2D Trajectory-based Position Estimation and Tracking of the Ball in a Basketball Video

Bodhisattwa Chakraborty[1] and Sukadev Meher[2]

[1, 2] Department of Electronics and Communication Engineering,
National Institute of Technology, Rourkela
Rourkela, Odisha. Pin 769008, India

Abstract. In this paper, the problem of ball detection-and-tracking in a real time video is addressed. The presence of many moving objects in the background in a sports video makes ball detection a very difficult job. Added to this, the ball-images are also get deformed due to the high speed movement of the ball. It is very difficult to correctly detect and track a ball directly in a sports video. In this paper, a trajectory based ball-detection-and-tracking method is proposed. Using the trajectory information the ball locations are estimated and finally the ball is efficiently tracked along the trajectory.

1 Introduction

The analyses of sports video have created a lot of enthusiasm among researchers. The game videos have rich multimedia contents and can be commercially harnessed. Key areas of sports video analysis are shot classification, highlight extraction and object tracking.

Previous research works shows different ways of shot classification in a sports video based on various multimedia features like audio, speech, colour distribution, camera motion and edge distribution [1]. Highlight extraction has gained much interest in the recent era to provide a compact summary of a long game to the viewers. Many research works show efficient highlight detection technique from broadcast sports video based on audio analysis [2] and marker detection [3]. Object tracking is one of the most important aspects of sports video analysis. It has been extensively used to detect and track the players and the ball in a sports video. Common tracking technique used direct detection methods based on Kalman filter based tracking [4] and circular Hough transform based ball detection-and-tracking using neural classifier [5]. Another approach of tracking is based on trajectory information of the moving objects in the frame [6], [7], [8]. While some algorithms are based on 2D trajectory analysis [6], [7], few used more complex 3D trajectory analysis [8], [9] for more detailed representation using multiple cameras.

In this paper we discussed the trajectory-based ball detection-and-tracking algorithm with trajectory interpolation to find out the missing ball location along the ball flight path due to occlusions and merging of the ball image with players and backboard borders.

The rest of the paper is organized as follows. In Section 2, the proposed method is presented. Section 3 gives an overview of the process of moving object detection. Section 4 presents the method of ball candidate identification using various constraints like shape, size and compactness. In Section 5 the idea to plot the trajectories of ball-like objects and to extract the ball trajectory from the group of potential trajectories is presented. In this section the trajectory interpolation method is also discussed to determine the missing ball locations in the frame. Experimental results are analysed in Section 6. Finally the paper is concluded in Section 7.

2 Proposed Method

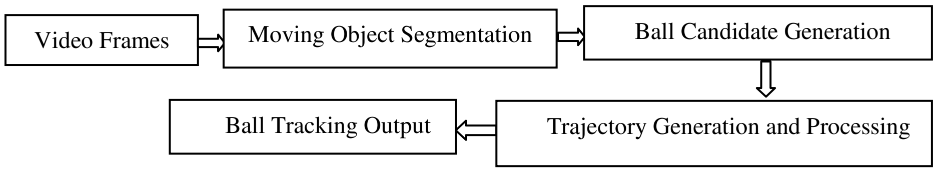


Fig. 1. Block diagram for position estimation and tracking of a basketball from a real time video.

The flowchart of the proposed method is shown in Fig. 1. The first step is to segment out the moving objects in every frame which is done using background subtraction method taking three consecutive frames for concurrent processing. The ball candidates along with several ball-like objects are generated among which the ball candidates are identified using several filters based on size, shape and compactness. The deformation of the ball image due to ball speed and occlusion, it becomes very difficult to detect the ball properly. Hence a set of 2D trajectories are generated by plotting the centroid locations of the ball candidates over time (i.e. the number of frames). The true ball trajectory can be identified by analysing the physical motion of the ball. Trajectory interpolation is done to find the missing ball positions and finally the computed trajectories are superimposed on the original frames to track estimate the ball position along the trajectory.

3 Moving Object Segmentation

The moving objects present in a video frame are segmented out by using background subtraction method. The background subtraction can be done by using the simple frame differencing method. In this method, the intensity difference of every two consecutive frame is calculated and thresholded to obtain foreground pixels as shown in Eq. (1).

$$Intensity_n(x, y) = \begin{cases} 255, & if \left| Intensity_n(x, y) - Intensity_{n-1}(x, y) \right| > T_s \\ 0 & Otherwise \end{cases} \quad (1)$$

where n is the number of frames in the video sequence and T_s is the threshold value. In case of fast moving objects like a ball, the *two-frame differencing techniques* gives erroneous results as it generates many "ball-like" objects. To incorporate with this, we use a *three-frame differencing technique* [10] where we use three consecutive frames instead of two. Morphological opening, closing and dilation operations are performed to fill the gap between the segmented images. To detect the significant discontinuities in the intensity values in the segmented images, an edge detection method is used.

4 Ball Candidate Generation

Many objects in a frame look like the ball after segmentation. On the other hand, the ball shape gets deformed due to the motion. To deal with this, we employ some filters to efficiently detect the ball candidates such as, size filter, shape filter and compactness filter. The objects which satisfy the constraints are considered as the ball candidates.

4.1 Size Filter

The ball size may vary in frame to frame because of the motion of the ball and location of the ball with respect to the camera. For a video of frame size 640 × 480, analytical result shows that the basketball size should fall in the range [20, 70].

4.2 Shape Filter

In many frames, the ball image does not look like a circle. A threshold for the shape filter is defined which is set to be 4 for the video data set used in this algorithm. The objects having the aspect ratio within the range [1/4, 4] are retained.

4.2 Compactness Evaluation

In order to filter out the non-ball objects more specifically, the compactness filter is used. The degree of compactness C_d is defined in Eq. (4),

$$C_d = S_{ob} / A_{rec} \tag{2}$$

Where S_{ob} is the size of the object and A_{rec} is the area of the smallest rectangle drawn around the circle. The threshold of compactness filter is to be chosen as 50%. All objects below the threshold are filtered out as non-ball objects.

5 Trajectory Generation and Processing

5.1 Candidate Trajectory Generation

In a long shot sequence of a basketball game, the ball moves in a parabolic path. Hence, a 2D distribution analysis of the ball candidates is used to determine the ball trajectory.

A set of candidate trajectories are generated by plotting the centroid locations of all the ball candidates over time. The plot represents the location of the ball candidates in each frame. In the basketball video, the ball is the continuous moving object over a number of frames. The ball trajectory can be identified from the set of candidate trajectories as one with a smooth and relatively long parabolic trajectory path. The non-ball objects exhibit very short trajectories or no trajectory at all. Fig. 2 depicts the generated candidate trajectories in 2D.

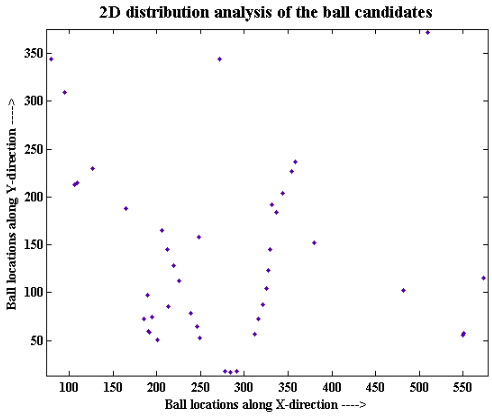


Fig. 2 Candidate trajectory generation.

5.2 Ball Trajectory Identification

To identify the ball trajectory from the set of candidate trajectories, the physical characteristics of ball motion over the frame is considered. For a long shot sequence in a basketball game, the ball trajectory is a parabolic curve due to the gravity of the earth. To identify the ball trajectory, the ball candidates in a frame are linked with the nearest neighbours in the next frame. The prediction function used to predict the ball location in the next frame is given by,

$$y = p \bullet n^2 + q \bullet n + r, p > 0 \tag{2}$$

The prediction function is initialized if the number of linked candidate is equal to 4. The best-fitting quadratic function for each ball location is calculated using the regression analysis. The ball trajectory can be isolated from the candidate trajectories as the length of the ball trajectory should be the longest among the set of trajectories. Furthermore, the prediction error is calculated as the average of the distances from the location of the ball candidate and the parabolic curve. A threshold of prediction error is defined to correctly identify the ball trajectory.

5.3 Trajectory Interpolation

In a basketball game, the ball may get occluded with the player's body part or the backboard borders. To obtain the missing ball position, a trajectory interpolation method is used in which the missing ball location is predicted. A ball trajectory is a sequence of points where the distance between two consecutive points is very less. By calculating the distance between the ball locations in consecutive frames and comparing the result with a threshold value, it is possible to estimate the location of the missing point. In the proposed algorithm, the threshold value is chosen to be 20. Once the missing ball position is correctly estimated, the ball locations are plotted and superimposed on the original frame to verify with actual ball flight path.

6 Experimental Results

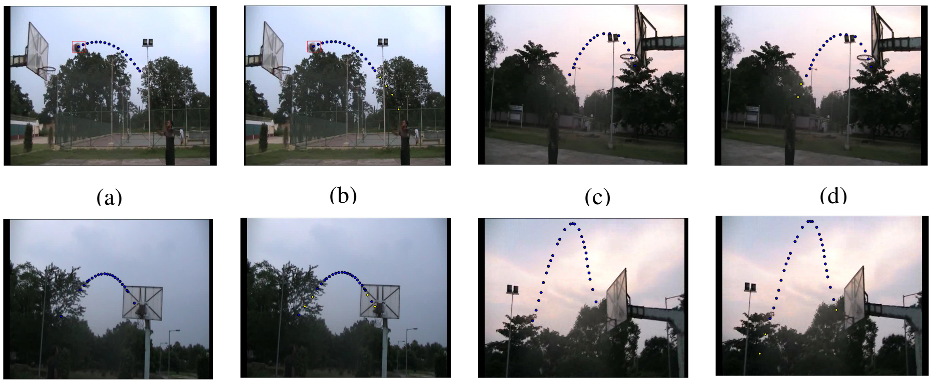
The experiment was performed on four different video sequences namely BB_1, BB_2, BB_3 and BB_4, taken using a Canon® Camcorder in an outdoor basketball court. The resolution of each video is 640 $\times$480, the frame rate is 30 frames per second. The performance of the algorithm is summarized in Table 1. The notations #tf and #bf are used to denote total number of frames in the video and number of frames containing the ball respectively. The number of frames where the ball is correctly identified along with the no-ball frames is denoted as #correct. We let #miss as the number of frames where the algorithm fails to detect the ball and #false the number of false alarms generated after the trajectory processing phase. For performance evaluation both the ball detection results and the final results after trajectory processing are shown in Table 1. It can be noticed that the proposed algorithm attains an average accuracy of 96.22% in detecting the ball, whereas it gives 100% accuracy in tracking the ball correctly after trajectory processing. The experimental results are shown in Fig. 3.

Table 1. Performance analysis of the proposed algorithm.

Video Sequence	**Ground truth**		**Ball Detection Solution**			**Final Result**		
	#tf	#bf	*#correct*	*#miss*	*Accuracy (%)*	*#correct*	*#false*	*Accuracy (%)*
BB_1	90	20	86	04	95.5	20	00	100
BB_2	50	25	46	04	92.0	25	00	100
BB_3	64	19	62	02	96.87	19	00	100
BB_4	140	29	137	03	97.85	29	00	100
Total	**344**	**93**	**331**	**13**	**96.22**	**93**	**00**	**100**

7 Conclusion

It is evident from the experimental results that the proposed trajectory based algorithm not only detects and tracks the ball correctly, but it also helps to locate the occluded ball and the ball merged with other objects in the frame. The proposed 2D trajectory analysis is very much efficient in detecting the true ball trajectory and the same method can be applied to other ball games with similar ball motion characteristics. The next area of the research includes 3D trajectory reconstruction to provide more information about the trajectory of the ball for better analysis and visualization.



(a) (b) (c) (d)

(e) (f) (g) (h)

Fig.3 Position estimation of basketball for different video sequences with missing ball position estimation. The ball location is shown by blue dots and the missing ball position is shown by yellow dots. (a), (c), (e) and (g): Estimation of the ball locations in video sequences *BB_1, BB_2, BB_3* and *BB_4* respectively. (b), (d), (f) and (h): Estimation of the missing ball locations along the ball trajectory in video sequences *BB_1, BB_2, BB_3* and *BB_4* respectively.

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