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Recognizing jump patterns with physics-based validation in human moving trajectory

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ABSTRACT

This paper presents an approach to recognize jump patterns in human moving trajectory, differentiating jump tracks from planar moving tracks. Since human moving trajectory is one of the most informative representations for content understanding and event detection, trajectory-based video analysis has been gaining popularity. However, a jump action typically leads to violent change in human moving trajectory, since the person suddenly leaves the original plane on which he/she has been moving. The abnormal tracks of the trajectory would influence the performance of trajectory-based video analysis. Hence, differentiating jump tracks from planar moving tracks is of vital importance, not to mention that jump actions typically imply significant events, especially in sports games. In this paper, volleyball videos are used as case study to demonstrate the effectiveness of our proposed jump pattern recognition approach. We derive player trajectory by head tracking, analyze the movement of each player, and recognize potential jump tracks in player trajectories based on two important characteristics: (1) jumps cause pulse-like tracks in the trajectory and (2) the extensions of such tracks go through the vanishing point of vertical lines in the scenes. Finally, the jump positions/heights are estimated, in addition to the planar moving trajectory of each player on the court ground. The experiments show that satisfactory results can be obtained with the proposed recognition scheme.

1. Introduction

1.1. Motivation

The rapid advance in video production technology inspires manifold research issues, including content-based media analysis [1,2], copyright protection [3,4], video coding [5], etc. Especially, the proliferation of digital videos necessitates the development of automatic systems and tools for sematic video content understanding, analysis, and retrieval. Most of the traditional approaches rely on low-level features. However, humans interpret video in terms of semantics rather than low-level features. The demand for automatic video understanding and interpretation requires the mid-level representations mapping from low-level features to high-level semantics, such as shot class, camera motion pattern, color layout, object shape and object trajectory [1,2,6,7]. Object trajectory is one of the most informative representations which are frequently used by humans to analyze events. Hence, trajectory-based video analysis [8–14] has been gaining popularity. In human moving trajectory, a jump action typically leads to a violent change since the person suddenly leaves the original plane on which he/she has been moving. The abnormal tracks of the trajectory are likely to influence the trajectory-based video analysis. Hence, differentiating jump tracks from planar moving tracks is of vital importance. Furthermore, jump actions typically imply significant events, especially in sports games. For example, jump is related to *attack*—the most effective way to score in volleyball. As an important multimedia content, sports video has attracted considerable research efforts due to commercial benefits, and demands of entertaining functionality from the audience [6,7,12–24]. While some approaches of event detection and tactic analysis in sports video have been developed based on player trajectory, the situation of player jumping has rarely been considered in the literature. Hence, we are motivated to recognize jump patterns in human moving trajectory so as to differentiate jump tracks from planar moving tracks.

1.2. Related works

Object trajectory is one of the most informative mid-level representations which can bridge the semantic gap between low-level features and high-level events. Piciarelli et al. [8] propose a trajectory clustering method for video surveillance and monitoring sys-

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tems wherein the clusters are dynamic and built in real-time. The obtained trajectory clusters can provide proper feedback to the low-level tracking system and collect valuable information for the high-level event analysis modules. Su et al. [9] link the local motion vectors across consecutive video frames to form "motion flows," which are recorded and stored in a video database. For video retrieval, noise motions are filtered out and the retrieval process is triggered by query-by-sketch or query-by-example. Assuming trajectory information is already available, Bashir et al. [10] present an efficient motion trajectory-based indexing and retrieval mechanism for video sequences, aiming at solving the problem of trajectory representation when only partial trajectory information is available due to occlusion. Hsieh et al. [11] propose a hybrid motion-based video retrieval system through trajectory matching. First, a curve fitting technique is used by a sketch-based method to interpolate some missing data for the associated control points so that the visual distance between a pair of trajectories can be measured. Then, a string-based scheme is adopted to compare the two trajectories according to their syntactic meanings. With the help of the syntactic distance, a large number of inappropriate candidates can be filtered out and the accuracy of video retrieval can be greatly enhanced.

There has been an explosive growth in the research area of sports video analysis due to the large audience base and the tremendous commercial value. Zhu et al. [12] analyze the temporal–spatial interaction among the ball and the players to construct a tactic representation, *aggregate trajectory*, based on multiple trajectories in soccer video. The tactical patterns are analyzed using the tactic representations which include play region and aggregate trajectory. Yu et al. [13,14] present a trajectory-based algorithm for ball detection and tracking in soccer video. The ball size is first estimated from reference objects (goalmouth and ellipse) so that sequences of ball candidates can be detected and connected into potential trajectories. Finally, the true trajectory is extracted from these potential trajectories by a Kalman filter-based verification procedure. Analyzing tennis video, Han et al. [15] detect the court net and court lines for camera calibration. Players are tracked by the mean-shift method with their real-world positions being used to classify events of service, net approach, and baseline rally. Based on the camera modeling of [15], Han et al. further propose a mixed-reality system in [16]. By changing the parameters of the original camera, a variety of mixed-reality scenes can be synthesized for scene visualization on mobile devices. Luo et al. [17] interpret and analyze human motion in sports video using video object extraction, semantic event modeling, and the Dynamic Bayesian Network (DBN) for characterizing the spatial–temporal nature of the semantic objects. Zhu et al. [18,19] recognize the player actions by considering the movement of body parts for semantic and tactic analysis in tennis video. The *affective* features which simulate a user's emotion are extracted from player actions and trajectories for highlight ranking. Our previous works [20–22] perform physics-based ball tracking in sports video to provide trajectory-based game analysis, such as pitch evaluation in baseball, set type recognition in volleyball, and shooting location estimation in basketball.

To meet the sports-professional's requirement, Hu et al. [23] propose a robust camera calibration method for broadcast basketball video, which extracts player trajectories by a CamShift-based tracking method and maps player trajectories to the real-world court model. The player position/trajectory information is further utilized for professional-oriented applications, including wide-open event detection, trajectory-based target clips retrieval, and tactic inference. However, they do not mention the case of player jumping, which often happens in basketball. Thomas et al. [24] present a particle filter-based approach to track players in beach volleyball using a single camera. With camera calibration, the player trajectory can be mapped to real-world court plane. However, the players are off the ground plane during jumps, resulting in incorrect estimation of the real-world player positions. Fig. 1 gives a sample result of [24]. One can see that a jump leads to an abnormal track in the trajectory, which may be misinterpreted as a movement of the player across the center line of the court.

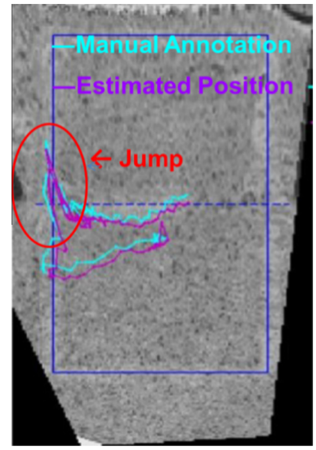

Fig. 1. Player tracking result of [24].

1.3. System framework and contribution

With regard to the foregoing limitations of existing works, we propose a video analysis system for jump pattern recognition in this paper. Fig. 2 illustrates the flowchart of the proposed framework, which contains three main components: camera calibration, head tracking, and the core module—jump pattern recognition. Utilizing a set of corresponding points, the camera calibration aims to compute the geometric transformation between image positions and real-world coordinates. Assuming that the information of each player's height is available, the "ground" trajectories of players over frames are derived by mapping the tracked head positions onto the court plane with the above transformation. Then, the jump patterns in these trajectories are recognized, with the associated jump points/heights estimated. Since this paper mainly focuses on the approach of jump pattern recognition and validates the effectiveness of the proposed method, we choose less complex test sequences of 2-on-2 volleyball games where players rarely occlude one another.

The main contributions of our work are summarized as follows. Jump is an important and frequent action, especially in sports games, but it is rarely mentioned and considered in the literature. Hence, we put forward a jump pattern recognition framework based on some important characteristics. First, it is well known that the extensions of vertical lines in the video frame intersect at a vanishing point. In this paper, we further identify that extensions of pulse-like tracks caused by jumps in a player's moving trajectory will also go through the same vanishing point. To the best of our knowledge, this characteristic has never been used or even been mentioned in the literature. Thus, an effective jump track detection approach based on this newly observed characteristic is designed. Furthermore, considering the theorem of gravitational acceleration and Newton's Second Law of Motion, a physics-based approach is proposed to validate the detected jump tracks for possible reduction of false alarms. In general, jump pattern recognition can be extensively applied to many domains to detect jump-related events, such as attack in volleyball, dunk in basketball, etc. On the other hand, the ability of differentiating the jump tracks