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INTELLIGENT COMPUTER VISION SYSTEM FOR SCORE DETECTION IN BASKETBALL

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Abstract. *Development of an intelligent computer vision system for Smart IoT basketball training and entertainment includes the development of a range of various subsystems, where score detection subsystem is playing a crucial role. This paper proposes the architecture of such a score detection subsystem to improve reliability and accuracy of the RFID technology used primarily for verification purposes. Challenges encompass both hardware-software interdependencies, optimal camera selection, and cost-effectiveness considerations. Leveraging machine learning algorithms, the vision-based subsystem aims not only to detect scores but also to facilitate online video streaming. Although the use of multiple cameras offers expanded field coverage and heightened precision, it concurrently introduces technical intricacies and increased costs due to image fusion and escalated processing requirements. This research navigates the intricate balance between achieving precise score detection and pragmatic system development. Through precise camera configuration optimization, the proposed system harmonizes hardware and software components.*

Key words: *Computer vision, intelligent score detection, basketball training system, convolutional neural networks*

1. INTRODUCTION

In recent years, advancements in technology have ushered in a new era of innovation across various domains, with sports training and exercise systems being no exception. The convergence of cutting-edge hardware, software, and data analytics has given rise to the

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development of intelligent sports training solutions that transcend traditional methodologies. Among these pioneering systems, smart basketball IoT training and gaming system presents novelty, where the core of the system is the intelligent multi-sensory vision based system for detecting scores in basketball.

This system is a comprehensive ecosystem consisting of different subsystems, each tailored to different aspects of basketball training and exercise. The most important among these subsystems is the critical domain of detection and verification of results. The effectiveness of this subsystem is critical to the overall user experience and the achievement of training objectives. While the existing mechanism for detecting results, which uses radio-frequency identification (RFID) technology, forms the base of the smart basketball IoT training and gaming system, the fundamental desire for increased redundancy and accuracy encourages research into additional methods of detection and verification.

In response to these challenges, this paper will introduce a comprehensive enhancement methodology which not only leverages the capabilities of YOLOv8's object detection but also integrates predictive analytics and robust validation mechanisms. This multifaceted approach is designed to address the inherent limitations of current detection systems, offering a more accurate mechanism for basketball score detection. By combining the advanced object detection with trajectory prediction and real-time validation, the goal is to create a system that is both precise and resilient to the dynamic nature of basketball games.

This research sets out to improve the subsystem for detection and verification of results through the integration of a vision-based approach. Adopting a vision-based subsystem introduces a host of challenges and complexities, requiring a comprehensive understanding of hardware and software intricacies.

The convergence of these challenges underscores the intricate interplay between hardware and software development, highlighting the mutually dependent relationship required for the successful implementation of a vision-based score detection system. The foundation of this lies in the discerning choice and strategic placement of cameras. While the deployment of multiple cameras offers an extended field coverage and enhanced score detection precision, it simultaneously causes a lot of technical intricacies and development costs. It is noticeable that the installation of multiple cameras requires the fusion of recorded images and the use of more powerful processing units, which greatly affects the overall price of the product.

In the following chapters, the current state of the art in smart basketball training systems is presented, followed by the convolutional neural network based system for score detection and results of vision-based detection subsystem. We address the complexities associated with hardware-software dependencies, camera selection, image fusion, and computational requirements. Through a synthesis of theoretical analysis, empirical research, and innovative design considerations, this study seeks to pave the way for a robust and accurate vision-based score detection system, elevating the smart basketball training and exercise system to new heights of efficiency and user satisfaction.

2. Literature Review

Computer vision techniques have gained significant attention in various domains, including sports analytics. In basketball games, these techniques have been applied to object detection, event classification, visual search strategies, decision-making, and shooting motion trajectory analysis [1]. The advancements in computer vision have contributed to a deeper understanding of the game and player performance, enabling better training methodologies and strategic insights for teams and coaches. Player detection and tracking in basketball analytics play a crucial role in analyzing player movements, team strategies, and individual performance. Neural networks, especially Convolutional Neural Networks (CNNs), have remarkably improved the accuracy and efficiency of player detection algorithms. Various studies have focused on player detection and tracking in sports videos, utilizing different approaches and algorithms [2]. Shitrit et al. proposed a tracking algorithm based on global appearance constraints using a CNN-based multibox detector and KLT tracker (Kanade-Lucas-Tomasi algorithm) [3]. Ramanathan et al. introduced a detection and tracking architecture combining a CNN- based multibox detector and KLT tracker, addressing the limitations of existing multi-person video datasets. In [4] Acuna presented an online detection and tracking framework utilizing YOLOv2 for detection and sort algorithms for tracking [5]. Chakraborty and Meher employed Kalman filtering to predict the ball's future position for ball tracking. In the field of basketball analytics, there has been a notable surge in research and development focused on player detection algorithms, incorporating both image-based and video-based methodologies. These algorithms utilize various computer vision techniques, extracting dynamic ellipsoidal bounding boxes from regions of interest (RoI) generated by selective search and classifying them later [6]. Video-based player detection algorithms analyse the temporal information in consecutive frames to detect players in basketball games. These algorithms track players across multiple frames, considering their appearance and motion characteristics. In [3] Recurrent Neural Networks (RNNs) trained on local features of each player were employed. The process involves video stabilization, image recognition, preprocessing, feature extraction, and image characterization using AI algorithms such as SVM (support vector machine). The system's results show improved accuracy in identifying shooting positions and locked positions of players [7]. The performance of player tracking techniques is evaluated based on metrics like tracking accuracy, precision, recall, and computational efficiency. Factors such as camera quality, player occlusions, rapid player movements, and variations in lighting conditions can influence the effectiveness of tracking algorithms. In [8] authors explored the use of machine learning algorithms, specifically neural networks, to analyse shooting performance in basketball. By leveraging data such as player characteristics, shooting positions, and environmental factors, developed a predictive model that can estimate the likelihood of a successful shot. Fu et al. [9] proposed a camera-based basketball scoring detection (BSD) method using CNN for object detection and frame difference-based motion detection. The method utilizes the real-time object detection (YOLO) to locate the basketball hoop position and the motion detection to determine basketball scoring conditions. The proposed method achieves satisfactory accuracy in the real-time scoring detection. Player detection in basketball games faces challenges such as occlusions, drastic interactions, and variations in player appearance and motion. Occlusions occur when players block each other, making it difficult to detect individual players accurately. Drastic interactions, like slam dunks or steals, can also hinder player detection algorithms [3]. Furthermore, variations in player appearance due to different uniforms, accessories, or lighting conditions can pose additional challenges. Overcoming these limitations is crucial for achieving accurate and reliable player detection in basketball analytics [4]. Single-player tracking algorithms focus on tracking a specific player of interest throughout a basketball game, useful for analysing individual player performance, movement patterns, and contribution to team strategies [10]. In contrast, multiple-player tracking algorithms aim to track all players simultaneously in a basketball game and it is particularly challenging compared to the multiple object tracking (MOT) in other scenes due to various factors: visual similarity among players in the same team, complex interactions between players, and frequent and severe occlusions [11]. These algorithms consider interactions between players and employ techniques like multi-object tracking, data association, and graph-based methods. In [12] the detection of basketball players was performed using HOG (Histogram of Oriented Gradients) descriptors and an SVM classifier. Multiple-player tracking enables comprehensive analysis of team dynamics, spacing, offensive and defensive strategies, and collective player performance. Computer vision techniques have been utilized to automate the analysis of basketball games, enabling the recognition of player actions, event classification, and tactical analysis. Wu et al. [13] proposed an ontology-based approach that leverages global and collective motion patterns for event classification in basketball videos. They constructed a hierarchical ontology and utilized SVMs to achieve accurate event recognition. In contrast, [14] introduced a fusion method that combines motion patterns with key visual information, exploring the use of deep neural networks alongside traditional machine learning techniques. Long et al. [15] presented an innovative approach to recognize basketball player actions using the image-based bi-directional Long Short-Term Memory (Bi-LSTM) and Sequence-toSequence models. Their study achieved high correlation coefficients, indicating promising results in the action recognition. Incorporating deep CNN is suggested to further enhance the accuracy of the recognition system. The analysis of screen strategies in basketball videos has been a topic of great interest. T. S. Fu, H. T. Chen, C. L. Chou, and W. J. Tsai [11] focused on analysing screen strategies in broadcast basketball videos using player tracking techniques. Screens are important tactical manoeuvres used by teams to create scoring opportunities, space for shooters, or confuse opponents' defence. By combining computer vision techniques and player tracking, the authors proposed a method to automatically detect and analyse screen actions in basketball videos. The method involves player detection and tracking, screen detection, and screen action analysis. The authors utilize appearance-based features and motion information for player tracking. Event tactic analysis and activity recognition in basketball games have been explored using computer vision techniques [16]. Huang et al. conducted event tactic analysis based on broadcast sports video, including basketball. Their work delved into the analysis of sports events from video footage, encompassing player movements, tactical strategies, and gameplay dynamics. Activity recognition and action classification in basketball games are achieved by analysing player tracking data and video footage. Player tracking is performed using a combination of appearance-based features and motion information [17]. These classifications provide valuable insights into player performance, tactical decisions, and team strategies. Player tracking data allows for in-depth tactical analysis in basketball. By analysing the movements and interactions of players, algorithms can identify offensive and defensive strategies, spatial patterns, pick-and-roll plays, and other key tactical elements. This analysis helps coaches and teams understand their opponents, devise effective game plans, and optimize player positioning and decision-making [18]. By integrating deep learning-based object tracking techniques with player tracking data, it becomes possible to accurately track players in real-time and analyse their movements and pass relationships on the basketball court [19]. This combination enables a comprehensive evaluation of overall performance by incorporating player tracking information with statistical analysis. Additionally, accurate trajectory prediction of basketball movements using deep bidirectional LSTM and mixture density network has been studied [20]. This prediction is essential for various applications in sports analytics, such as player performance evaluation, game strategy planning, and real-time decisionmaking. In [21] authors conducted research on the prediction of shot success for basketball free throws by studying visual search strategies. They investigated the relationship between visual search behaviour and shooting accuracy, providing insights into the cognitive aspects of shooting performance. Zuccolotto et al. [22] investigated the modelling of scoring probability in basketball using big data analytics. The study focused on understanding the effect of shooting under high-pressure conditions and provided insights into scoring patterns and decision-making in critical situations. These papers and studies contribute to the body of knowledge related to player detection, player tracking, event classification, screen strategy analysis, activity recognition, shooting accuracy prediction, and modelling scoring probability in basketball. By utilizing various computer vision techniques, machine learning algorithms, and deep learning models, researchers aim to improve the accuracy, efficiency, and comprehensiveness of basketball analytics. Continuous evaluation and refinement of these techniques are crucial for reliable and insightful analysis of basketball games.

3. SYSTEM ARCHITECTURE

In the pursuit of developing an intelligent computer vision system for score detection in basketball that seamlessly blends technical innovation with commercial viability, a sensible hardware solution is paramount. The following paragraphs delve into the details of this hardware solution, giving a complete overview of its technical complexities while also carefully considering practical and business aspects.

To ensure durability and minimal susceptibility to damage, the hardware solution recommends the integration of a single camera discreetly positioned behind the backboard, directly above the basketball hoop (Fig. 1). This strategic placement not only precludes potential damage from ball impacts during shooting practices and games but also eliminates the need for additional infrastructure around the court.

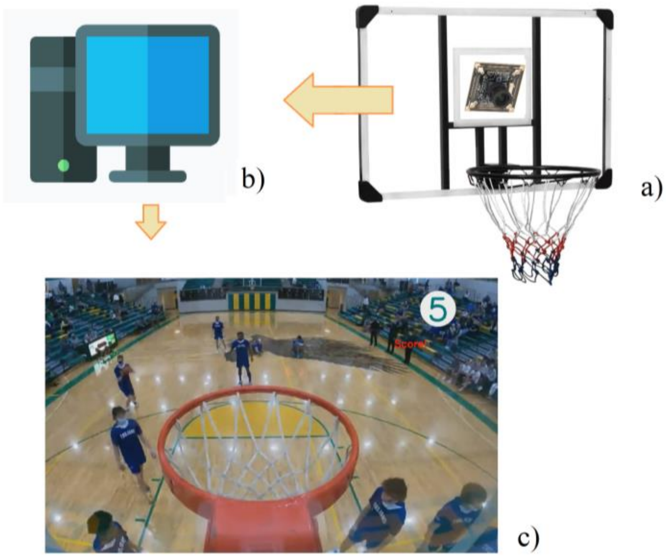

Fig. 1 Functional scheme of Vision Based Basketball Score Tracking System: a) Image aquisition using 2MP camera module with the wide-angle lens; b) Data processing; c) Output results presented within the camera view

The most important part of the hardware configuration is the selection of an appropriate camera with attributes that harmoniously fulfill the system's objectives. The camera, which is fundamental to accurate score detection, requires a fisheye lens with an exceptional 170 or 180-degree field of view. This vision sensor covers large scene, basketball hoop and court, as shown in Fig. 1. This expansive perspective facilitates comprehensive court coverage and facilitates ball tracking as it crosses the hoop. An example of a candidate that meets these requirements is the 2MP 1085P H.264 UVC fisheye video camera board.

The adoption of a fisheye lens is underpinned by its unique optical characteristics, particularly its ability to capture a wide panoramic view with minimal distortion. This attribute is of paramount importance in a dynamic basketball court environment, where tracking the trajectory of the ball necessitates a lens that can capture its movement across various spatial dimensions. The inherent curvature of the fisheye lens allows it to encompass a significant field of view, enhancing the system's ability to detect shooting events with exceptional accuracy.

Furthermore, the combination of the fisheye lens and camera resolution contributes to the acquisition of high-quality images, facilitating accurate ball tracking and spot detection. The proposed hardware solution thus overcomes technical pragmatism, embracing commercial viability while at the same time strengthening the accuracy and robustness of the system.

Enhancing the carefully designed hardware solution is a sophisticated software framework that relies on the capabilities of YOLOv8. YOLOv8 [19], an advanced object detection algorithm, serves as the foundation for the system's image analysis and detection of scoring events, while highlighting importance and practical application within the context of the intelligent computer vision system for score detection in basketball.

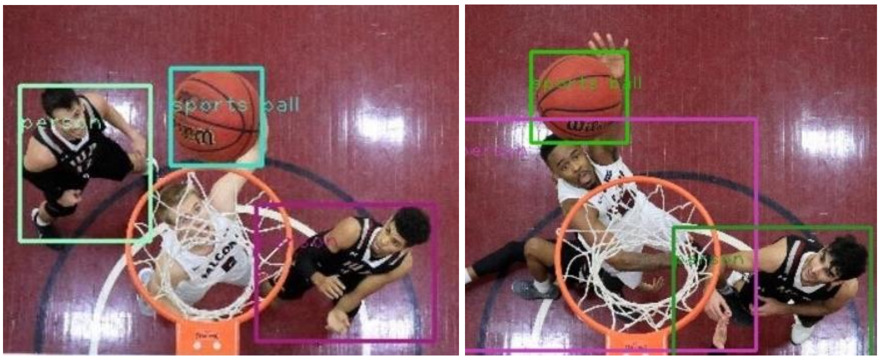

Fig. 2 Players and ball segmentation

YOLOv8, renowned for its efficiency and accuracy, employs a single convolutional neural network to simultaneously predict object classes and their associated bounding boxes in real-time. This real-time processing capability aligns seamlessly with the dynamic nature of basketball gameplay, facilitating a prompt and accurate scoring event detection. The utilization of YOLOv8 addresses a critical facet of the system's development: the ability to instantaneously recognize and locate the basketball as it traverses the hoop (Fig. 2).

4. Visual Score Detection Methodology

The process of score detection begins with a camera equipped with a fisheye lens capturing a panoramic view of the court, including the basketball and hoop. This image is subsequently fed into the YOLOv8 algorithm, which should identify and track the position of the basketball in the frame. The YOLOv8's inherent ability to handle complex scenes and rapidly changing object positions should empower it to robustly track a basketball, even amid the frenetic motion inherent in a basketball game. The integration of YOLOv8 should leverage the algorithm's adaptability to varying environmental conditions, ensuring consistent performance regardless of factors such as lighting changes or player movements.

To enhance YOLOv8's performance within the specific context of basketball score detection, custom training and optimization are undertaken. A custom dataset of basketball gameplay images was curated, derived from public domain basketball videos, capturing a wide range of scenarios and score-related events. The neural network undergoes training to specialize in recognizing basketballs and accurately predicting their spatial coordinates, enabling robust score detection.

The integration of YOLOv8 as an object detection algorithm within the intelligent computer vision system for score detection in basketball introduces promising advancements. However, it still reveals inherent limitations that require thoughtful consideration. While YOLOv8 demonstrates proficient object recognition within the dynamic basketball court environment, several critical drawbacks undermine its applicability for comprehensive score detection.

Foremost, YOLOv8's performance in detecting the basketball across consecutive frames during image acquisition exhibits variability. This inconsistency raises concerns about its reliability, potentially leading to missed scoring events. Furthermore, YOLOv8's deficiency in ball tracking impedes real-time trajectory monitoring, limiting its predictive capabilities and accurate analysis of ball movement.

Notably, YOLOv8's architecture lacks inherent mechanisms for recognizing scoring events, hindering the system's autonomous ability to identify when the basketball successfully passes through the hoop. Consequently, the system remains reliant on supplementary interventions to determine and validate scoring occurrences.

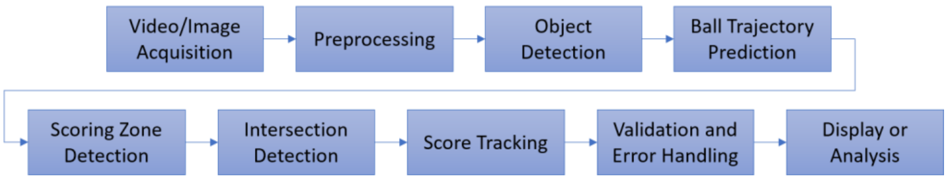

Fig. 3 Methodical process improvement for accurate basketball score detection

To address the limitations of the object detection algorithm, a comprehensive enhancement methodology is proposed (Fig. 3). This approach amalgamates the YOLOv8's object detection with predictive analytics and validation mechanisms. By strategically integrating these elements, the enhanced system aims to overcome the shortcomings of YOLOv8 and provide the accurate basketball score detection.

1. Initialize:
    *scoreCoun*t = 0
    set *ScoreZoneCoordinates*
    set *exclusionZones* (e.g., timeout areas)
    previousBallPosition = null
2. Video/Image Acquisition:
    Start capturing *video_frame*
3. FOR *video_frame*:
    Preprocessing:
        Resize *video_frame* to *standardized_dimensions*.
        Apply filtering techniques to *video_frame*.
        Adjust color balance to *video_frame*.
    Object Detection using CNNs from *video_frame*:
        Identify *court elements* and store in *courtElementsLis*t.
        Identify *players* and store in *playersList*.
        Identify *basketball* and store its position in *currentBallPosition*.
    IF *previousBallPosition* is not null:
        Ball Trajectory Prediction:
            Use mathematical models to compute *projectedPath* from *previousBallPosition* to *currentBallPosition*.
        Scoring Zone Detection: Define the scoring zone near the hoop using Intersection Detection
            IF projectedPath intersects with the scoring zone:
                Score tracking: *scoreCount* = *scoreCount* + 1.
    previousBallPosition = *currentBallPosition*.
    Validation and Error Handling:
        Listen for referee announcements.
        Check for intersections with *exclusionZones*.
        IF any inconsistency detected:
            Apply error correction techniques and adjust *scoreCount* if necessary.
4. Display and Analysis:
    Display *scoreCount* in real-time.
    Compute statistical insights.
    Integrate with external analysis systems.
5. END

The proposed methodology entails a sequential progression of key steps, described in a form of a pseudo-algorithm above. After defining constants and setting the boundary conditions upon the Initialization phase, the methodology starts with the Video/Image Acquisition step, which involves the strategic placement of cameras above the hoop to capture comprehensive visual data of the basketball court. Preprocessing techniques are applied to optimize video frames or images, encompassing resizing, filtering, and colour balance adjustments. The pivotal process of Object Detection employs advanced algorithms, notably convolutional neural networks (CNNs), to accurately identify court elements, players, and the basketball itself. Ball Trajectory Prediction leverages mathematical models to anticipate the basketball's path based on its tracked positions over time. Scoring Zone Detection defines a specific area proximal to the hoop, employing geometric shapes or predetermined coordinates to delineate potential scoring events. Intersection Detection then monitors the projected ball trajectory, facilitating the identification of intersections with the defined scoring zone. Score tracking contributes to an ongoing tally of successful scores, incrementing the count upon detecting intersections. Validation and Error Handling mechanisms should be implemented to ensure precision and to encompass cross-referencing with referee announcements, timeout-based exclusion zones and error correction techniques (see Fig. 4). Finally, Display and Analysis leverage the accumulated score data for real-time presentation, statistical insights, and integration with broader analysis systems, culminating in a comprehensive and functional framework for accurate basketball score detection.

Fig. 4 An example of missdetection of a YOLOv8 model

YOLOv8 serves as a robust foundation for object recognition, but its limitations necessitate a comprehensive methodology to achieve accurate and real-time basketball score detection. The interplay between YOLOv8 and the proposed enhancement underscores the potential to advance sports training systems, elevating the intelligent computer vision system for score detection in basketball to new heights of accuracy and functionality.

5. Conclusion and Further Research and Implementation Direction

In this study, we embarked on the creation of an intelligent computer vision system, designed to revolutionize basketball score detection by merging cutting-edge computer vision techniques with machine learning algorithms. Our proposed methodology provides a comprehensive framework encompassing camera-based image acquisition, preprocessing, object detection, trajectory prediction, scoring zone delineation, intersection analysis, real-time score tracking, validation mechanisms, and display functionalities. This integration holds tremendous promise in increasing the accuracy and reliability of score tracking in basketball.

However, the successful implementation of such a system requires rigorous calibration, parameter fine-tuning, and adept handling of specific challenges inherent to basketball courts and video feed conditions. Overcoming challenges in computer vision, like occlusions, rapid ball motions and fluctuating lighting situations is imperative for achieving accurate score detection. Additionally, achieving the real-time processing capabilities is a pivotal factor in ensuring seamless integration for live applications, introducing an added layer of complexity to the development journey.

As we embark on future research and implementation directions, several avenues call for refinement and improvement of our proposed system. Continued research into advanced object detection algorithms, including potential improvements of the proposed structure or other innovative alternatives, promises the potential for more accurate and simpler ball tracking. Delving into techniques for handling dynamic player interactions, such as player screening scenarios, and integrating player-specific tracking for comprehensive analysis represent further promising avenues of research.

The successful implementation of a vision-based basketball score detection system goes beyond mere technology. By seriously addressing the challenges highlighted in this study and embarking on dedicated research and development endeavors, this innovative technology could pave the way for transformation for the field of basketball training, analytics and audience engagement. The journey towards this visionary evolution continues to be full of possibilities, highlighting the limitless potential to reshape the future of basketball through the fusion of computer vision and machine learning.

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