Measurement and Performance Evaluation of Lob Technique using Aerodynamic Model In Badminton Matches

Lejun Shen[1], Hui Zhang[2], Min Zhu[1], Jia Zheng[3], and Yawei Ren[1]

[1] Chengdu Sport University, Tiyuan Road, Chengdu, China,
sljcool@sina.com,
WWW home page: http://www.shenlj.cn/en
[2] Zhejiang University, Tianmushan Road, Hangzhou, China,
zhang_hui@zju.edu.cn
[3] Sichuan Sports College, Taipingsi Road, Chengdu, China

Abstract. In badminton matches, lob is a special technique and can be classified into two categories: defensive and offensive. These lobs are difficult to quantitatively measure, analyze, and evaluate. In this paper, we propose a new aerodynamic model to estimate the 3D trajectory from a single camera video and evaluate the performance of lobs. The experimental results show that this model is reliable. Offensive lobs are easily identified by the height of the trajectory. Good lobs are placed farther from the opponent than the bad lobs.

Keywords: Badminton, Computer Vision, Ordinary Differential Equations, Lob, Aerodynamic Model, Monocular 3D reconstruction

1 Introduction

Badminton is a popular racket sport included in Olympic Games. In badminton matches, the number of strokes of a rally can vary considerably due to several possible tactical actions. Lob is a special technique because it causes an opponent to move and traverse their defensive space [4]. Lobs can be classified into two categories, namely, defensive and offensive. The offensive lob is a flat trajectory toward the back of the opponent's court, and the defensive lob generates a rising trajectory. These lobs are difficult to quantitatively measure, analyze, and evaluate. Thus, the 3D shuttlecock trajectory is vital in badminton game analysis. In this paper, we propose a new physical model to estimate the 3D trajectory from a single camera video and evaluate the performance of lobs.

In 2017, Shen et al. obtained a 3D ball trajectory from a single-view television video by using a confirming point method and an air-ball friction model [6]. It's hidden assumption is that the air-ball friction coefficient is constant during the flight. Physical theory indicates that a shuttlecock in flight is subject to two distinct forces, namely, gravity and air drag force. A natural-feather shuttlecock is an extremely high-drag projectile. Thus, the air-ball friction coefficient is not constant, and consequently the 3D trajectory has no analytical solution.

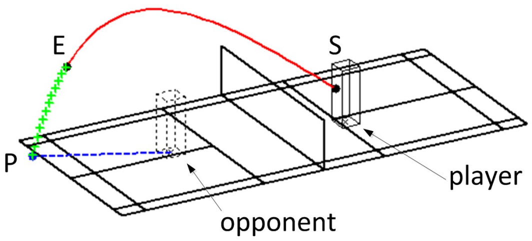

Fig. 1. Offensive lob in badminton game. Please see the text for more details.

The proposed aerodynamic model includes six ordinary differential equations (ODEs). As shown in Fig. 1, we use these equations to reconstruct the 3D shuttlecock trajectory (red trajectory) and evaluate the placement of lobs (blue dot P). Given a starting point (S), ending point (E), and flight time t , these ODEs find the initial velocity vector V_S and consequently reconstruct the 3D trajectory.

Moreover, given S and V_S, these ODEs generate a prolonged (green) 3D trajectory using a very large flight time (e.g., 4 s). The placement can be computed by the intersection of trajectory and ground plane. The experimental results show that the reconstructed 3D trajectories are more accurate than those produced by previous models and that the computed placements indicate the quality of lobs in a badminton match.

1.1 Aerodynamic model of the shuttlecock in a badminton match

In badminton matches, the human body and shuttlecock must obey physical rules. For example, the flying shuttlecock (from S to E in Fig. 1) is subject to two distinct forces: gravity and air drag force. Gravity is a constant force denoted by g, and air drag force is proportional to the square of the velocity, which is denoted by

$$f = C_D \frac{1}{2} \frac{\pi d^2}{4} \rho v^2 \tag{1}$$

where C_D is the drag coefficient (=0.59) [1], d is the shuttlecock diameter (=0.06 m), ρ is the density of air (=1.29 kg/m^3) and v is the velocity. The direction of the drag force is in the exactly opposite direction of velocity. Hence, the coefficient of air drag acceleration is

$$\alpha = C_D \frac{1}{2} \frac{\pi d^2}{4} \frac{1}{\mathrm{m}} \rho \tag{2}$$

Using the above physical model, the motion of shuttlecock can be modeled as the following set of coupled first-order ODEs

$$
\begin{aligned}
\frac{\partial x}{\partial t} &= v_x \\
\frac{\partial y}{\partial t} &= v_y \\
\frac{\partial z}{\partial t} &= v_z \\
\frac{\partial v_x}{\partial t} &= -\alpha v v_x \\
\frac{\partial v_y}{\partial t} &= -\alpha v v_y \\
\frac{\partial v_z}{\partial t} &= -\mathrm{g} - \alpha v v_z
\end{aligned} \tag{3}
$$

where (x,y,z) and (v_x,v_y,v_z) denote the position and velocity of the shuttlecock trajectory, v is the velocity $\sqrt{{v_x}^2 + {v_y}^2 + {v_z}^2}$, t is time, g is the acceleration of gravity (9.8 m/s^2), and α is the coefficient of air drag acceleration (=0.2152).

The above set of equations has no analytical expression. Given a starting point S, initial velocity V_S, and flight time t, these equations simulate a numerical 3D trajectory

$$f_i(S, V_s, t) \tag{4}$$

for i = 1, 2, 3. This simulation is a solution of ODSs.

2 Application of Aerodynamic model to monocular 3D reconstruction

Traditional monocular 3D reconstruction methods [5] estimate the 3D trajectory by fitting an analytically expressed physical model in 3D space to observations in 2D images. However, previous ODEs (3) have no analytical expression. Thus, we transform the monocular 3D reconstruction problem into a two-point Boundary Value problem.

First, we obtain the starting point $S = (x_S, y_S, z_S)$ and ending point $E = (x_E, y_E, z_E)$ by using the confirming point method [6]. Second, the flight time t is the duration between the starting and ending point in the video. Given these two points (S and E) and flight time t, the initial velocity $V_S = (V_{x,S}, V_{y,S}, V_{z,S})$ at the starting point S can be computed by a shooting method [3]. Third, the shooting method is a multidimensional root-finding method. The method finds the adjustment of the free parameters V_S to minimize the discrepancy between the ending point E and $f(S, V_S, t)$ to zero

$$x_E - f_1\left(x_S, y_S, z_S, V_{x,S}, V_{y,S}, V_{z,S}, t\right) = 0 \tag{5}$$

$$y_E - f_2\left(x_S, y_S, z_S, V_{x,S}, V_{y,S}, V_{z,S}, t\right) = 0 \tag{6}$$

$$z_E - f_3\left(x_S, y_S, z_S, V_{x,S}, V_{y,S}, V_{z,S}, t\right) = 0 \tag{7}$$

This root-finding problem can be solved by the Newton-Raphson method [3]. The initial guess for the root is the solution of ODEs (3) without air drag force, i.e., $\alpha = 0$. We use a numerical difference to approximate local derivatives because ODEs have no analytical expression. Newton-Raphson method converges quadratically and has one and only one solution.

Table 1. Comparison of different methods.

Method	Smash Speed (m/s)	Mean-Square Error
Gravity model [5]	25.14±4.91	5988.99
Air-ball friction model [6]	-	1559.37
Our aerodynamic model (3)	**96.83±14.11**	**179.73**

We build a Hawkeye dataset, in which the smash speed is collected from the television videos. The smash speed of this dataset is 102.39±4.75 m/s. We also compute the smash speed using different monocular 3D reconstruction methods [5, 6]. We then compare the difference between the Hawkeye dataset and two reconstruction methods.

In table 1, the smaller MSE (Mean-Square Error) indicates the corresponding method is the better. The error of [5] is maximal because it does not consider the air drag force. The error of our aerodynamic model (3) is minimal because they are more realistic than the gravity model [5] or the constant air-ball friction model [6]. This evidence suggests that our method is reliable and the air drag force influences the measurement process significantly and cannot be ignored.

3 Application of Aerodynamic model to badminton technique evaluation

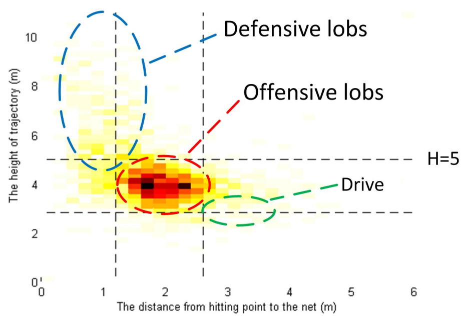

Fig. 2. Difference between defensive and offensive lobs

In racket sports, the placement of strokes is an important factor to achieve the tactical aim. In a badminton match, however, the shuttlecock never lands on the ground except the final stroke. We cannot find the landing area because image evidence is not available; rather, the landing area can only be computed by numerical simulation. Given the starting point S, initial velocity V_S, and flight time t, the 3D trajectory can be represented by a series of line segments computed by the fourth-order Runge-Kutta method [3].

We collected 8,699 strokes from 10 badminton television videos and obtained the players' hitting positions, the opponents' locations, and the shuttlecock's 3D trajectory.

The height of the trajectory (H) is the maximum Z-value of the 3D trajectory, and D is the distance from the hitting point to the net. Fig. 2 shows the H-D distribution of lobs. This distribution can be divided into two categories, namely, defensive and offensive lobs, by a horizontal line (H = 5). The majority of lobs are offensive lobs. This result confirms the observation that badminton players are more willing to attack than defend.

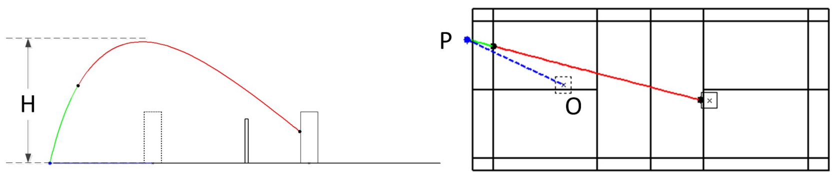

Fig. 3. Height (H) of the trajectory and distance from the placement to the opponent (PO)

Given a very large flight time (e.g., 4 s), ODEs generate a series of line segments (3D trajectory). This 3D trajectory is longer than the true 3D trajectory and intersects the ground plane. The intersection point is called *virtual placement*. In Fig. 3, the blue dotted line PO is the distance from the virtual placement (P) to the opponent (O) gives us a quantitative evaluation of lob technique.

A total of 117 lobs were used by receiving players, Long Chen, to serve; this total included 100 good lobs and 17 bad lobs. Fig. 4 shows the distribution of distances from the placement to the opponent. Red rectangles indicate good lobs, while blue rectangles indicate bad lobs. Bad lobs are defined by the opponent's next action and lead to the opponent's smashing and scoring. This result indicates that good lobs are placed farther from the opponent than bad lobs.

4 Conclusion

– The shuttlecock motion model presented in this work involves a set of six ODEs. This physical model is highly realistic in badminton games and, con-

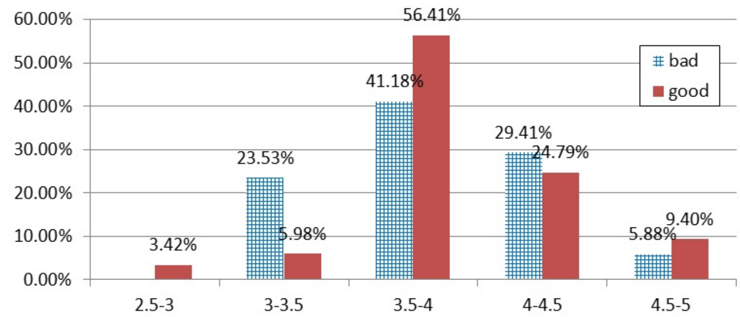

Fig. 4. Distributions of distance from the placement to the opponent (PO)

sequently, more accurate than traditional models. This model is reliable for evaluating badminton technique. The source code of (3) and the dataset can be found in our home page "http://www.shenlj.cn/en" .
- In badminton games, two types of lobs are used, namely, defensive and offensive. Offensive lobs are easily identified by the height of the trajectory using our monocular 3D reconstruction method. Good lobs are placed farther from the opponent than bad lobs based on the distance from the placement to the opponent.
- The proposed shuttlecock motion model helps us both acquire data and analyze badminton games.

References

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