touching, time infractions, and out-of-bounds occurrences [16]. Leveraging image recognition technology, the module monitors these patterns and issues immediate visual and auditory alerts upon detecting a violation. It records relevant information, including the time, location, and type of infraction, thereby providing a reliable basis for referee decision-making.

The scoring assistance module offers a quantitative scoring reference derived from the output of the difficulty grading model. This module integrates the difficulty rating of a movement with an evaluation of its execution quality. Factors such as difficulty level, accuracy, and consistency are used to calculate a preliminary score based on a predefined scoring formula. Additionally, the module aggregates scores and penalty points for all movements performed during the competition, generates a real-time overall ranking, and provides referees with recommendations for scoring adjustments. Referees can finalize scores by combining the system's suggestions with their professional judgment, enhancing the accuracy and efficiency of the scoring process.

The system also incorporates a data management module and a user interaction module. The data management module ensures the secure storage, querying, and backup of information such as match data, action videos, and scoring results, safeguarding data integrity. Meanwhile, the user interaction module offers a user-friendly interface that simplifies system setup, data visualization, and scoring tasks, thereby improving overall usability for referees.

5. Application Effect Evaluation and Challenge Response

5.1. Technical Performance and Application Effect Evaluation

To comprehensively evaluate the effectiveness of AI visual recognition technology in the freestyle roller skating maneuver difficulty grading and referee assistant system, an evaluation system was developed that includes metrics such as recognition accuracy and response time. Recognition accuracy refers to the percentage of maneuver types correctly identified by the system, calculated by comparing system recognition results with those manually annotated. Response time, defined as the interval between receiving movement data and outputting recognition and grading results, reflects the system's real-time processing capabilities.

This study evaluated the system using a combination of simulated competitions and actual competition testing. In the simulated competition, 10 athletes completed a pre-set repertoire. The system's recognition and classification results were recorded and compared with the manual judgments of three experienced referees. In the actual competition test, the referee assistant system was applied to the officiating process of a regional freestyle roller skating competition, where system performance data and referee feedback were collected.

Evaluation results indicate that the system's movement recognition accuracy exceeds 92%. The accuracy for basic and advanced movements is even higher, surpassing 95%. Although the recognition accuracy for difficult movements is relatively lower due to their greater complexity, it still reaches over 85%. The Kappa coefficient for grading consistency is 0.83, demonstrating high consistency between the system's grading results and expert ratings. The average response time is 0.3 seconds, meeting the requirements for real-time referee assistance.

A comparative analysis revealed that the system significantly improved referee efficiency. Both referees and athletes generally provided positive evaluations of the system, noting that it offered objective scoring references and contributed to enhancing competition fairness.

5.2. Key Challenges and Solutions

During the system's application, several challenges were encountered, with recognition robustness in scenarios involving complex lighting and motion occlusion being particularly significant. Variations in lighting conditions at the competition venue, such as differences in light intensity between sunny and cloudy days and changes in lighting angles, were found to affect image quality and result in inaccurate feature extraction. Additionally, when athletes performed movements, body parts occasionally obstructed one another, leading to incomplete detection of skeletal key points and reducing motion recognition accuracy.

To address these issues, a multimodal data fusion strategy was implemented. In addition to visual image data, inertial sensor data was incorporated as a supplementary source. Inertial sensors, which record information such as acceleration and angular velocity, are unaffected by illumination and occlusion. By integrating visual and inertial sensor data, a data fusion algorithm was employed to comprehensively analyze motion characteristics, enhancing the system's recognition robustness in complex scenarios. Furthermore, the image preprocessing algorithm was refined, and adaptive light compensation technology along with an occlusion recovery algorithm were utilized to minimize the impact of illumination variations and occlusion on image features.

The challenge of human-machine collaboration during technology implementation also required attention. Some referees expressed concerns about adopting new technologies, fearing that the system might replace human referees [17]. Discrepancies between system-generated scores and human judgments highlighted the need for an effective coordination mechanism. To address this, a refereeing model based on "AI assistance + manual review" was developed, clearly defining the system's auxiliary role. The system provides scoring references and violation alerts, while the final refereeing decisions remain under the authority of human referees.

6. Conclusion

This paper proposes a freestyle roller skating maneuver difficulty grading model and a referee assistant system based on AI visual recognition technology. The system advances the field by covering the full process from quantitative extraction of movement features to automatic difficulty grading and referee support in decision-making. The results confirm the value of AI technology in improving the objectivity of movement evaluation and referee efficiency. The constructed CNN-LSTM hybrid model achieves high movement recognition accuracy, effectively alleviating the strong subjective bias and low efficiency associated with traditional manual evaluation. The developed referee assistant system further improves referee efficiency through real-time recognition and violation detection. However, the study still faces challenges, including the need to improve the recognition accuracy of high-difficulty movements and limited adaptability to complex scenarios. Future work should further optimize multimodal fusion algorithms, enlarge the dataset, and promote the standardized application of the "AI-assisted + manual review" model in competitions, thereby supporting the intelligent development of freestyle roller skating.

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