International Journal of Computer Applications (0975 – 8887)
Volume 153 – No 12, November 2016

Simultaneous Localization and Mapping for Trajectory Prediction of Tennis Ball

Zeeshan Ali Haq
Jamia Hamdard

ABSTRACT
Object detection and tracking its movement is an important aspect in today's sports broadcasting industry. It helps in post-match analysis, studying previous matches to find drawbacks in one's technique and also helps in discussion and debate. Detecting a moving object is a cumbersome technique as it involves a very complex human movement as well. In this paper, movement of tennis ball is detected, tracked and its a-priori path has been studied to predict the posteriori movement. The detection of the tennis ball is performed using Matlab. Tracking and path prediction is performed using Kalman filter. This filter works on an algorithm having two stages: prediction and updating. The ball detection accuracy of 96% has been achieved. The parameters of a moving ball that has been studied are its acceleration, process noise and measurement noise. The error found in tracking the ball while varying its various parameters is also discussed.

Keywords
Trajectory prediction, Kalman filter, objects tracking, moving object detection.

1. INTRODUCTION
Detection of moving objects in an environment, and tracking those objects are an important part in the sports broadcasting, security measures, surveillance, etc. This paper focuses on presenting an optimal solution to solve the issue of real time simultaneous object detection and tracking. For experimental purpose the object of interest has been a tennis ball which is being detected and tracked when it is in play. In the sports of tennis the ball is the most important object of concern as far as its detection and tracking is concerned [1] along with the movement of players. The importance of its detection and tracking lies in the fact that it can be reviewed for umpiring decisions, after match analysis and for future study references [2-3]

In this paper the main focus is presenting a methodology for establishing a movement of a tennis ball i.e. detection, tracking and prediction. Tracking of the ball from a video sequence is a difficult task as the movement of the ball is very fast and the size of the ball is very small as compared to the background [4]. On a tennis court, there are many objects that might pass as a tennis ball candidate thus it becomes important to segregate the ball candidate from the non-ball candidate [5].

In tennis the movement of the ball is either player controlled: spin introduced, angle and speed of hit or naturally introduced: weather condition which include wind speed and direction, pressure, and surface of court. In this paper the detection of ball is done using MATLAB, its tracking and path prediction is done by using Kalman filter based on predictor and corrector algorithm. The factors which affect the ball movement as mentioned above are used as control inputs to the algorithm.

This paper has been divided into five sections. The first section is the introduction section. In this section the problem and tis solution is discussed in brief. The section II includes the related work that has been performed in the field of object detection, tracking and trajectory prediction. The third section provides a detail description about the proposed methodology used to solve the problem. The fourth section presents the results of the experimental setup and comparisons. It also presents a discussion about the result obtained in previous works. Section five is the concluding section which summarizes the result in brief.

2. RELATED WORK
The detection of moving object plays a pivotal role in autonomous industry. This is widely used in sports broadcasting and automated surveillance. In sports broadcasting, the moving object detection is used in tennis, cricket, football etc. There are various techniques to detect the moving object and the most commonly used among them is the background subtraction method. In background subtraction method, two input frames are taken and using the background subtraction, the moving object which is in the foreground is detected. But the drawback in this method is that the camera should be stationary. To overcome this drawback, the author has proposed an approach which uses moving camera and takes the frames in the form of panorama [6]. In this method, the moving object is found using the image matching technique.

Detection of tennis ball is also performed using a method [7] for detection based on frame differencing. Using frame differencing method [8], the area of moving object is detected. The noise present is removed using morphological operation on the fragmented regions of moving object. Using the ball size filtering and ball location filtering the tennis ball is detected in the frame.

The ball detection can be considered on low-level curve detection and the curve that is detected is a circle. A popular technique for tracking a coloured ball is based on optical recognition of planer fiducial marker [9]. In this method, it finds large number of visible markers and their orientations and relative positions. Though, this method has many limitations. To overcome these limitations, a new technique is presented which uses coloured ball as known markers having the size same as that of the ball to be detected [5]. This method is robust to noise, partial occlusion and detects different coloured balls. Another method for ball tracking based on track-After-Detection method [10] which is sub-divided in to two parts: the object detection and the object tracking. The object detection is done using motion segmentation and blob classification. The tennis ball has a standard yellow colour and could be used as an important factor for blob classification [11]. A data association method for object tracking is presented which takes the measurement as independent random process [12]. It is called as Probabilistic Multi-Hypothesis Tracker (PMHT). It is based on recursion technique for tracking the object.

A single camera is used for ball detection and focuses of generation of tens ball candidate [11], [13-14]. The blobs detected, are tested for ball candidacy using size, shape and colour of the ball. The length of the tennis court is 78 feet and if the ball is hit with 1% more speed, then the ball will land 18 inches farther than before [15]. Also, if the horizontal angle of hitting is 1 degree more, the ball will land 16 inches more towards left or right depending on the direction in which the angle is increased. Thus the speed of hitting the ball, the horizontal and vertical angle determine the trajectory that the ball will take. Apart from these, the top spin and back spin introduced by the player also helps in determining the trajectory of the ball. The top spin will increase the height after the bounce whereas the back spin will reduce the height of the ball after the bounce.

The trajectory of the ball is determined by comparing all the trajectories of the objects detected in the frame [16]. The candidate trajectory which does not give the trajectory resembling the ball trajectory is discarded.

3. METHODOLOGY

In this paper the proposed method is employed for the detection, tracking and trajectory prediction of a tennis ball. The proposed method is described by the process flow diagram given in figure 1.

The first process is image acquisition. The experimental setup for image acquisition includes a Nikon Coolpix L610 camera with a 14 megapixel lens and a computer system which is compatible to the camera. The camera is mounted on a tripod stand placed at the centre of the side-lines of the tennis court. The camera mounted is used to capture a sequence of a tennis shot being played by the player. Once the sequence has been recorded, it is obtained in a form of a video file. The video file is transferred to the computer system connected with the camera which converts the video file into frame format. The frames thus acquired are used as a data set in the subsequent process.

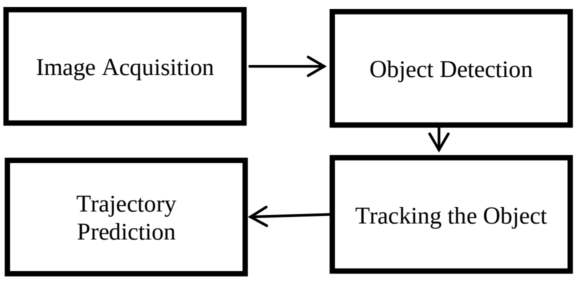

Figure 1: Process Flow Diagram

The object detection process is performed on the images acquired in the previous process. In a tennis match, moving ball is not the only object that is detected. Along with the ball, tennis players, ball boys and other objects are also detected. Thus it becomes necessary to differentiate between the ball-candidate and the non-candidates. In this process, the acquired image is used to detect the object. The parameters used to differentiate the ball candidate from the non-candidate are the size, shape, and also the standard yellow colour of the tennis ball. When the ball is hit, due to the blurring of the ball in the image acquired, the shape is not oval but is elongated. This also helps in differentiating the ball candidate from the non-candidate.

The location of the ball is determined from determining the coordinate for the centre of the ball. This can be solved using triangulation process for localization.

$$X_b = \frac{d_1 y_{32} + d_2 y_{13} + d_3 y_{21}}{2(x_1 y_{32} + x_2 y_{13} + x_3 y_{21})}$$

$$Y_b = \frac{d_1 x_{32} + d_2 x_{13} + d_3 x_{21}}{2(y x_{32} + y_2 x_{13} + y_3 x_{21})}$$

Where, X_b & Y_b are the coordinates for the location of the ball which is calculated using the concept of coordinate geometry

In the previous process the ball is detected and its location, in the form of coordinates on the court, is recorded. These coordinates helps in the tracking process of the tennis ball. For tracking of tennis ball Kalman filter – having two algorithms: predictior and updation – is used as shown in figure (2).

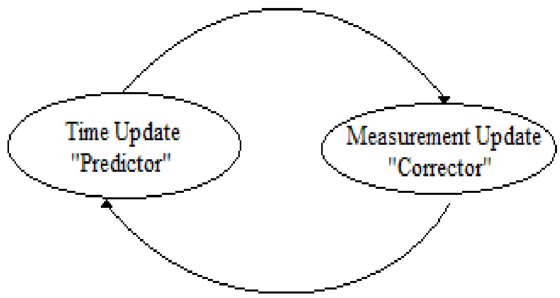

Figure 2: two step algorithm

The predictor algorithm is mathematically shown in equation (1). Here the previous position is used to find the next position. In equation (2) the error introduced between the original position of the object and calculated position of the object is calculated. This part of the algorithm is called as correction part.

$$X_k = AX_{k-1} + BU_{k-1} + W_{k-1} \quad (i)$$

$$X_k = X_{k-1} + K\left(Z_k - H_{X_k}\right) \quad (ii)$$

Where, K = Kalman gain, Z_k = actual measurement, H_{XK} = predicted measurement. After calculating the Kalman gain we use the second algorithm of the filter i.e. the updation algorithm which uses the Kalman gain to reduce the error between the original and calculated position of the object. This is performed using equation (3)

$$K_k = \frac{P_k^- H^T}{H P_k^- H^T + R} \qquad (iii)$$

Where, P_k^- = a priori estimate error covariance, H = predicted measurement, R = measurement noise covariance

After using the two step algorithm for Kalman filter, a posteriori state is estimated. This state estimate is the next position in the trajectory of the tennis ball. This is the final process of the proposed method. In this process, a-posteriori estimate of the state is calculated from the previous state, from which the trajectory of the tennis ball is to be predicted. The Kalman filter is a recursive filter and it keeps estimating the a-posteriori state. As the a-posteriori states are estimated, and the corrector equation keeps on reducing the error covariance, the trajectory of the tennis ball is determined.

4. RESULTAND DISCUSSION

To evaluate the performance of the tennis ball trajectory prediction, the results of the proposed method is shown in this section. The first section of the proposed method is the experimental setup and data acquisition. In this section a data set is formed in the form of frames acquired from the video sequence captured by the mounted camera. Sequence of frames is shown in figure (3)

The second section of the proposed method includes the detection of ball candidate from the frame. This is done using Matlab. The input to Matlab is one of the frames, and it detects the yellow coloured tennis ball.

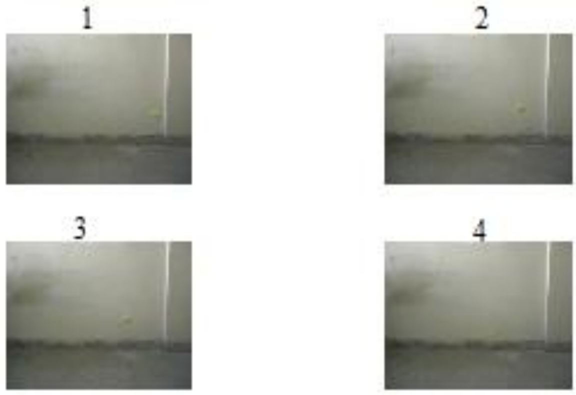

Figure 3: Sequence of Frames from the Data Set

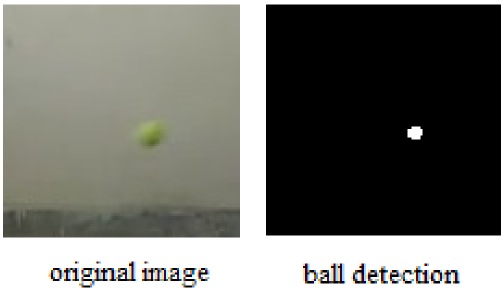

Figure 4: Detection of Tennis Ball

In [2], the detection technique used is based on frame differencing, while in this paper the technique used is the detection of standard yellow colour of the tennis ball. The precision obtained in the detection of ball in [2] is shown to be 96.08% where as in this paper the accuracy obtained is 96.7%. The problem in detection using the proposed method is when the ball is occluded by the players or racket or even the net. Also when the tennis ball is on the farther side of the court, the filtering out of noise has to be very strong.

The coordinates of the detected balls in the sequence of frames is determined and the plot in figure (5) shows the position of the ball on the tennis court. The camera used has a low frames per second thus the distance between the ball position is large. To over-come this drawback curve fitting is used which fits and smooth's the curve to the best fit. The negative coordinates on the Y-axis shows the width of the playing area reducing.

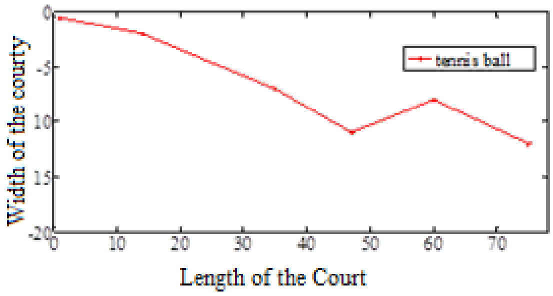

Figure 5: Coordinates of the tennis ball

The third section of the proposed method is the section where Kalman filtering of the proposed model is done using the two-step algorithm as discussed in the proposed method. The Kalman filter is first used to show the ball detection and its tracking. The result of detection and tracking is shown in the figure (6).

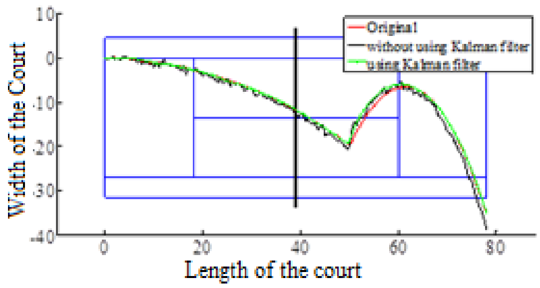

Figure 6: Tennis Ball Detection and Tracking

In the above figure the court is drawn to the dimensions of a real tennis court. The red curve shows the original position of the ball and the black curve shows the tracking of the ball without using by using only the predictor step of the two step algorithm of the Kalman filter. The green curve shows the detection and tracking of the ball by using both the predictor and corrector equation. The detection and tracking of the ball gives us the a-posteriori state estimate of the ball at times step 'k'. The accuracy and errors introduced in tracking of the ball is shown in figures (7-9). The errors introduced in the modelled system on behalf of varying the parameters used are discussed below. This is done in the form of graphs where the RMS Error is varied according to the variation in the parameters.

The graph in figure (7) shows the variation of RMS Error with according to the variation in the measurement noise.

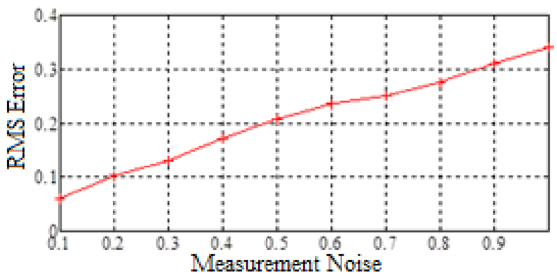

Figure 7: Variation of RMS Error with Measurement Noise

From the graph it could be seen, as the amount of measurement noise is increased in the modelled system, the Root Mean Square (RMS) Error is increased in the prediction of ball trajectory. The measurement noise, which is used to model the difference between the original trajectory and the predicted trajectory, is varied in the above graph. When the measurement noise is 0.1, the error between the predicted and original trajectory is 0.06 but as the measurement noise is increased to 1, the error introduced on the part of sensor is increased to 0.340.

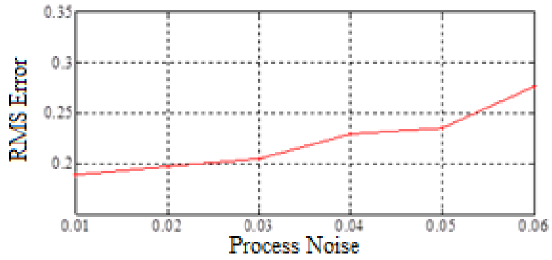

Figure 8: variation of RMS Error with Process Noise

The graph in figure (8) shown is the variation between the RMS Error and due to varying the process noise. When the process noise, which models the accuracy of the system in estimating the a-posteriori state, is varied from 0.01 to 0.06, the error in estimating the a-posteriori state increases from 0.18 to 0.28 which is shown in the graph plotted above.

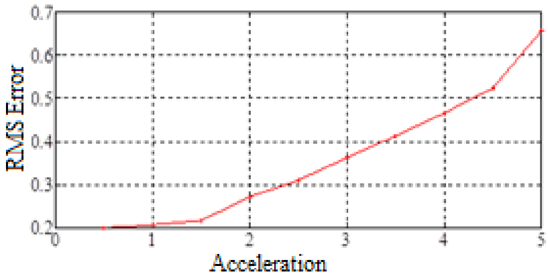

Figure 9: Variation of RMS Error with Acceleration

Figure (9) shows the variation in the RMS Error as the acceleration of the tennis ball as generated by the tens player is varied. As the acceleration is increased, the RMS Error is increased between the original trajectory of the tennis ball and the predicted trajectory of the ball. The increase in the error is due to the fact that the speed of the ball is increased, which leads to difficulty in detection and tracking of the original trajectory.

The fourth section of the proposed method is the prediction of the trajectory of a tennis ball. In this section the trajectory of the ball is predicted from two positions. One position is when the ball crosses the net and the other position is when the ball bounces. The result of both the predictions is shown in the figures (7-8).

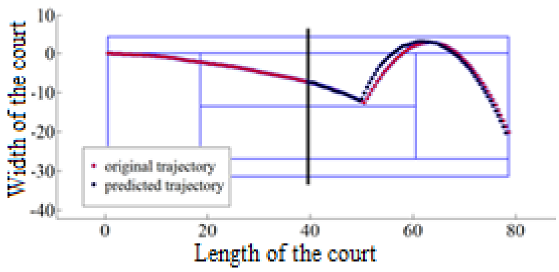

Figure 10: Trajectory Prediction from the Net Position

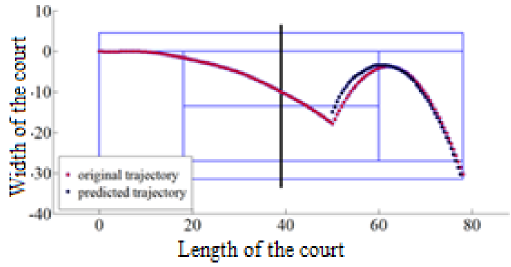

Figure 11: Trajectory Prediction from the Ball Bounce

In both the figures, the red curve is the original track of the ball and the black curve shows the predicted trajectory of the ball. In both the predictions it could be seen that there exists some error between the original and the predicted trajectory. The error present in the modelled system is shown in the form of normal probability distribution. The error probability distribution is shown in the figure (9).

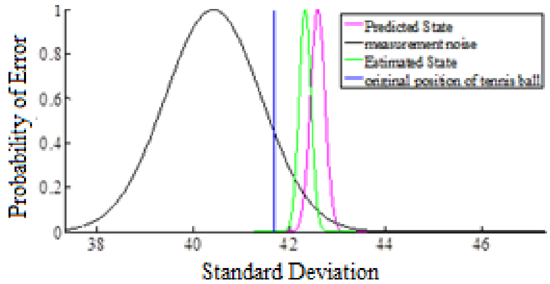

Figure 12: Error probability distribution function

In the figure, the blue curve is the original trajectory of the tennis ball. Thus its curve is a straight line. The curve in magenta colour shows the error probability distribution function of the predicted state when only the predictor equation of the algorithm is employed. The curve in green colour is the curve showing the error probability distribution function of the estimated state where both the predictor and corrector equations of the algorithm are shown. The curve in black colour shows error probability distribution in the measurement noise of the modelled system.

5. CONCLUSIONS

The object detection, tracking and predicting the trajectory is important in helping the umpiring decisions, broadcasting of the match and post-match analysis purpose. The tennis ball detection using the size, colour and aspect ratio of the ball is achieved to the accuracy of 96.7%. For the tracking purpose, the Kalman filter is employed along with its two step predictor-corrector algorithm and the error due to changing parameters of the Kalman filter is shown in the graph plotted. The main objective of the paper is to predict the trajectory of the tennis ball, which is effectively achieved by predicting the trajectory of the tennis ball from the net position and when the ball bounces.

6. REFERENCES

[1] Needham, Chris J., and Roger D. Boyle. "Tracking multiple sports players through occlusion, congestion and scale." BMVC. Vol. 1. No. 1. 2001.

[2] Farin, D. "Current and emerging topics in sports video processing." 2005 IEEE International Conference on Multimedia and Expo. IEEE, 2005.

[3] Yu, Xinguo, et al. "Trajectory-based ball detection and tracking in broadcast soccer video." Multimedia, IEEE Transactions on 8.6 (2006): 1164-1178.

[4] Sýkora, D., Sedlacek, D., & Riege, K. (2008, May). Real-time Color Ball Tracking for Augmented Reality. In IPT/EGVE (pp. 9-16).

[5] Larson, Noble G., and Kent A. Stevens. "Automated camera-based tracking system for sports contests." U.S. Patent No. 5,363,297. 8 Nov. 1994.

[6] Kim, S. W., Yun, K., Yi, K. M., Kim, S. J., & Choi, J. Y. (2013). Detection of moving objects with a moving camera using non-panoramic background model. Machine vision and applications, 24(5), 1015-1028.

[7] Teachabarikiti, K., Chalidabhongse, T. H., & Thammano, A. (2010, December). Players tracking and ball detection for an automatic tennis video annotation. In Control Automation Robotics & Vision (ICARCV), 2010 11th International Conference on (pp. 2461-2494). IEEE.

[8] Prabhakar, N., et al. "Object tracking using frame differencing and template matching." Research Journal of Applied Sciences, Engineering and Technology 4.24 (2012): 5497-5501.

[9] Claus D., FitzgibbonA.: Reliable fiducial detection in natural scenes. In Proceedings of European Conference on Computer Vision (2004), pp. 469–480.

[10] Yan, F. (2007). Tennis Ball Tracking for Automatic Annotation of Broadcast Tennis Video (Doctoral dissertation, University of Surrey).

[11] G. S. Pingali, Y. Jean, and I. Carlbom. Real time tracking for enhanced tennis broadcasts. In IEEE International Conference on Computer Vision and Pattern Recognition, pages 260–265, 1998.

[12] R. Streit and T. Luginbuhl. Probabilistic multi-hypothesis tracking. Technical Report, 1995.

[13] H. Miyamori and S. Iisaku. Video annotation for content-based retrieval using human behavior analysis and domain knowledge. In International Conference on Automatic Face and Gesture Recognition, pages 320–325, 2000.

[14] X. Yu, C. Sim, J. R. Wang, and L. Cheong. A trajectory-based ball detection and tracking algorithm in broadcast tennis video. In International Conference on Image Processing, volume 2, pages 1049–1052, 2004.

[15] Mehta, Rabindra D. "Aerodynamics of sports balls." Annual Review of Fluid Mechanics 17.1 (1985): 151-189.

[16] Yu, X., Sim, C. H., Wang, J. R., & Cheong, L. F. (2004, October). A trajectory-based ball detection and tracking algorithm in broadcast tennis video. In Image Processing, 2004. ICIP'04. 2004 International Conference on (Vol. 2, pp. 1049-1052). IEEE.