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Tennis drop-point prediction model research based on matlab simulation

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ABSTRACT

Pumping ball technology is the most common the most utilizing and important technology of tennis; it is also an important manifestation of tennis basic skills. Therefore, study various factors that impact tennis player to forecast and judge opponent pumping drop-point, make them master the timing and method of pumping the ball drop-point, which is of important guiding significance to improve the predictive judgment accuracy and timeliness on pumping the ball drop-point for tennis players and to improve back hitting ball quality. This article assumes that by "Eagle Eye" system we already has obtained three-dimensional coordinates, speed and speed direction of a point in tennis flight, build the model under condition of not considering the air resistance and the resistance to flow around, and calculate the tennis drop-point image using MATLAB simulation. Finally consider tennis rotate, according to Bernoulli's principle, forecast the drop-point of tennis using differential equations in mathematics and mechanical model built on turbulent fluid knowledge. In this study, by analyzing athletes of different levels and training time, the differences in the predictive judgment provide some useful reference for the selection of the tennis player.

KEYWORDS

Differential equations;
Movement trajectory;
Force analysis;
Drop-point.

INTRODUCTION

View from the international and domestic research, on different projects many scholars already went through study on predicted judgment problem, like Abernethy, 1988 who is an expert conducted drop-point judgment for badminton player - novice comparative analysis, in order to study the impact of age and professional skills to badminton motion perception skills development; Changzhu Qi, 2001 used film fixed grid technology - conduct research on information selection and predicted judgment ability in novice mode, to reveal the nature of sports expertise; Bin Wang and Quan Fu also carry through related analysis and research in the sports decision-making ability for handball and fencing. But it is difficult to find a similar study on the tennis; hence it is necessary to discuss this issue from both theory and practical point of view.

Pumping ball technology is the most common the most utilizing and important technology of tennis; it is also an important manifestation of tennis basic skills. Therefore, study various factors that impact tennis player to forecast and judge opponent pumping drop-point, make them master the timing and method of pumping the ball drop-point, which is of important guiding significance to improve the prediction and judgment accuracy and timeliness on pumping the ball drop-point for tennis players and to improve back hitting ball quality. In this study, by analyzing athletes of different levels and training time, the differences in the predictive judgment provide some useful reference for the selection of the tennis player

MODEL ASSUMPTIONS AND SYMBOL INSTRUCTIONS

Model assumptions

Ignore the effect of floating force, the shape resistance and friction torque on the ball; Due to the difference between gravity and the air resistance is large; the air resistance is ignored in the vertical direction;

In tennis motion process, because the respective speed in different direction is different, in large speed place pressure is small, in small speed place pressure is large, and therefore tennis can rotate. In problem one and two, do not consider rotation of the tennis. All ball rotation is attributed to two kinds: topspin or bottom-spin and left-spin or right-spin. This is a reasonable assumption based on actual service motion.

In the modelling process, presume there are no other environmental factors like wind in tennis flight.

Symbol instructions

g: Gravitational acceleration;

(x_0, y_0, z_0): Three-dimensional coordinates of a point in Tennis flight;

v_0: The initial velocity of the tennis ball;

H: The rising height of the tennis ball;

V_{z_0}: The initial velocity of the tennis ball in the Z-axis vertical direction;

V_{x_0}: The initial velocity of the tennis ball in the X-axis vertical direction;

V_{y_0}: The initial velocity of the tennis ball in the Y-axis vertical direction

z_0: The initial height of the tennis ball in the Z-axis direction;

x_0: The initial displacement of the tennis ball in the X-axis direction;

y_0: The initial displacement of the tennis ball in the Y-axis direction;

t: Time from drop-point to ground; T: Time from drop-point to ground;

t_1: The time of the tennis ball rising; t_2: The time of the tennis ball descending;

S_x: The displacement of the tennis ball in the X-axis direction;

S_y: The displacement of the tennis ball in the Y-axis direction;

ρ: Air density; η: Air viscosity coefficient; f: Resistance; Re: Reynolds number

F_M: Magnus force; p: Trajectory curvature

MODEL BUILDING AND SOLVING

Take underscore midpoint as the coordinate origin, the X-axis is parallel to the bottom line direction, the Y-axis is parallel to the edge line direction, the Z-axis is vertically upward, create a three-dimensional coordinate system, the unit length is in meters. According to the independence of movement, make:

$$U = \sqrt{x_0^2 + y_0^2 + z_0^2}$$

$$\begin{cases} v_{z_0} = \dfrac{z_0 \times v_0}{U} \text{(The initial velocity of the tennis ball in the Z-axis vertical direction;)} \\ v_{x_0} = \dfrac{x_0 \times v_0}{U} \text{(The initial velocity of the tennis ball in the X-axis vertical direction;)} \\ v_{y_0} = \dfrac{y_0 \times v_0}{U} \text{(The initial velocity of the tennis ball in the Y-axis vertical direction;)} \end{cases}$$

In case of not considering air resistance, by Kinematics formulas: By

$$\begin{cases} {v_{z_0}}^2 = 2gH \\ v_{z_0} = t_1 \times g \\ \dfrac{1}{2} g {t_2}^2 = H + z_0 \end{cases}$$

(1) Tennis first does uniformly decelerated motion, and then uniformly accelerated motion in the Z-axis direction. During uniform deceleration, the rising height of the tennis:

$$H = \frac{{v_{z_0}}^2}{2g};$$

The time of the tennis ball rising: $t_1 = \dfrac{v_{z_0}}{g}$;

The time of the tennis ball descending: $t_2 = \sqrt{\dfrac{2\times(H+z_0)}{g}}$.

(2) Tennis does uniformly linear motion in the X-axis direction. Multiply the resolved velocity and time, and obtain the tennis displacement in the X-axis direction:

$S_x = x_0 + v_{x_0} \times T$.

(3) Tennis does uniformly linear motion in the Y-axis direction. Multiply the resolved velocity and time, and obtain the tennis displacement in the Y-axis direction:

$S_y = y_0 + v_{y_0} \times T$.

So the drop-point coordinates of tennis is $(S_x, S_y, 0)$.

Get the time from drop-point to ground from derivation.

$T = t_1 + t_2$, i.e.: $T = \dfrac{v_{z_0}}{g} + \sqrt{\dfrac{2\times(H+z_0)}{g}}$,

Unit is second.

The displacement in the X-axis is: $S_x = x_0 + v_{x_0} \times \left(\dfrac{v_{z_0}}{g} + \sqrt{\dfrac{2\times(H+z_0)}{g}}\right)$,

The displacement in the Y-axis is: $S_y = y_0 + v_{y_0} \times \left(\dfrac{v_{z_0}}{g} + \sqrt{\dfrac{2\times(H+z_0)}{g}}\right)$.

The drop-point coordinates of tennis is (Sx, Sy, 0), namely, tennis drop-point coordinates:

$\left(x_0 + v_{x_0} \times \left(\dfrac{v_{z_0}}{g} + \sqrt{\dfrac{2\times(H+z_0)}{g}}\right), y_0 + v_{y_0} \times \left(\dfrac{v_{z_0}}{g} + \sqrt{\dfrac{2\times(H+z_0)}{g}}\right), 0\right)$.

Take underscore midpoint as the coordinate origin, the X-axis is parallel to the bottom line direction, the Y-axis is parallel to the edge line direction, the Z-axis is vertically upward, create a three-dimensional coordinate system, the unit length is in meters. If tennis acquires a speed of 15.75 m / s at point (0, 0, 1) in direction (2, 16, 1), find the drop-point of tennis.

$U = \sqrt{x_0^2 + y_0^2 + z_0^2} = \sqrt{2^2 + 16^2 + 1^2} = 16.1555$

$v_{z_0} = \dfrac{z_0 \times v_0}{U}$ =1*15.75/16.1555=0.9749; $v_{x_0} = \dfrac{x_0 \times v_0}{U}$ =2*15.75/16.1555=1.9498

$v_{y_0} = \dfrac{y_0 \times v_0}{U}$ =16*15.75/16.1555=15.5984; $H = \dfrac{v_{z_0}^2}{2g}$ =0.0484;

Tennis trajectory diagram is shown in Figure 1.

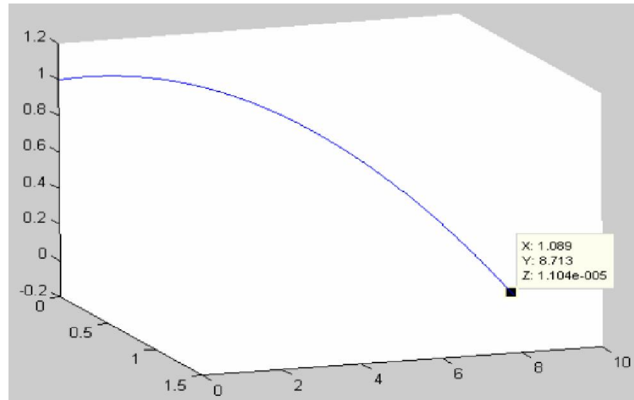

Figure 1 : Tennis trajectory diagram

So, the drop-point coordinates of tennis is (Sx, Sy, 0), namely, tennis drop-point coordinates is (1.089, 8.713, 0).

As tennis in movement often has rotation, due to Bernoulli's principle movement trajectory has a certain deflection of direction. If presume that tennis also goes through point (0.2215, 1.5517, 1.0485), we re-determine the drop-point of the tennis.

In the tennis movement process, it receives gravity, air resistance and ascending force vertical to the movement direction - Magnus force, as well as the internal friction torque of air on the rotating ball.

First, calculate the air Reynolds number of tennis movement:

$$Re = \frac{\rho v l}{\eta} = \frac{1.205 \times 15.75 \times 0.065}{1.81 \times 10^{-6}} = 6.82 \times 10^4$$

We can see when Re>4000, the fluid is turbulent flow, then:

The air resistance of the tennis:

Resistance: $f = \dfrac{c\upsilon A v^2}{2}$; $k = \dfrac{c\rho A}{2} = \dfrac{0.4\times1.205\times3.14\times(0.065/2)^2}{2} = 7.993\times10^{-4}$; Then $f = kv^2$.

Tennis receives force that is perpendicular to the plane of the rotational angular velocity direction and velocity direction. The specific direction can be determined by the right hand regulation: the right thumb, forefinger and middle finger vertical to each other, thumb pointing to the direction of rotational angular velocity, index finger pointing to the direction of moving speed, then the middle finger direction is the Magnus force direction.

Magnus force: $F_M = \dfrac{8}{3}\pi\rho\omega a^3 v$; Suppose: $G = \dfrac{8}{3}\pi\rho a^3 = \dfrac{8}{3}\times3.14\times1.205\times(0.065/2)^3 = 3.464\times10^{-4}$; Then $F_M = G\omega v$.

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(4) The determination of rotational direction of the angular velocity

In fact, the rotation of the ball can be approximately divided by the following two situations: up-spin or down-spin ball, left-spin or right-spin ball. According to the right-hand rule, the up-spin or down-spin ball is mainly due to the rotational angular velocity along the X-axis direction, resulting in the Magnus force that make the ball up and down deviation along the Y-axis direction; left-spin or right-spin ball is mainly due to the rotational angular velocity along the Z-axis direction, resulting in the Magnus force that make the ball left and right deviation along the x-axis direction;

About topspin along the z-axis direction, the rotational angular velocity is generated along the x-axis direction of the Magnus force, so that the ball about to deviate from.

Therefore, according to the ball's offset distance, we can determine the direction of the ball's rotational angular velocity.

According to the subject, the ball passes through point (0.2215, 1.5517, 1.0485). Through the projectile model that task one established, we can seek that the nearest point from this point is: (0.1940, 1.5517, 1.0485) in the ideal ball's movement trajectory. Accordingly, we can determine that the ball deviated to the x-axis direction. Therefore, the ball belongs to the left-spin ball.

(5) Dynamics model of left-spin ball:

Force analysis of L-ball is shown in Figure 2:

Suppose that the initial rotation direction (angular velocity direction) of the ball is along the OZ axis; the torque of the internal friction is small, and its effects can be ignored. According to the angular momentum conservation law, we can consider the ball always rotate along the OZ axis. By the Bernoulli equation we can judge Magnus force that football suffered is always located within a horizontal plane, and perpendicular to the direction of sphere speed, pointing to the curvature center of the sphere movement trajectory, as shown in Figure 3.

Through Force analysis and motion analysis, the horizontal plane movement is equivalent to movement in a circular. According to Newton's second law, get kinetic differential equation:

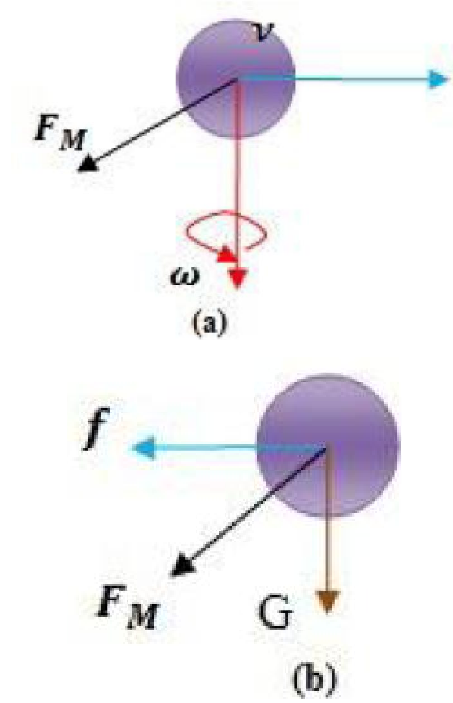

Figure 2 : Tennis Force Analysis a direction judgment of the Magnus force b. tennis overall force analysis

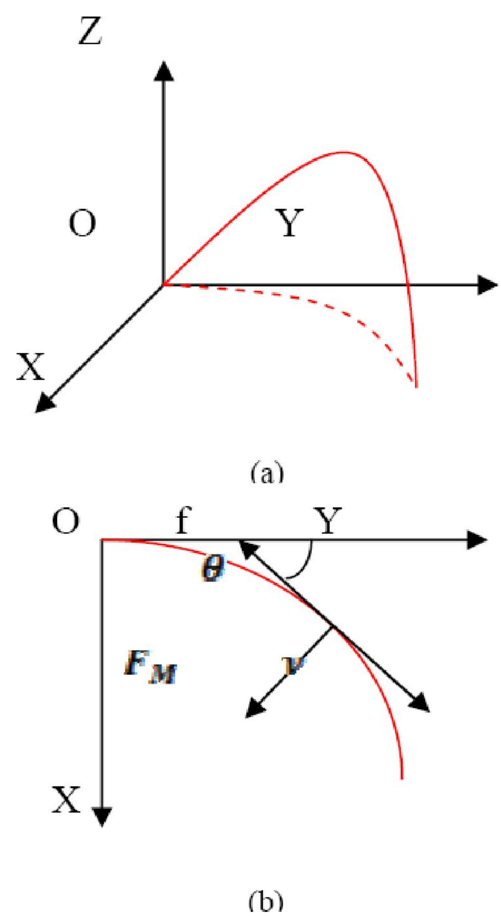

Figure 3 : Tennis Motion Analysis a Tennis left-spin movement trajectory b. Tennis motion analysis in XOY plane

$$\begin{cases} m\dfrac{d^2 z}{dt^2} = -mg \\ m\dfrac{dv}{dt} = -kv^2 \\ m\dfrac{v^2}{\rho} = G\omega v \end{cases}$$

Among them: ρ is trajectory curvature. Conduct integration to equation: $-\dfrac{1}{v} = -\dfrac{k}{m}t + C_1$

By the initial conditions: $v(0) = v_0$, get: $v = \dfrac{mv_0}{m + kv_0 t}$

Because $ds = vdt$ and $\rho = \dfrac{ds}{d\theta} = \dfrac{ds}{dt}\dfrac{dt}{d\theta} = v\dfrac{dt}{d\theta}$, Substitution into equation: $\left|\dfrac{d\theta}{dt} = \dfrac{G\omega}{m}\right.$

Thus $\theta = \int_{\theta_0}^{\theta} d\theta = \int_0^t \dfrac{G\omega}{m}dt + \theta_0 = \dfrac{G\omega}{m}t + \theta_0$. θ_0 is the two-component angle of the initial velocity in the XOY surface? As the velocity angle is very small, here approximately it is 0.

Therefore:

$$v_x = v\sin\theta = \frac{mv_0}{m + kv_0 t}\sin\frac{G\omega}{m}t \quad , v_y = v\cos\theta = \frac{mv_0}{m + kv_0 t}\cos\frac{G\omega}{m}t$$

Due to actually the motion time in the air of tennis is very small, furthermore $kv_0 = 0.0125 < m = 0.0567$, thus $\dfrac{mv_0}{m + kv_0 t} \approx v_0$.

Therefore, conduct integral of (4) and (5), according to the initial conditions:, we can obtain:

$$x = \frac{v_0 m}{G\omega}\left(1 - \cos\frac{G\omega}{m}t\right), \; y = \frac{v_0 m}{G\omega}\sin\frac{G\omega}{m}t$$

We also know that the ball goes through point (0.2215, 1.5517, 1.0485), we can determine $\omega = 163.97$.

Thus we can obtain: $x = 15.75(1 - \cos t),\; y = 15.75\sin t$.

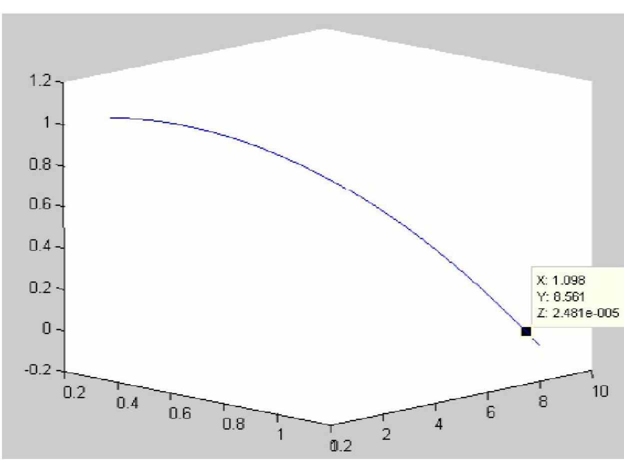

Figure 4 : The movement trajectory of left-spin ball

Finally calculate the vertical direction: $z = z_0 + v_z t - \dfrac{gt^2}{2}$, $i.e. z = 1 + 0.975t - 4.9t^2$ At the drop-point $z=0$, then the solution of the equation is $t=0.562s$, substituting equation of x,y, get: $x=1.098$, $y=8.561$. This paper uses MATLAB to simulate the trajectory; the result is shown in Figure 4:

CONCLUSIONS

This paper makes the reasonable assumption on the issue so that the problem can be simplified, then it establishes the appropriate model and obtains accurate results. For the established model, intuitively, easily and clearly map out the movement trajectory to determine the drop-point of tennis properly using MATLAB simulation. Use approximation method to handle Tennis rotation problem, the problem can be simplified.

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