# Tennis Ball Tracking: 3D Trajectory Estimation using Smartphone Videos

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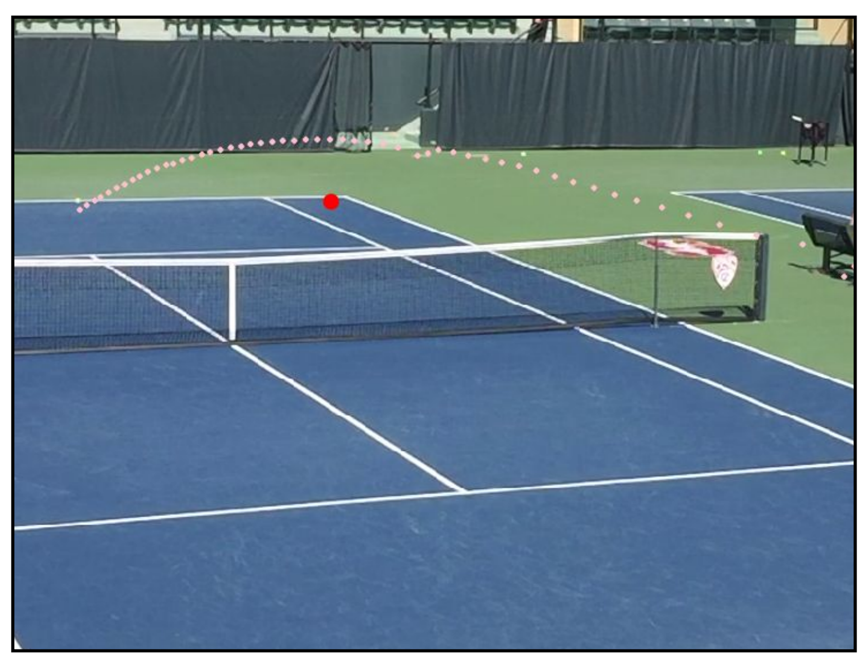
## Overview

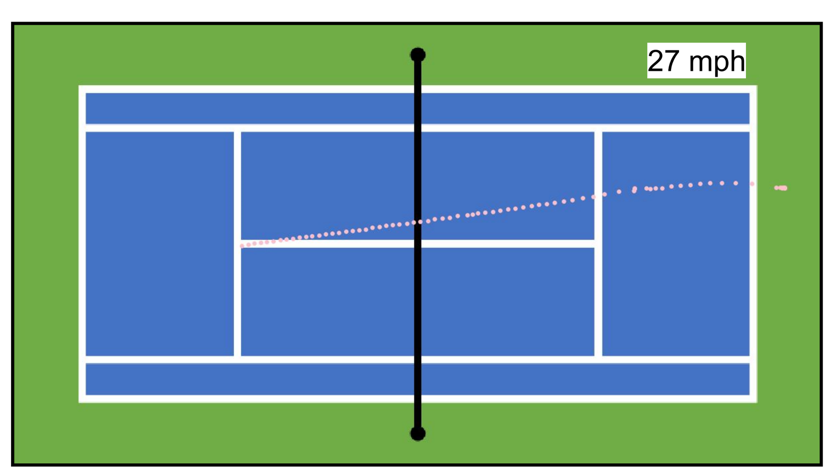
Tennis is a sport which is enjoyed by millions of people around the world. For players who are practicing to improve their skills, useful information is gathered from studying the 3D trajectory of the ball as it moves during play. However, measuring this trajectory typically requires highly specialized recording equipment and careful calibration. In our project, we challenge this by making trajectory estimation more consumer-accessible.

We present a ball trajectory-measuring system which relies only on two smartphone cameras and our own algorithm for automatically interpreting the recorded stereo footage. Given two recorded views of the tennis game, our system outputs frame-by-frame data including the ball's speed and estimated 3D position (to ~0.3m).

## Demonstration



***Above:*** Ball Detected: 186 of 201 frames, Court Corners Location Error: <25 pixels, Estimated World-Space Ball Position Error: <0.3 m



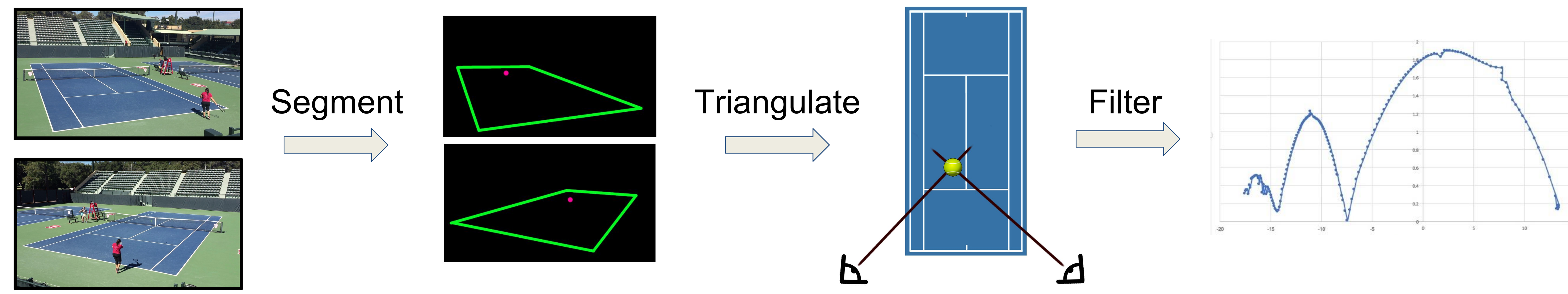

*Above*: Our tennis-ball tracker successfully traces the path of the ball in each of the videos. With the image-space position of the ball and court boundaries, we can reconstruct the ball's trajectory from any angle, such as the bird's-eye-view (shown left). Additionally, we estimate the speed of the ball at each frame.

## Related Work

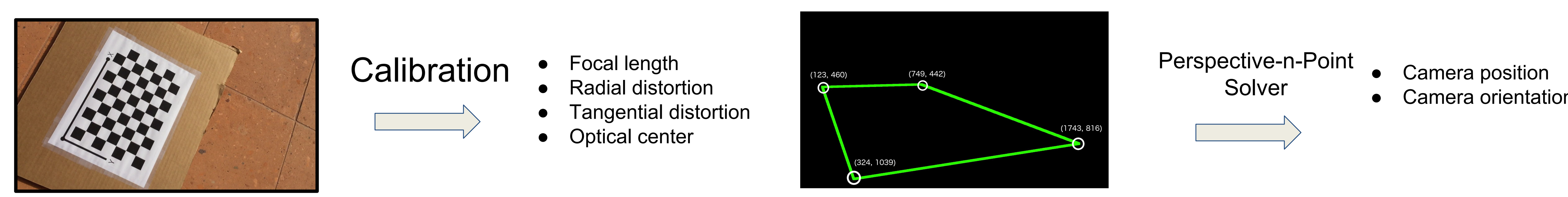

1. T. Qazi, P. Mukherjee, S. Srivastava, B. Lall and N. R. Chauhan, "Automated ball tracking in tennis videos," *2015 Third ICIIP*, Waknaghat, 2015, pp. 236-240
2. C. Lyu, Y. Liu, B. Li and H. Chen, "Multi-feature based high-speed ball shape target tracking," *2015 IEEE Int. Conference on Information and Automation*, Lijiang, 2015, pp. 67-72.
3. Archana, M., Geetha, M.K.: An efficient ball and player detection in broadcast tennis video. In: Berretti, S., Thampi, S.M., Srivastava, P.R. (eds.). AISC, vol. 384, pp. 427–436. Springer, Heidelberg (2016).
4. Yan, F, Christmas, W and Kittler, J (2005) *A Tennis Ball Tracking Algorithm for Automatic Annotation of Tennis Match* In: BMVC, 2005-09-05 - 2005-09-08, Oxford, UK.
5. B. Ekinci, M. Gokmen, "A ball tracking system for offline tennis videos", International Conference on Visualization Imaging and Simulation 2008
6. Yu, X. Sim, C.-H. Wang, J.R. Cheong, L.F., A trajectory-based ball detection and tracking algorithm in broadcast tennis video, ICIP Image Processing, Vol. 2, pp. 1049- 1052, 2004


## Design and Implementation

In our design, we use a multi-stage pipeline to identify the court and ball positions in each frame. Then, we infer the camera position and triangulate the ball. To account for extraneous noise in our system (such as false positives in the ball segmentation step), we include a filtering step which can predict the ball's position and velocity under uncertainty.

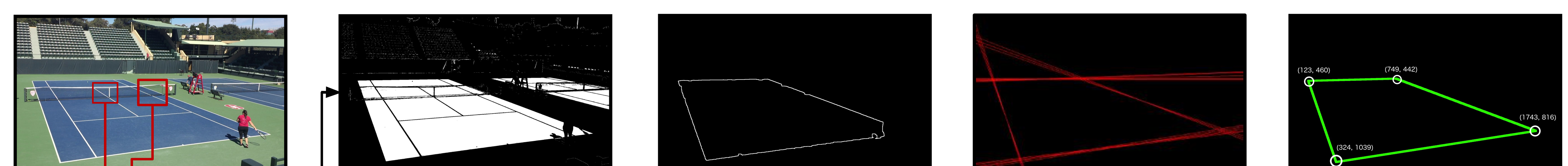



### Camera Calibration: Determining Intrinsic and Extrinsic Parameters




Our system is flexible enough to account for smartphone cameras with different focal lengths and distortion coefficients. Using the MATLAB Image Processing Toolbox, we calibrated two iPhone 6 cameras by capturing a planar checkerboard pattern to find the focal lengths, distortion coefficients, and optical centers for each camera. Then, in the triangulation stage, we solve for the camera's position and orientation using a perspective-n-point solver with the detected locations of the court's corners.

### Image Segmentation: Court-Finding and Ball-Finding

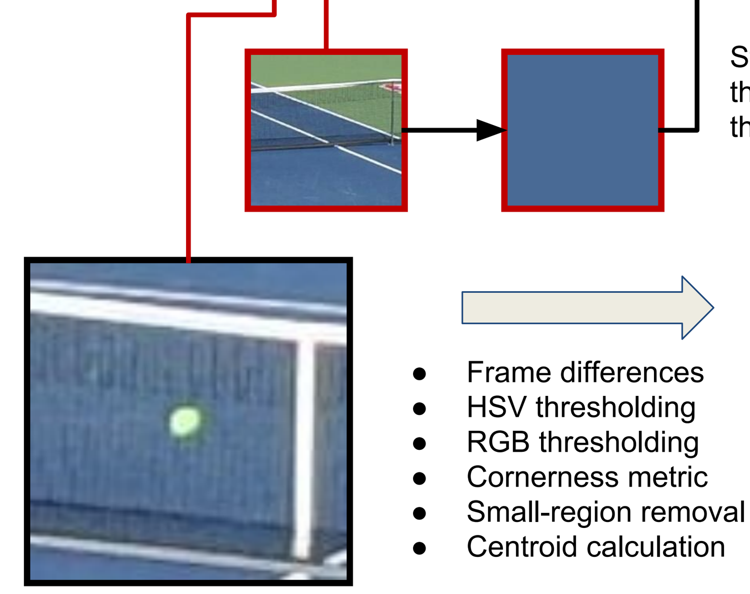


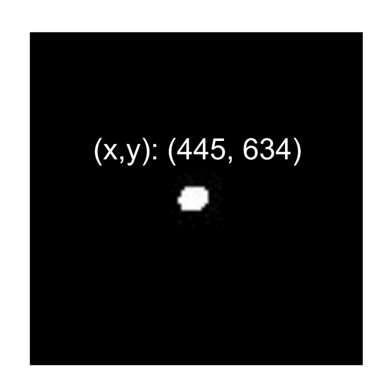
Step 1: Segment the court using color thresholding for the dominant color from the center of the image.

Step 2: Extract the court outline by applying canny edge detection to the largest court-colored blob.

Step 3: Apply Hough transformation and locate the line intersections that are near the court's edges.

Step 4: Find the centroids of intersection clusters. These are taken to be the court corners.




Our algorithm generates robust estimations of the pixel coordinates for the four corners of the court and the ball. For finding the court, we approximate the corner locations using a Hough transform-based method. We use several filter types for identifying ball location candidates. In some cases the ball is misidentified or not found in a particular frame, so we generate multiple candidate positions for the ball's location and leverage the most informative candidates using state-estimation techniques.