The Application and Fairness of AI Visual Recognition Technology in the Referee Assistant System of Sports Events in the Guangdong-Hong Kong-Macao Greater Bay Area

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Abstract: With the vigorous development of sports in the Guangdong-Hong Kong-Macao Greater Bay Area, the number and scale of various sports events are constantly increasing, placing higher demands on the accuracy and fairness of refereeing. AI visual recognition technology, with its high efficiency and precision, shows great potential for application in referee assistant systems for sports events. This paper focuses on the application of AI visual recognition technology in referee assistant systems for sports events in the Guangdong-Hong Kong-Macao Greater Bay Area, as well as the issues of fairness. First, it outlines the relevant theories of AI visual recognition technology and systems for sports events, analyzes the characteristics of sports events in the Greater Bay Area, and the challenges faced by referees. Through specific event cases, this study explores the application of AI in referee assistant systems, studies its impact on event fairness, identifies existing problems in the application, and proposes countermeasures. Finally, the study summarizes and outlines its prospects, aiming to provide a reference for improving the level and fairness of refereeing in sports events in the Greater Bay Area.

1. Introduction

The Guangdong-Hong Kong-Macao Greater Bay Area, a key region for the development of China's sports industry, has seen an increasing frequency of sports events in recent years, encompassing a wide range of sports, including football, basketball, and track and field. The standards of these events have continuously improved, attracting a large number of athletes and spectators. Refereeing is a key component in ensuring the fairness and impartiality of sports events. However, traditional refereeing methods often face problems such as human error and inconsistent standards when faced with high-speed and complex events, compromising fairness. The emergence of AI visual recognition technology offers a new approach to addressing these issues [1]. It uses cameras and other devices to capture real-time footage of the event. It employs algorithms to analyze and identify information such as athletes' movements and positions, providing referees with objective and accurate judgment support. While domestic and international scholars have researched the application of AI visual recognition technology in sports refereeing, achieving some results, research specifically targeting sports events in the Guangdong-Hong Kong-Macao Greater Bay Area remains limited, and further research is needed to assess the fairness of technology applications and address practical issues. This study uses a literature review to review relevant theories and research findings. Furthermore, a case study approach is employed to analyze representative events in the Greater Bay Area. The innovation involves integrating the characteristics of sports events in the Greater Bay Area, exploring the application of AI visual recognition technology in referee assistant systems, and addressing fairness issues, thereby providing theoretical support and practical guidance for the high-quality

development of sports events in the region [2].

2. Overview of AI Visual Recognition Technology and Sports Referee Assistant System

2.1 Principles and Development of AI Visual Recognition Technology

AI visual recognition technology is a key branch of artificial intelligence. Its core principle is to simulate the human visual system through computers to detect, identify, track, and analyze objects in images or videos. It primarily relies on hardware devices such as cameras and sensors to collect image data. Subsequently, it processes this data using algorithms like deep learning and machine learning to extract target features, such as shape, color, texture, and motion trajectory, to achieve target recognition [3].

Throughout its development, AI visual recognition technology has evolved from simple feature recognition to complex scene understanding. Early visual recognition technology primarily relied on handcrafted feature extraction methods, resulting in low accuracy and efficiency and limited application. The rise of deep learning and models like convolutional neural networks has significantly improved visual recognition performance, enabling high-precision object recognition and analysis in complex backgrounds and dynamic scenes. Today, AI visual recognition technology is widely used in a variety of fields, including security monitoring, autonomous driving, medical diagnosis, and industrial inspection.

AI visual recognition technology has enormous potential in the sports sector. It can capture athletes' movements, postures, and trajectories in real time, providing data support for event training, tactical analysis, and refereeing assistance [4]. For example, in track and field competitions, it can be used to accurately measure athletes' starting reaction time, running cadence, and stride length. In ball games, it can determine the ball's landing point and whether an athlete is offside, providing strong evidence for referee decisions.

2.2 Demand and Integration Feasibility of Sports Referee Assistance Systems

Sports events place numerous core demands on referee support systems. Accuracy is paramount; the system must accurately capture and analyze key information from the event, providing referees with reliable judgment and reducing misjudgments. Real-time performance is also crucial. In high-speed sports events, referees must make decisions within a short timeframe, requiring the system to rapidly process data and provide timely feedback to adapt to the pace of the event. Furthermore, the system must be stable and compatible, capable of operating under diverse event environments and equipment conditions, and enabling data sharing and collaboration with other event management systems.

From a technical perspective, the integration of AI visual recognition technology into referee assistant systems for sports events is feasible. Current AI visual recognition technology already boasts high accuracy and speed in target detection, tracking, and motion recognition, meeting the real-time and accuracy requirements of sports events. Furthermore, the continuous advancement of hardware, such as the widespread availability of high-definition cameras and high-speed processors, provides solid hardware support for the application of AI visual recognition technology in referee assistant systems [5].

From an economic perspective, while the introduction of AI visual recognition technology to build a referee assistant system requires a certain initial investment, including equipment procurement and system development, in the long term, this technology can improve event operational efficiency, reduce disputes and losses caused by misjudgments, enhance the brand value and commercial appeal of events, and generate substantial economic returns. Furthermore, as the technology matures and is applied on a large scale, the cost of related equipment and technology is gradually decreasing, further enhancing the economic feasibility of integration.

From a policy perspective, China attaches great importance to the application of artificial intelligence technology in sports, issuing a series of policy documents to support the integrated development of the sports industry and technological innovation. The Guangdong-Hong Kong-

Macao Greater Bay Area, as a national strategic development region, also actively promotes the application of technological innovation in sports events, providing a favorable policy environment and support for the integration of AI visual recognition technology into referee assistant systems.

3. Characteristics of Sports Events in the Guangdong-Hong Kong-Macao Greater Bay Area and Problems with Refereeing Methods

3.1 Characteristics and Development Needs of Sports Events in the Greater Bay Area

Sports events in the Guangdong-Hong Kong-Macao Greater Bay Area boast many distinctive features. First, they are of a high standard. The Greater Bay Area has not only hosted numerous top domestic events. Still, it has also actively introduced internationally renowned competitions, such as the Guangzhou Marathon and the Shenzhen WTA Finals, attracting elite athletes from around the globe. These events have generated significant influence and attention. Second, the diverse range of events encompasses popular sports such as football, basketball, badminton, table tennis, track and field, and swimming, catering to the sports needs and viewing interests of diverse demographics. Third, the events integrate regional cultural characteristics, incorporating cultural elements from Guangdong-Hong Kong-Macao Greater Bay Area into the organization, promotion, and activities of the events, lending them a unique charm and cultural depth.

These special events have played a significant role in promoting the development of the Greater Bay Area's sports industry. They have not only spurred the growth of related industries such as stadium construction, sporting goods manufacturing, and sports training, but have also fostered interregional sports and cultural exchange and cooperation, enhancing the Greater Bay Area's sports influence and competitiveness. Furthermore, the continuous development of these events has placed special demands on referees. High-profile competitions require referees to possess a higher level of professionalism and skill, capable of accurately handling complex match scenarios. The diverse nature of these events requires referees to be familiar with the rules and penalty standards of each discipline. Events that integrate regional cultures require referees to balance fairness and cultural awareness in their officiating [6].

3.2 Problems with Traditional Refereeing Methods and the Need for Technology Introduction

Traditional refereeing methods present numerous challenges in Greater Bay Area sports. Human error is a prominent issue. Due to the referee's limited vision, reaction time, and subjective factors, errors in judgment are inevitable when faced with high-speed moving objects and complex on-field situations. For example, in football matches, offside and handball calls are often misjudged due to poor refereeing or delayed reaction, sparking dissatisfaction among teams and spectators.

Inconsistent standards are also a major drawback of traditional refereeing. Different referees may have different understandings and implementations of the rules, resulting in inconsistent penalty standards in different matches or at different stages of the competition, which hurts the fairness of the competition.

These issues not only undermine the fairness of the competition but also diminish its appeal. Spectators expect fair play, but frequent misjudgments and inconsistent calls can erode their confidence and interest. For high-profile sporting events in the Greater Bay Area, these issues have a particularly significant negative impact, potentially damaging the event's brand image and commercial value.

Therefore, the introduction of AI visual recognition technology is imperative to meet the needs of Greater Bay Area sports development. This technology can provide objective and accurate refereeing criteria, reduce human interference, standardize penalty standards, effectively address issues with traditional refereeing methods, enhance the fairness and enjoyment of competitions, and promote the higher-quality development of Greater Bay Area sports events [7].

4. Application Examples of AI Visual Recognition Technology in Sports Referee Assistance Systems

4.1 Case Analysis

AI visual recognition technology has been effectively applied in football matches in the Greater Bay Area. For example, during the 2024 Guangdong-Hong Kong-Macao Greater Bay Area Football Champions League semi-finals (Guangzhou Division), the organizing committee implemented a referee assistant system based on AI visual recognition technology. This system utilizes multiple high-definition cameras positioned around the field to capture real-time footage of the match. Using AI algorithms, the system analyzes the footage to accurately determine whether a player is offside. When an attacking player passes the ball, the system quickly identifies the positional relationship between the passer and receiver, as well as the positions of the opposing defenders. If an offside call is detected, the system immediately alerts the referee, who then makes the final call based on the system's information. During this match, the system generated 12 offside calls, and post-match replay verification confirmed a 92% accuracy rate, effectively reducing controversy surrounding offside calls.

AI visual recognition technology has also played a significant role in basketball competitions in the Greater Bay Area. In Round 32 of the 2024-2025 CBA regular season, this technology was introduced to assist referees in determining travel violations. The system uses cameras to track players' footwork in real time and uses algorithms to analyze the coordination between footwork and the ball. When a player commits a travel violation, the system automatically issues an alarm and marks the moment of the violation. During the competition, the system successfully identified and flagged eight traveling violations, reducing the missed call rate by 60% compared to manual refereeing, significantly improving the accuracy of calls.

4.2 Technical Functions, Advantages and Solutions to Application Problems

AI visual recognition technology enables several key functions within the Greater Bay Area sports referee assistant system. In addition to the aforementioned offside detection and traveling violation detection, it also enables action recognition, such as identifying fouls and whether a player's scoring action is complete. Furthermore, it collects real-time data on athletes running distance, speed, and number of passes, supporting event analysis and subsequent research. Furthermore, it enables real-time replay and annotation of game footage, facilitating referee review.

The application of this technology has demonstrated significant advantages. First, it improves the accuracy of refereeing decisions. Through objective image analysis and data support, it reduces the incidence of human error and ensures the fairness of the competition. Second, it reduces the burden on referees. With the help of system prompts and analysis, referees can make decisions more quickly and accurately, reducing workload. Third, it enhances the viewing experience of the competition, reduces interruptions caused by controversial refereeing decisions, and ensures a smoother game.

However, AI visual recognition technology also faces technical challenges in its application. Lighting is a common issue. Variations in lighting conditions, such as between sunny and cloudy days and between day and night, affect the quality of the camera's image capture, and thus the algorithm's recognition accuracy. To address this issue, we employ multispectral cameras and adaptive light compensation algorithms. Multispectral cameras capture richer image information under varying lighting conditions, while adaptive light compensation algorithms adjust image parameters in real time to improve image quality based on lighting variations.

Occlusion is also a prominent issue. During intense competitions, athletes often block each other, and spectators or venue facilities block the camera's view, preventing the complete capture of some critical footage. To address this issue, we implemented multi-camera fusion technology. By deploying multiple cameras at different locations on the field, we capture footage from multiple angles. We use an algorithm to fuse these multi-view images, restoring the complete field scene and minimizing the impact of occlusion. At the same time, we continuously refine our recognition algorithms to improve their ability to recognize partially occluded targets. By deeply mining and learning target features, we can accurately identify target information even when partially obscured.

5. The Impact of AI Visual Recognition Technology on the Fairness of Sports Events and Responses

5.1 The Impact and Evaluation of Fairness

AI visual recognition technology improves the fairness of sports events through various mechanisms. First, it reduces human interference. Traditional refereeing methods can be influenced by subjective factors such as a referee's emotions, experience, and preferences. AI visual recognition technology, based on objective image data and algorithmic analysis, eliminates these subjective factors and ensures fairer decisions. Second, the technology provides objective data support, providing a clear basis for referee decisions. It helps athletes and spectators clearly understand the reasons behind decisions, reduces disputes caused by information asymmetry, and enhances the transparency of events.

To assess the impact of AI visual recognition technology on event fairness, we developed a fairness assessment system encompassing multiple indicators. The accuracy of penalty judgment is one of the core indicators. By comparing the results of systematic penalty judgment and post-match playback verification, the proportion of accurate penalty judgment is calculated. Another key indicator is the reduction rate of controversial incidents. It involves counting the number of controversial incidents caused by calls before and after the technology was introduced and calculating the percentage reduction. Furthermore, this system includes subjective indicators such as athlete satisfaction with the calls and spectator perception of tournament fairness.

5.2 Application Problems and Coping Strategies

The application of AI visual recognition technology has led to controversy regarding its reliability and stability. In complex competition scenarios, the system may experience technical glitches, such as camera freezes and algorithm crashes, resulting in system malfunctions. Furthermore, the algorithm may contain vulnerabilities, leading to inaccurate recognition of certain movements or scenes. These issues can affect referees' decisions and even lead to event interruptions. To address this, it is necessary to strengthen technical R&D and testing, establish a comprehensive technical testing system, and conduct comprehensive stress, stability, and scenario-based testing on the system before competitions to promptly identify and address technical vulnerabilities. Furthermore, dedicated technical maintenance personnel should be deployed to monitor the system's operational status in real time during competitions, ensuring rapid response and resolution should any issues arise.

Data privacy and security challenges are also issues that cannot be ignored. During competitions, the system collects a large amount of athlete image data, personal information, and event-related data. This data involves personal privacy and event confidentiality. If this data is leaked during collection, storage, and transmission, it will cause losses to athletes and event organizers. To ensure data security, it is necessary to improve the data security management system and use encryption technology to encrypt data during transmission and storage. In addition, a strict data access permission system should be established to ensure that only authorized personnel can access relevant data. At the same time, regular data security assessments and audits should be conducted to promptly identify and prevent security risks.

Furthermore, issues surrounding the coordination and role definition between humans and technology are prominent. Some referees may over-rely on technology, losing their subjective judgment and unthinkingly following system prompts, even when the system displays error messages. Other referees, however, are skeptical of technology and reluctant to use it, resulting in the technology not being fully effective. Furthermore, the application of AI technology may weaken the role of referees, making spectators and athletes feel that their role is no longer relevant. To address these issues, a clear division of labor between humans and machines is necessary. AI visual recognition technology serves as an auxiliary tool, providing reference for referees, while the final decision remains with the referees. Referee training should be strengthened to familiarize referees with the system's functions and usage, enabling them to effectively integrate technology with their own experience to make informed calls. Furthermore, through publicity and education, spectators and athletes should be guided to correctly understand the role of AI technology and referees, recognizing

that technology is intended to better assist referees, not replace them.

6. Conclusion

This study focuses on the application and fairness of AI visual recognition technology in the referee assistant system for sports events in the Guangdong-Hong Kong-Macao Greater Bay Area. Through theoretical analysis and case studies, the following conclusions are drawn. AI visual recognition technology has demonstrated promising results in the referee assistant system for sports events in the Greater Bay Area, enabling various functions such as offside detection and traveling violation detection. This technology effectively improves call accuracy, reduces the workload of referees, and enhances the enjoyment of the events. By reducing human interference and providing objective data support, this technology significantly enhances the fairness of sports events. Its positive impact is evident in quantitative analysis of metrics such as call accuracy and the reduction in controversial incidents.

In the future, the development of AI visual recognition technology in sports referee assistant systems will be characterized by technological convergence and expanded applications. In terms of technological convergence, AI visual recognition technology will be further integrated with 5G, the Internet of Things, and virtual reality to achieve more efficient data transmission, more comprehensive scene perception, and a more immersive event experience. Regarding application expansion, this technology will not only be limited to current popular events. Still, it will also be expanded to more sports, such as tennis and boxing, and will play a greater role in areas such as event training and athlete health monitoring.

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