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The impact factor research of table tennis ball control based on the equation of state

Genghua Lei[1]*, Long Zhang[2]

[1]Department of Physical Education, Xi'an Peihua University, Xi'an, Shaanxi, (CHINA)

[2]Department of Physical Education, Xidian University, Xi'an, Shaanxi, (CHINA)

ABSTRACT

This paper analyzes the force condition of the table tennis during the flight process, focuses on the analysis of the effect of air resistance on the ball, provides a basis for the establishment of the kinematic model; then on the basis of stress analysis it establishes a kinematic model of table tennis, discredited the sport continuity equation, obtains the easy-to-computer-implemented equation of state of tennis flight, based on the equation of state, analyzes the collision process of table tennis, introduces the speed attenuation coefficient, establishes the movement equation of state of table tennis before and after the collision; finally, respectively, it achieves the process experiment of 40 groups' tennis flight and crash process via computer, conducts the comparative study on the actual data with the camera and the predicted data of the placement position and placement time obtained using the model, obtains the reliability and precision characteristics of the model, and provides a theoretical basis for precise shots of table tennis and the development in other areas of table tennis.
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KEYWORDS

Stress analysis;
Kinematical equation;
Equation of state;
Prediction models;
Table tennis.

INTRODUCTION

The winning factor in the movement process of Table tennis is the precise control of the ball placement position and placement time; the movement of the table tennis consists basically flight and crash two processes; so the stress analysis and motion analysis of these two processes is an important way to study the accuracy of the ball control[1-3]; this article starts from these two aspects, analyzes the flight and crash analysis process of table tennis in order to establish a rational, scientific and easy computer-implemented mathematical model and provide a theoretical basis for precise ball control of table tennis[4,5].

Many scholars have studied the flight process and collision course of table tennis; the established models and research results of these scholars promote the precision ball technology of athletes, wherein: Jia Fang (2011) mentioned table tennis modeling in her thesis and elaborated model principles[1]; Zhao Lei et al (2010) studied the whole flight process from the racket hitting the ball, ball table collision to flying out of the tableboard, on the basis of the established model, used Matlab to simulate the trajectory[2]; Lihong De (2010) described the general movement of table tennis, and took the right topspin of table tennis, for example, made detailed analysis on its force and movement, parsed the formation mechanism of right topspin trajectory in the space[3,6].

On the basis of previous studies this paper studies the flight course and collision process of the table tennis to explore the kinematics laws that the ball meets in the course of these two movement processes and contribute to the accurate ball control of table tennis.

MATHEMATICAL MODEL OF TABLE TENNIS' FLIGHT AND COLLISION

In the sport of table tennis, the athletes' precise control of the ball is the key to win the game; the movement process of table tennis is generally divided into three states: static or scrolling, rotating, flying and collision; apparently static or scrolling has no research significance, what worth motion analysis is the process of air rotating, flying and collision; the paper puts aside the rotation process, studies the impact of table tennis' flight and collision on its trajectory and placement, in order to have a reasonable forecast on Table Tennis' flight and collision process through the adoption of a reasonable mathematical model, provides a theoretical basis of ball batting accuracy for table tennis players and other areas in table tennis[7-9].

Under reasonable assumptions, this paper conducts mechanics analysis on table tennis' flight and collision process, and establishes the mathematical model of these two sports process.

Condition assumptions and parameter settings

- First assume that table tennis has no rotation during exercise, and the movement in the three axes direction of space coordinates satisfies mutual independence;
- Ball only receives gravity and air resistance in flight process, and the size of the air resistance is proportional to the velocity of the ball, and the direction is opposite to the moving speed of the ball;
- Collision between table tennis and table can be seen as elastic collisions, and the state of motion after bouncing is only related to the state of motion at the landing moment.
- Table tennis is a sphere with 4cm diameter, the centroid position is in the center of the sphere, and weigh is 2.7g.

Stress analysis of table tennis in flight process

Table tennis suffers mainly air resistance, buoyancy and gravity during the flight, among them the sports model of buoyancy is the most complex; first analyze the role of fluid force on table tennis moving in the air stream[10,11].

Air is a relatively fluid to table tennis; when the fluid flows through the stationary object slowly, due to the presence of the viscous resistance the flow rate of each portion of the fluid is the same; for the viscous resistance, the resistance f has the following relationship with the effective area (cross sectional area)of the object receiving the fluid impact ΔS, the fluid viscosity coefficient η and fluid velocity gradient $\frac{dv}{dy}$ in the formula (1):

$$= \eta\Delta \left(\frac{}{dy} \right) \tag{1}$$

By the formula (1) the viscous drag of the spherical object when moving slowly in the fluid is $6\pi\eta v$. When the fluid object moves, it will be separated from the whole, it will flow through the different sides of the object; in the portion near the object the fluid velocity is slower; and in the back side of the object it forms into a low pressure region, so that the fluid far distant from the object will quickly and naturally add to the low pressure region, which results into the turbulence phenomena; Figure 1 shows the formation schematic of the pressure drag of the object in a fluid.

Pressure drag would be more obvious only under larger viscous fluid; the resistance is proportional to the square of the relative velocity of the object in the fluid; since air viscosity is small, the paper ignores the pressure drag, counting only the viscous resistance.

Figure 2 shows the stress analysis schematic of table tennis flying in the air at a speed of v.

In Formula (4) $K = k / m$.

$$() \;—(\quad) \qquad (5)$$

Equation of state of table tennis' flight process

If the air resistance is not considered, the air resistance coefficient k will be very small; if seek the limit on the spatial position s in $k \to 0$ the relationship can be obtained as in formula (6) shown below:

$$() \quad () \quad (\qquad (6)$$

If the camera adopts the sampling frequency of 60Hz, conduct discrimination on the three components and velocity components of the spatial position; we can set $()$ $()$ $($, the component of table tennis centroid rate in the three axes direction is shown in the formula (7) below:

$$\frac{(\quad)}{()} \qquad (7)$$

Therefore the discrimination equations of the table tennis flying in the air may have the form like the formula (8) below:

$$\mathbf{X_{i\ 1} = AX_i + BU_i + w_i} \qquad (8)$$

Without considering the air resistance, table tennis' movement in three directions axes can be carried out by the state variable speed v and position p, the state equation of table tennis' flight is shown in formula (9) below:

$$(\quad) \qquad (\quad (\quad) \qquad (9)$$

In formula (9), w means the system error.

Equation of state of table tennis' collision process

By the condition assumptions, table tennis collision course is an elastic collision; in the absence of rotation it satisfies the law of reflection; if assuming that the speed of table tennis the moment before collision is v_{colli^-}, the speed the moment after the collision is v_{colli^+}, the collision case between the table tennis and table-board is shown in Figure 3:

The positional relationship between the angle $\alpha = \beta$ and the ball when colliding with the table-board in Figure 3 is shown in the formula (10) below:

$$(\quad) \qquad (\,) \qquad (\tag{10}$$

In Formula (10) the collision time is t_{col_z}, through the collision and the flight model in the previous section we can obtain v_{colli^-}, which was expressed as the formula (4); set a damping coefficient for the velocity in each direction, namely k_x, k_y, k_z, the speed after the collision is shown in the formula (11):

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TABLE 2 : The relevant data comparison when the table tennis reaches the designated plane after crashing the table-board based on model and camera measurement

Movement Trajectory	Predicted position		The actual position		t_{pre}	t_{act}	t_{err}	Position coordinate error		
	x	z	x	z				X	Z	X, Z
1	-75.6	221.6	-109.7	182.6	653.3	676.6	23.3	-34.1	-39.0	51.8
2	-129.9	253.4	-119.9	260.0	667.1	660.1	7.0	9.9	6.6	11.9
3	-102.0	245.5	-112.6	237.6	651.2	633.4	17.8	-10.6	-7.7	13.1
4	-30.2	215.1	-102.5	194.6	652.2	661.9	9.7	-72.3	-20.5	75.2
5	-5.8	256.0	-13.2	200.7	641.3	672.7	31.4	-7.4	-55.3	55.4
6	214.4	328.6	180.6	333.0	500.0	517.6	17.6	-33.8	4.4	34.0
7	182.8	335.4	142.1	350.7	493.6	514.0	20.4	-40.7	15.3	43.4
8	169.6	329.0	160.3	334.0	485.3	498.0	12.7	-9.3	4.9	10.6
9	214.6	337.0	161.3	348.4	497.5	502.8	5.3	-53.4	11.4	54.5
10	194.4	335.4	161.3	367.6	482.4	520.9	38.5	-33.1	32.2	46.2
11	285.1	327.5	244.1	338.7	481.4	499.3	17.9	-41.0	11.2	42.5
12	217.3	331.6	194.1	334.8	493.6	497.6	4.0	-23.2	3.2	23.5
13	144.3	324.7	135.4	337.0	474.2	489.8	15.6	-8.9	12.3	15.2
14	170.0	328.3	179.8	342.7	473.3	484.1	10.8	9.8	14.4	17.4
15	154.1	329.4	149.5	335.4	481.8	485.0	3.2	-4.6	6.0	7.6
16	256.3	330.0	190.2	346.1	477.5	497.2	19.7	-66.1	16.1	68.1
17	-89.6	301.6	-141.1	309.2	534.1	537.8	3.7	-51.5	7.6	52.0
18	-84.6	293.8	-132.2	301.9	543.7	562.7	19.0	-47.6	8.1	48.3
19	-139.9	294.8	-168.6	295.2	525.9	532.0	6.1	-28.7	0.43	28.7
20	-166.1	330.0	-165.9	340.3	504.1	514.3	10.2	0.15	10.3	10.3

Note: the coordinate unit is mm, the time unit is ms

$$\left[\quad \right] \quad (11)$$

If ( ) ( ) (represents the current location of the table tennis, ( ) ( ) (means the current position of table tennis, ( ) ( ) (means the location of the table tennis in next cycle, (x_{colli}, y_{colli}) means the coordinates of the collision point, r means the radius of table tennis, based on the position point before and after the collision the collision point's coordinates can be drawn in the formula(12):

the flight process, placement and collision process of the table tennis; apparently the latter two are the points that athletes concern; in order to verify the reliability of the model, this paper uses two ways of the model method and high-speed video camera to conduct comparative analysis for table tennis placement and collision time; the TABLE 1 shows the trajectory data situation of 20 table tennis with different initial conditions.

From the data in TABLE 1 we can draw the error distribution diagram of the 20 table tennis' placement position and collision time between the predicted trajectory and the actual trajectory.

From the data in Figure 4 the time error is less than 15ms, that is 0.015s; placement position error is less than 60mm, that is 6cm; and table tennis' diameter is 4cm, therefore the predictive model has accurate predictions for the placement position and placement time of table tennis.

Model validation after table tennis collision

After the collision of the table tennis with the tableboard rebound phenomenon will appear; after the rebound the table tennis can reach the position of the detection plane; model algorithm has a prediction, the predicted value is very close to the actual value, which indicates that the collision model established in this paper is very precise; for the amount that is capable of reflecting the model accuracy, one is the position point which falls on the detection plane, and the other is time landed on a specified plane; the paper gives the predicted value and the actual value of the 20 table tennis' flight path for the error comparison and the results are shown in TABLE 2.

From the data in TABLE 2 we can draw the error distribution diagram of the 20 table tennis' placement position and placement time between the predicted trajectory and the actual trajectory on the specified plane after rebound.

From the data in Figure 5 the time error is less than 40ms, that is 0.040s; placement position error is less than 80mm, that is 8cm; and table tennis' diameter is 8cm, therefore the predictive model has accurate predictions for the placement position and placement time of table tennis on the specified plane.

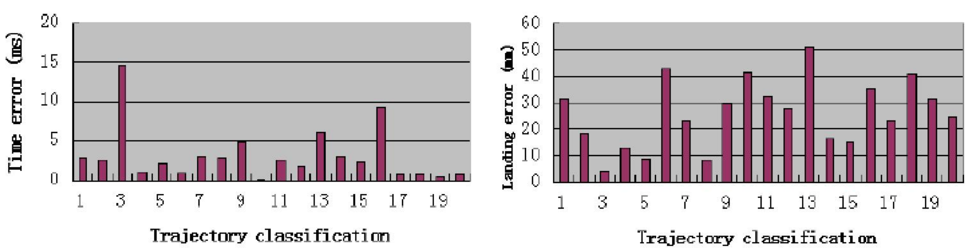

Figure 4 : The error distribution diagram of the table tennis flight path's placement position and collision time

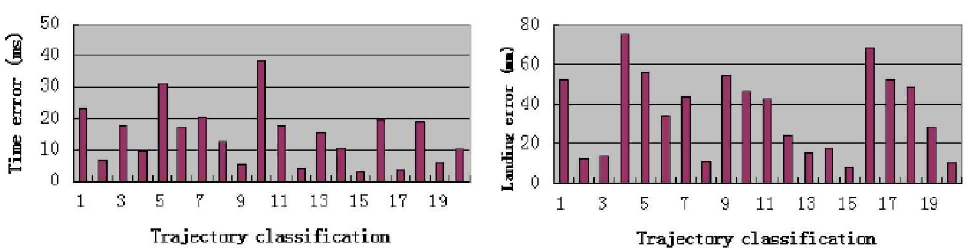

Figure 5 : The error distribution diagram of the placement position and placement time on the specified plane after the rebound

CONCLUSIONS

First, the study first analyzes the forces condition of the table tennis in the motion process, provides a basis for kinetic studies; under conditions of stress analysis results of table tennis in the movement process and the conditions assumptions, it establishes the kinematic equations of table tennis flight, provides a basis for the discrete state equation that computer algorithm is easy to implement; by the continuous kinematic equations of tennis flight, it obtains the discrete equation with 60hz camera measurement frequency, and translates it into the state equation of the speed and position, and provides a theoretical basis for computer implementation and movement trajectory portray; on the basis of mathematical model for table tennis flight process, it studies the table tennis collision process with speed attenuation coefficient, discreteness continuous kinematic equations, and establishes the state equation of table tennis movement before and after the collision course; finally it collects the predicted data of the model placement position of the table tennis, placement time of the table tennis, placement location and placement time of the specified plane, and compares it with the actual measured data by the camera, and the comparing results show that the position error is less than 8cm, the time error is less than 40ms, the accuracy and feasibility of the model is obtained.

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