Tennis Serve Speed Estimation

Undergraduate
Research Scholars
LAUNCH: UNDERGRADUATE RESEARCH

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Background

- Serve speed plays a key role in determining match outcomes [1]
- Accurate radar-based systems expensive and inaccessible for the typical player
- Calculating serve speed from simple camera video enables cost-effective performance monitoring for typical players and coaches

Research Questions

- **Primary Research Question:** How can we accurately estimate tennis serve speed using only video data from a single camera?
- Can traditional image processing methods offer a more explainable and consistent solution than machine learning techniques?

Methodology

- Use frame differencing, filtering, and DBSCAN to consistently track the tennis ball
- Track tennis ball across frames, and turn into trajectories filtered by frames, speed, and angle change
- Interpolate 1st and 2nd trajectory to find frame and location where tennis ball hit the ground
- Track serving player cluster to find serve starting frame, then locate tennis ball location
- Track court corners, project serving point onto ground, and use 3D projections to find spatial distance in meters
- Compute change in horizonal distance (meters) and time (seconds)
- Use Equation 1 to compute the initial velocity

Figure 1: Trajectory plotted before and after hitting the ground

$$V_o = \frac{e^{kC_d x} - 1}{kC_d t}$$

Equation 1:
- Cd is the drag coefficient
- k is a constant including mass, cross sectional area of the tennis ball, and density of the air
- x is the change in horizontal distance (meters)
- t is the time (seconds) [2]

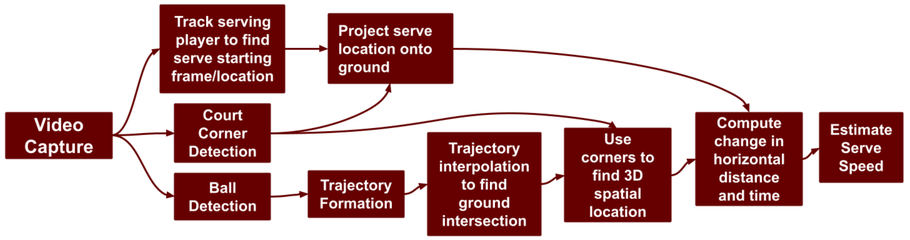
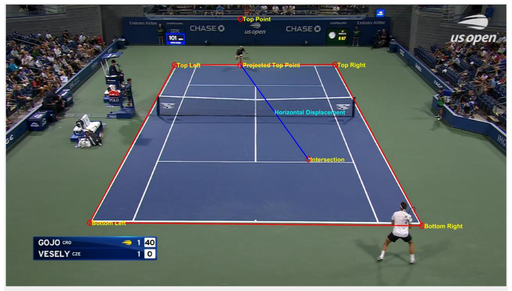


Figure 2: Flow Chart explaining methodology



Distance Estimate: 18.09 m | Time Estimate: 0.53 s
Final Speed: 92.65 mph | Radar Speed: 96.00 mph

Distance Estimate: 17.65 m | Time Estimate: 0.46 s
Final Speed: 102.12 mph | Radar Speed: 106.00 mph

Distance Estimate: 18.06 m | Time Estimate: 0.42 s
Final Speed: 114.96 mph | Radar Speed: 106.00 mph

Figure 3: MATLAB final plot outputs for three different rally clips

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Results

- Achieved Accuracy: Consistently within 4% of radar-based ground truth across 3 different trials
- Observations: The algorithm works optimally when the serving player is on top, and there is a distinct angle change when the tennis ball hits the ground

	Algorithm (MPH)	Radar (MPH)	Error (%)
Trial 1	92.7	96	3.49 %
Trial 2	102.1	106	3.66 %
Trial 3	115.0	116	**0.900 %**

Figure 4: Algorithm estimates vs radar ground truth

Conclusion

- The traditional image processing approach works well, although currently faces limitations on generalizability
- Future Works: Refine algorithm, implement AI-based object detection and compare with traditional object detection approach

References

1. Colomar, J., Corbi, F., Brich, Q., & Baiget, E. (2022). Determinant physical factors of tennis serve velocity: A brief review. *International Journal of Sports Physiology and Performance, 17*(8), 1159–1169. https://doi.org/10.1123/ijspp.2022-0091
2. Cross, R. (n.d.). *Ball trajectories.* Retrieved from http://www.physics.usyd.edu.au/~cross/TRAJECTORIES/42.%20Ball%20Trajectories.pdf