A Trajectory-Based Ball Detection and Tracking System with Applications to Shot-type Identification in Volleyball Videos

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***Abstract*—This paper presents a trajectory-based ball detection and tracking algorithm for volleyball videos to classify the different types of shots in the game. In case of volleyball games, the task of ball detection and tracking become more complex due to the presence of too many number of players in a rather small space. The direct detection methods often fail due to the high rate of occlusion of the ball image with players. The distortion of the ball image due to the effect of ball and camera motion leads to a number of wrong detection. In this paper, the trajectory information of a volleyball for different shot sequences is studied and used to estimate the ball locations. The ball candidates are generated using the shape and size features. A Kalman filter-based approach is used to generate a set of candidate trajectories. The actual ball trajectory is extracted by analysing the physical characteristics of the ball motion. The trajectory informations are then used to classify the different shot sequences in the volleyball game for better representation and analysis.**

***Index Terms*—Sports video, ball detection and tracking, trajectory-based, shot classification,trajectory growing, interpolation.**

I. Introduction

The sports video analysis is widely used and studied in recent times to add entertainment values for the viewers and is also helpful for better analysis of the game to enhance the performance of the players. The main research areas of sports video analysis includes shot classification [1], highlight extraction [2], [3] and object tracking.

Object tracking is extensively used in sports video analysis to detect and track the ball, the players or both the ball and the players together in a sports video. Many previous works shows various ways to track the ball and the players in a sports video. Seo *et al.* [4] proposed an algorithm of ball tracking in broadcast sports video (BSV) using Kalman filter based template matching and backprojection. D'Orazio *et al.* [5] used modified circle Hough transform along with neural network classifier to detect the ball. Li *et al.* [6] proposed a scheme for automatic detection and analysis of player action in moving background sports video sequences using global motion estimation with adaptive outliers filtering and automatic human body tracking. The advanced application of sports video analysis includes content insertion [7] and computer-assisted refereeing system [8].

The ball tracking in a sports video is a difficult job because the ball shape and size varies from frame to frame due to the high velocity of the ball and the occlusion of the ball with different objects in the frame. The small size of the ball with respect to the frame size complicates the task. Thus the direct detection methods based on ball size, shape and colour often give erroneous results. To overcome these problems, the trajectory-based ball detection and tracking approach [9],[10], [11] is used. In this approach, the first step is to generate a set of ball candidates for each frame. The next step is to generate a set of candidate trajectories. The actual ball trajectory is then identified from the set of candidate trajectories and the ball location in each frame can be accurately estimated.

In this paper a trajectory-based ball detection and tracking algorithm with an robust background subtraction model is proposed. The candidates trajectories are generated using Kalman filter-based prediction method of the ball locations. The physical characteristics of the ball motion is exploited to identify the actual ball trajectory from the set of candidate trajectories. The trajectory informations are then used to identify the different types of shots played in a particular volleyball video clip. The algorithm provides a simple approach of ball location estimation and shot-type recognition in volleyball games without need of any complex hardware designing.

The rest of the paper is organized as follows. In Section II, the proposed model is discussed. Section III gives an overview of the process of moving object segmentation. Section IV presents the method of ball candidate identification using constraints like shape and size. In Section V, the idea to plot the 2-D candidate trajectories along X- and Y-direction is presented. Section VI addresses the process of ball trajectory identification from the set of candidate trajectories and gives an idea of trajectory interpolation method to determine the missing ball locations in the frame. Section VII gives the idea of different shot-type identification in the video. Experimental results are analysed in Section VIII. The paper is finally concluded in Section IX.

II. PROPOSED MODEL

The proposed model of ball detection-and-tracking in a volleyball game video is shown in Fig. 1. Given a video sequence, the moving objects in the foreground are first separated using a robust model of background subtraction. The second step comprise of generating a set of ball candidates for each frame based on the size and shape constraints. To precisely detect the ball location, a trajectory-based approach is used in which a set of candidate trajectories are generated from the candidate distribution plots along X- and Y- direction separately. The ball trajectories are identified in X- and Y- distribution plot exploiting the physical characteristics of ball motion. An interpolation technique yields the missing locations of the ball along the trajectory path. The results of trajectory processing are superimposed on the original video frame to determine the exact ball locations. Using the trajectory informations, the shot type in a particular game sequence is identified. The proposed model gives excellent results for videos of different types and resolutions.

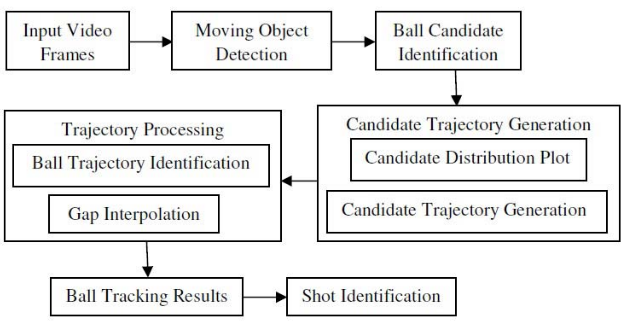


Fig. 1: Block diagram of the proposed model for position estimation and tracking with application to shot-type identification in volleyball videos.

III. MOVING OBJECT DETECTION

A robust background subtraction method has to be used to detect the moving object in the foreground without detecting the non-stationary objects in the background such as moving banners, spectators etc. To incorporate with this, median filtering based background subtraction method can be used [12]. In this method, the previous *n* frames are stored and the background is calculated as the median of the stored frames. The background is subtracted from the current frame and thresholded to determine the foreground pixels.

This method is fast and robust but the memory requirement is very high. A more efficient way is the *recursive approximation of the median filter* which is used in this work and it gives extremely good results for a fast moving object like ball. The pseudo code for this method is given below.

Algorithm 1 Recursive Approximate Median Method

Read the first frame as background frame.
Determine the absolute difference of each frame from the background.
Threshold the result to obtain the foreground pixel.
if
  The intensity value of the current pixel > intensity value of the background pixel **then**
  (background pixel value + 1)
else
  (background pixel value - 1)
end if

In this way, the background converges to an estimate where half the pixels values are greater than the background and half are less than the background. The morphological opening, closing and dilation operations are performed to remove the small gaps and to minimize the effects of background noise. Edge detection is then performed to detect the discontinuities in the intensities in every frame.

IV. BALL CANDIDATE IDENTIFICATION

Many objects form the background resemble the ball after segmentation. The banners in the background, moving body part of the players along with their uniform, portion of the net and sideline borders often generates a number of “ball-like” objects in a frame. The high speed motion of the ball and the camera motion causes the deformation of the ball image. The occlusion of the ball with players also deforms the ball image after segmentation. To identify the ball candidates, the constraints like size and shape of the ball is used. The objects which satisfy the constraints are considered as the *ball candidates.*

A. Size Sieve

The size of the ball varies in frame to frame as the ball comes closer or moves away form the camera. The ball size is also different in various videos under test. Different objects in the background like the banners, net line, court borders and the player’s body part generates many large objects after segmentation. To filter out the ball candidates, the size sieve is used. For videos with different resolutions, the generalized size of the ball ranges from 3 to 15 pixels.

B. Shape Sieve

In sports videos, the ball traverse in high speed between frames and often the ball images get distorted and not look like a perfect circle. The occlusion of the ball with player’s body part and the merging of the ball image with different objects in the background also changes the shape of the ball. Therefore, the objects which are far from being a circle are filtered out employing the shape sieve. The *roundness* of the object is defined as the ratio of the square of the circumference of the object to πr^2, where *r* is the larger value between the height and width of the object under consideration. The objects with roundness greater than 0.5 are retained as ball candidates.

V. CANDIDATE TRAJECTORY GENERATION

After the ball candidate identification phase, a set of ball candidates,$S_b(F)$, is generated for each frame *F*. The plot represents the location of the ball candidates in each frame. To generate the candidate trajectories, the ball motion in X-direction and Y- direction is analysed separately. The X and Y-direction plots are created by plotting the distribution of ball candidates against the time along X and Y-directions respectively. A set of candidate trajectories $S_T(F)$ are then generated using these plots. A Kalman filter based prediction algorithm [13], [14] is used to generate the candidate trajectories by linking the ball candidates in each frame. To initiate the prediction process, a *trajectory seed* is identified as the pair of ball candidates in two consecutive frames that are close to each other. A threshold is defined to make the decision over the ball candidates. Once the trajectory seed is determined, the Kalman filter is initialised to predict the ball locations as,

$$
\begin{aligned}
x_k &= F_k.x_{k-1} + G_k.u_{k-1} + w_k \\
z_k &= H_k.x_k + v_k
\end{aligned}
\tag{1}
$$

where x_k is the state vector, u_k is the known input vector and w_k is the process noise vector. z_k represents the measurement vector and v_k represents the measurement noise vector.

The Kalman filter predicts the ball location in each frame and the predicted location is then verified with the actual location of the ball candidate in the respective frame. If there exists a ball candidate near the predicted location, the trajectory growing is continued by updating the parameters of the Kalman filter. The best-fitting function to draw the candidate trajectories are computed for each ball candidate in X- and Y- direction plot using the following equations.

$$
\begin{aligned}
y &= a \cdot n^2 + b \cdot n + c, \quad c > 0 \\
x &= d \cdot n + e
\end{aligned}
\tag{2}
$$

The trajectory growing process terminates when the number of frames for which the verification fails (F_m), exceeds a judicially selected threshold value (T_m).

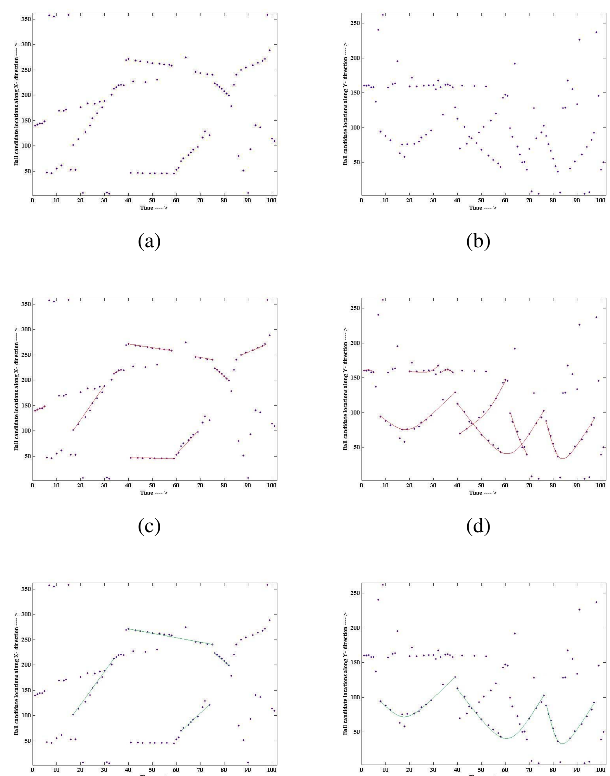
VI. TRAJECTORY PROCESSING

A. Ball Trajectory Identification

Once the candidate trajectories are generated, the ball trajectory can be identified by analysing the horizontal and vertical motion of the ball. For different types of volleyball shots like *"serve"*, *"set"* and *"bump"*, the two dimensional analysis of ball trajectory reveals the fact that the ball movement along X-direction forms a straight line despite the air friction and the motion path of the ball along the Y-direction forms a parabola or near parabolic curve due to the gravitational force of the earth. 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. For a volleyball shot sequence, the ball is the continuously moving object in a number of consecutive frames. That implies the ball generates a smooth and comparatively long trajectory path. On the other hand the non-ball objects exhibit very short trajectory or no trajectory at all. The actual trajectory created by a volleyball can be thus identified from the set of ball trajectories using the length and shape properties of the trajectory.

The complete candidate trajectory generation and trajectory processing algorithm is summarized as follows.

1. Select the trajectory seed for frames F_t and F_{t+1}.
2. Initialize the Kalman filter for frame F_t.
3. Estimate the ball location for frame F_{t+1}.
4. Verify the estimated ball location with the actual ball location in frame F_{t+1}.
   - 4.1 Continue the trajectory growing process if the prediction is verified in frame F_{t+1} by updating the variables of Kalman filter and continue trajectory growing process till the verified candidates.
   - 4.2 If the prediction is not verified for frame F_{t+1}, continue predicting next ball locations until $F_m > T_m$.
   - 4.3 Verify the prediction for the frame F_{t+k} when $k \leq T_m$.
   - 4.4 Extend the trajectory up to frame F_{t+k} and record the new trajectory.
   - 4.5 Select another trajectory seed and repeat the steps up to 4.4.
5. Find the longest trajectory (T_L) from the set of candidate trajectories $S_T(F)$ by checking the number of linked candidates in consecutive frame $L_n \geq T_n$, where T_n is the threshold.
6. Check whether T_L forms a straight line in the X- distribution plot and a parabola or near parabola in the Y- distribution plot.
7. Identify T_L as the ball trajectory.



(a) (b) (c) (d) (e) (f)

Fig. 2: Illustration of candidate trajectory generation and ball trajectory identification using X- and Y-distribution analysis.

Fig. 2 shows the different phases of trajectory generation and identification. The X- and Y- distribution plots for the ball candidates are shown in Fig. 2 (a) and Fig. 2 (b) respectively.

Fig. 2 (c) - (d) shows the set of candidate trajectories while Fig. 2 (e) - (f) gives the identified ball trajectories for different shot sequences in X- and Y- direction respectively.

B. Gap Interpolation Process

The ball is often wrongly detected because of occlusion, merging or deformation. This leads to a number of "missing" ball locations along the trajectory where there exists no ball candidate close to the estimated ball location. The missing ball locations can be estimated using the Kalman filter based prediction method. When the prediction fails to verify the ball location in a particular frame, the Kalman filter continues to predict the ball locations for a next few frames until the prediction is verified. The trajectory growing process terminates when the number of consecutive frames for which the verification fails, exceeds a threshold value. The threshold is set to *5* for this work. The ball positions are then determined by superimposing the results of trajectory processing and trajectory interpolation onto the original frame.

VII. Shot Classification

There are mainly four types of shots used in a volleyball games: *serve*, *bump* or *pass*, *set* and *spike*. In a *"serve"* sequence, the ball moves almost along the net line and the eccentricity of the parabolic curve generated by the ball trajectory has a large value. The volleyball is served from the extreme end of the court, so the starting point of the ball trajectory can also be used to identify the *serve* sequence. The *"bump"* shot can be identified as a parabolic curve formed due to the ball motion having eccentricity value of nearly 1. In this shot, the players passes the ball to a fellow team member or sends the ball directly to the opponent's court, thus the ball traverse a long parabolic trajectory path. In a *"set"* shot sequence, the eccentricity of the parabolic curve generated due to the ball flight is of much shorter in length and the eccentricity of the parabola is less than 1. The *setter*, i.e. the player who sets the ball for a striker to spike, is positioned near the net. Thus *set* shot sequence can be identified as one which originates near the net and follows a shorter parabolic trajectory path. The *"spike"* shot is used to score points and the ball moves much faster than in other shots, thus making it very difficult to detect the ball. The *spike* shot can originate from any position at the court except the extreme end point of the court. The most common location of a striker is near the net and the ball trajectory formed by a *spike* shot is almost a straight line.

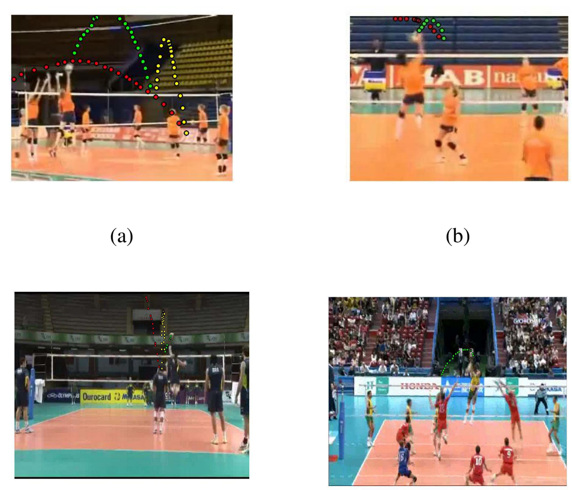
VIII. Experimental Results

The experiments are performed with six different video clippings of volleyball downloaded from internet. The videos are of different resolution, thus providing a challenging task for ball detection and tracking. The performance analysis of the proposed model for ball detection and tracking is given in Table I. A ball is said to be *"detected"* when the algorithm correctly detects a ball in a ball frame and does not detect a ball in a no-ball frame. The *"Ball Tracking Results"* gives the performance measure of the proposed algorithm for the trajectory based position estimation of the volleyball in a video sequence. While *"Tracked"* yields the number of frames in which the estimated ball location is matched with the actual ball locations, *"False Alarm"* gives the number of frames where the ball is wrongly detected in a no-ball frame or the ball is detected in an incorrect location in a ball frame. But the missing ball locations can be recovered using the gap interpolation method. It can be noticed that the proposed algorithm achieves an average accuracy of 91.8 % in detecting the ball, whereas the average accuracy of ball tracking using the trajectory based method is as high as 96.76 %.

TABLE II: Identification of different shot types in the volleyball game clippings

Video Sequence	Shot Type		
	Serve	***Bump***	***Set***
NZ-001	YES	YES	YES
NZ-002	NO	NO	YES
TR-001	YES	YES	YES
BR-001	NO	NO	YES
BT-001	YES	YES	YES
BT-002	NO	YES	YES

Table II shows the results of shot-type identification using the proposed method. We are mainly interested in three types of shots in a volleyball game: *serve*, *bump* and *set*. Each video contains either one, two or all three types of shots. In Table II, *YES* represents the identified shot-type for a particular video sequence and *NO* denotes that the particular shot is not present in the video clippings.



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

Fig. 3: Illustration of ball position estimation using the trajectory information and shot-type identification for different volleyball clips.

Fig. 3 shows the experimental results of ball detection and tracking and shot-type identification in a set of volleyball videos. The red dots denotes the *serve* shot, the green dots

TABLE I: Performance analysis of ball detection and tracking

Video Clips	Ball Detection Results				Ball Tracking Results		
	Total frames	*Ball frames*	*Detected*	*Accuracy (%)*	*Tracked*	*False Alarm*	*Accuracy (%)*
NZ-001	100	62	57	95	62	0	100
NZ-002	75	23	20	96	23	0	100
TR-001	90	40	29	87.7	36	4	95.5
BR-001	75	28	21	90.66	28	0	100
BT-001	70	46	41	92.8	44	2	97.1
BT-002	65	48	40	87.7	46	2	96.9
Total	**475**	**247**	**208**	**91.8**	**239**	**8**	**96.76**

denotes the *set* shot and the yellow dots denotes the *bump* shot respectively.

For performance comparison, we have implemented a Circular Hough Transform (CHT) based direct ball detection technique. The comparison results are shown in Table III. It is quite evident from Table III that the proposed method yields a much better result in terms of precision and recall in detecting the ball in the video sequences.

TABLE III: Comparison of proposed method and CHT based ball detection method

Video Clips	Proposed Method		CHT-based Method	
	Precision (%)	*Recall (%)*	*Precision (%)*	*Recall (%)*
NZ-001	100	91.93	76.0	70.97
NZ-002	100	86.97	78.7	73.91
TR-001	90.91	72.5	55.6	55.0
BR-001	100	75.0	70.7	57.14
BT-001	95.83	89.13	61.43	54.35
BT-002	96.0	83.3	58.46	52.1

IX. CONCLUSIONS

In this paper, a trajectory-based ball detection and tracking algorithm is presented for volleyball game sequences. The background subtraction technique based on adaptive approximate median works efficiently to discriminate the moving objects in the foreground. The generation of ball candidates in each video frame using the shape and size constraints reduces the number of misses as the missing ball locations due to merging and occlusion are also included as the ball candidates. The Kalman filter based prediction method generates a number of candidate trajectories. The analysis of the two-dimensional X- and Y- distribution of the ball candidates helps to identify the actual ball trajectory more reliably exploiting the physical characteristics of ball motion. Furthermore, based on the game-specific properties, atleast three different types of shots played in a single volleyball game sequence can be correctly identified exploiting the trajectory informations. This approach is different from previous approaches as it uses a complex background subtraction method and trajectory-based method in unison to detect-and-track the ball, and still yields the ball tracking result in almost real-time basis.

The same approach can be used to other sports videos to detect and track the ball for better analysis of the game. We have successfully applied a trajectory-based approach to detect and track the ball in basketball videos using the 2D distribution analysis of the ball candidates [15], [16]. We plan to use this approach for further analysis of a sports video including various event detection, more stringent shot classification and performance analysis of the players. The development of a 3D trajectory reconstruction system for better understanding of the game is also under consideration.

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