ISSN : 0974 - 7435 Volume 10 Issue 4

BioTechnology
An Indian Journal

FULL PAPER

BTAIJ, 10(4), 2014 [882-886]

Weighted-based table tennis robot return speed calculation applied research

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ABSTRACT

Table tennis is always Chinese sports meetings' strong event, all previous Olympic Games table tennis gold, silver and bronze medals are nearly taken by Chinese athletes. Chinese scholars' researches on table tennis theoretical basis also lead the world, which provides good theoretical basis for developing table tennis robots. By simplifying physical model, the paper proposes methods relative to robot return speed calculation; meanwhile it makes prediction on table tennis trajectory. By ignoring table tennis movement suffered Magnus force, it uses iterative fitting to predict table tennis movement trajectory, and uses simplified physical model to solve return speed. Meanwhile according to experience data calculation by computer, it gets table tennis movement trajectory and return speed based on experiences data. Based on weighted theoretical model and experience model, it gets new weight values to adjust calculation return speed method. It provides simple ways for table tennis robot hitting returning speed calculation geometric theoretical advantages and practical experience advantages. © 2014 Trade Science Inc. - INDIA

KEYWORDS

Table tennis robot;
Return speed;
Physical model;
Iterative fitting;
Biomechanics.

PREFACE

Though Chinese table tennis is number one in the world, it remains relatively underdeveloped in table tennis robot development aspect; in 1980s world made proposals of organizing table tennis robots competitions, after that all countries in the world started table tennis robots development, table tennis robots development was a kind of very complicated task. It included machine, automation, computer, mathematical model, physical model as well as control volume equation and others multiple disciplines that was interdisciplinary research field. Table tennis robots have varieties of forms, it mainly divides into humanoid robot and single arm multi-degree of freedom table tennis robot, by far world table tennis development achievements already can let robots and people fight each other. Formers have made lots of researches in the aspect of table tennis robot development, especially in mathematical model aspect, it has researches on the basis of simplified physical model calculation control equation and other mathematical algorithms, meanwhile based on experience data, it lets table tennis robot have self- learning and adjustment abilities. By far table tennis robot research is every country relative hot research; due to automation, machine, computer and other techniques backwardness, China also falls behind European and American developed countries in table tennis robot development aspect.

The paper starts from simplified physical model and experience data to research table tennis return speed calculation, it abandons theoretical perspective calculations' shortcomings, and makes supplements with experience actual data. The two common decide return speed sizes by setting weight values, improve weight values distribution relations by comparing actual value with predicted value, and constantly perfect weight values proportions by updating experience data. By algorithms improvement, it provides algorithms theoretical basis for table tennis robot return speed precise controlling.

TABLE TENNIS ROBOT WEIGHTED CALCULATE RETURN SPEED

By far, more established technique is German Darmstadt University of technology researchers developing table tennis robot by single arm and video. Researchers firstly gave the robot some handled table tennis techniques, and then set robot a kind of technique that names "kinesthesia self-learning" by complicated algorithms and computer technology that robot constantly learned techniques during process fighting with human race and recorded these techniques' relative techniques. Initially, robots cannot fulfill hitting; even opponent serve table tennis was relative stable. But based on robot "kinesthesia self-learning" system, it will learn to adjust and make combination move, and it can hit 79% table tennis after learning for a while.

Physical model-based return speed calculation

(1) Table tennis trajectory prediction

In case ignoring Magnus force, table tennis air movement state approximates to oblique projectile movement, table tennis suffers air resistance and gravity, and moves under these two resultant effects, which is physical model analyzes force influences on trajectory. Table tennis force analysis is as Figure 1 show.

According to momentum theorem, it gets:

$$m\Delta\vec{v} = (\vec{F}_f + \vec{F}_g)\,\Delta t$$

Among them, F_f represents table tennis suffered air resistance, it always opposites to speed direction.

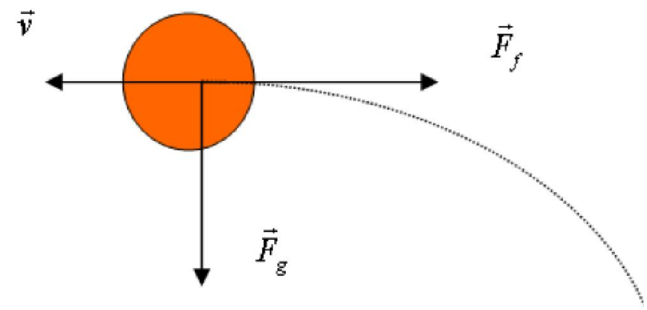

Figure 1 : Table tennis movement force analysis

F_g is table tennis suffered gravity, it is always vertical and downward. m Represents table tennis mass. Δv represents table tennis speed variable quantity in some time frame, it is changing all the time. Δt represents table tennis movement instant one time frame.

Formula(1) is continuous equation, in order to easier to computer operate, express it as discrete form, and carry out iteration solution and predict table tennis movement trajectory, according to table tennis table, it established three-dimensional rectangular coordinate system, decompose table tennis speed into three directions and table tennis position is defined by three-dimensional coordinates. Table tennis speed, position in three-dimensional coordinate system is as Figure 2 show, illustration three-dimensional rectangular coordinate system's table tennis speed and its position, as well as next time frame table tennis movement state and position description.

Table tennis at t-1 time position coordinate is $(x_{t-1} \quad y_{t-1} \quad z_{t-1})$, and after Δt time, t table tennis position is got by following iterative formula calculating:

$$\begin{pmatrix} x_t \\ y_t \\ z_t \end{pmatrix} = \begin{pmatrix} x_{t-1} \\ y_{t-1} \\ z_{t-1} \end{pmatrix} + \Delta t \begin{pmatrix} v_{x_{t-1}} \\ v_{y_{t-1}} \\ v_{z_{t-1}} \end{pmatrix}$$

Among them, Δt represents iterative cycle here.

Table tennis at t-1 time speed components in each direction is as above figure show, and then speed changes solution iterative formula is:

$$\begin{pmatrix} v_{xt} \\ v_{yt} \\ v_{zt} \end{pmatrix} = \begin{pmatrix} v_{xt-1} \\ v_{yt-1} \\ v_{zt-1} \end{pmatrix} - \Delta t \begin{pmatrix} K\|v_{t-1}\|v_{xt-1} \\ K\|v_{t-1}\|v_{yt-1} \\ K\|v_{t-1}\|v_{zt-1} \end{pmatrix}$$

In above formula, K represents coefficient, its ex-

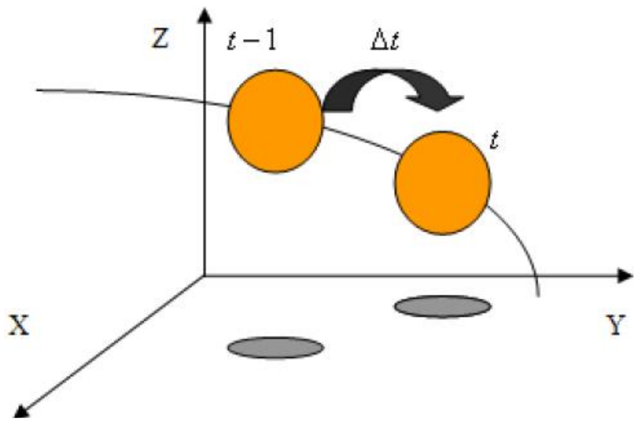

Figure 2 : Table tennis three-dimensional coordinate system's speed, position

pression is:

$$K=\frac{1}{2}m\rho S\mu$$

Among them, m represents table tennis mass, ρ represents air density, S represents table tennis effective area μ represents air resistance coefficient, Δt still represents iterative cycle.

(2) Simplified physical model return speed calculation

To table tennis, it gives hitting point $A(x_0, y_0, z_0)$, after hitting table tennis expected landing in table is $B(x_1, y_1, z_1)$, z_1 represents table tennis radius here. In plane, expected table tennis horizontal speed is v_{xy}. Actual table tennis drop point and speed cannot be completely the same as predicted value that is expected value, it has errors. Actual table tennis drop point $R(x_r, y_r, z_1)$. In case ignoring air resistance and Magnus force, calculate time that table tennis moves from hitting point to predicted drop point is:

$$t_{AB}=\frac{\sqrt{(x_0-x_1)^2+(y_0-y_1)^2}}{v_{xy}}$$

Table tennis all takes constant movements in horizontal direction, its trajectory equation is single linear. In the direction of initial value, table tennis takes accelerated movements; its trajectory is quadratic form. Then fit equation and get table tennis trajectory equation is:

$$\begin{pmatrix}x(t)\\y(t)\\z(t)\end{pmatrix}=\begin{pmatrix}a_x t+b_x\\a_y t+b_y\\a_z t^2+b_z t+c_z\end{pmatrix}$$

By initial condition $t=0$ is table tennis hitting point, it can get:

$$\begin{pmatrix}b_x\\b_y\\c_z\end{pmatrix}=\begin{pmatrix}x_0\\y_0\\z_0\end{pmatrix}$$

When $t=t_{AB}$, table tennis arrives at predicted drop point, it gets by calculating:

$$\begin{pmatrix}x_1\\y_1\\z_1\end{pmatrix}=\begin{pmatrix}a_x t_{AB}+x_0\\a_y t_{AB}+y_0\\a_z t_{AB}{}^2+b_z t_{AB}+z_0\end{pmatrix}$$

Calculate and get:

$$\begin{cases}a_x=\dfrac{x_1-x_0}{t_{AB}}\\a_y=\dfrac{y_1-y_0}{t_{AB}}\end{cases}$$

When time $t=t_{AB}$, table tennis vertical direction speed is:

$$v_z=2a_z t+b_z$$

Before and after Δt time, table tennis vertical speed is:

$$v_z'=2a_z(t-\Delta t)+b_z$$

According to table tennis flight speed iterative formula, it can get:

$$v_z=v_z'-k_f\|v'\|\Delta t-g\Delta t$$

Among them, $\vec{v}'$ speed that tablet tennis at $t-\Delta t$ time, is a quantity.

By above equations calculating, it gets:

$$\begin{cases}a_z t_{AB}^2+b_z t_{AB}+z_0=z_r\\k_f\sqrt{a_x^2+a_y^2+[2a_z(t_{AB}-\Delta t)+b_z]^2}*[2a_z(t_{AB}-\Delta t)+b_z]+2a_z=g\end{cases}$$

Solve above equation, it can get simplified physical model table tennis return speed is:

$$\vec{v}_b=[a_x\quad a_y\quad b_z]^T$$

Experience data-based return speed calculation

(1) Experience data storage

When table tennis robot hits, the points is uncertain, hitting point position exists in a three-dimensional space region, the region can be expressed as:

$x \in [x_{min}, x_{max}]$

$y \in [y_{min}, y_{max}]$

$z \in [z_{min}, z_{max}]$

Divide hitting section into educational several small regions, every small region corresponds to a storage space, it stores about return experience data, stored data constantly updates with new incoming data so as to get better return speed experience values. Experience data's form in storage section is as following:

$$E = \left(1,\ v_{1xy}, \frac{v_{1x}}{v_{1y}}, v_{1z}, x_2, y_2, v_{2xy}, l_1, l_2, l_3, l_4\right)$$

The first element is 1 then it shows the region has experience data and it has been stored. If the first element is zero, then it shows the region return speed has no experience data storage now. $\vec{v}_0 = (v_{0x} \quad v_{0y} \quad v_{0z})^T$ represents robot hitting speed. Among them: $v_{xy} = \sqrt{v_{0x}^2 + v_{0y}^2}$ (x_2, y_2) represents table tennis drop point coordinate in plane. v_{2xy} is speed at table tennis actual drop point. l_i is used to measure matcher actual drop point and expected drop point errors. The expression is as Figure 3. P_1, P_2, P_3 respectively represents hitting point, actual drop point, predicted drop point.

According to vision computer measurement, it gets new experience data, if some storage space has no data, how to store the data into it, if some storage space has experience data, then compare new experience data and previous experience data, which one gets closer to expected drop point, select smaller deviation data storage, constantly carry out updated learning, and let table tennis robot precise to be higher.

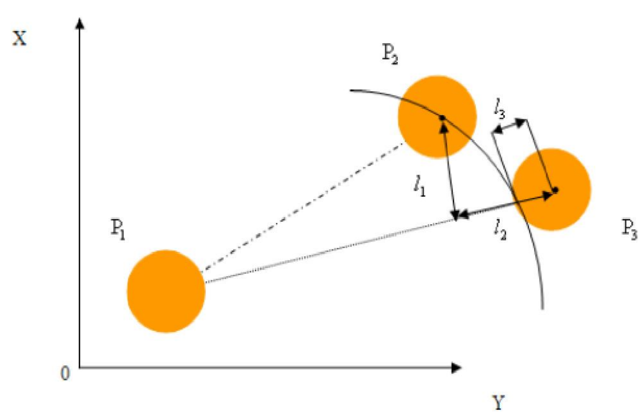

Figure 3 : Drop point deviation schematic

(2) Return speed calculation

According existing experience data parameters, it calculates v_{1x} and v_{1y}, computational method is as following:

$$v_{1x} = |\sin\theta||v_{1xy}|\operatorname{sgn}(x_3 - x_1)$$

$$v_{1y} = |\cos\theta||v_{1xy}|\operatorname{sgn}(y_3 - y_1)$$

Among them:

$$\tan\theta = \frac{v_{1x}}{v_{1y}}$$

In a smaller fixed table tennis hitting region, it can approximately regard table tennis ball speed as variables linear function relation to make solution and calculation, then it has:

$$\Delta x = x_3 - x_1$$

$$\Delta y = y_3 - y_1$$

$$\Delta z = z_3 - z_1$$

Then, ball speed in X direction can be expressed as:

$$v_{E1x} = (1 \quad \Delta x \quad \Delta y \quad \Delta z \quad v_{2xy}) \begin{pmatrix} \beta_{x0} \\ \beta_{x1} \\ \beta_{x2} \\ \beta_{x3} \\ \beta_{x4} \end{pmatrix}$$

Among them, β is fitted equation coefficient. Let

$$d_i = \sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2}, w_i = e^{(-d_i)^2}$$

w_i represents stored experience data weight. To stored all experience data, all multiply by corresponding weights, and can construct linear equation as following formula:

$$V_E = K\beta$$

Among them

$$V_E = (w_1 v_{E1x1} \quad w_2 v_{E1x2} \quad w_3 v_{E1x3} \quad \cdots \quad w_n v_{E1xn})^T$$

$$K = \begin{pmatrix} w_1 & w_1\Delta x_1 & w_1\Delta y_1 & w_1\Delta z_1 & w_1 v_{2xy1} \\ w_2 & w_2\Delta x_2 & w_2\Delta y_2 & w_2\Delta z_2 & w_2 v_{2xy2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ w_n & w_n\Delta x_n & w_n\Delta y_n & w_n\Delta z_n & w_n v_{2xyn} \end{pmatrix}$$

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Make use of mathematical computational method least square method to calculate, it can get fitted equation coefficient β:

$$\beta = (K^T K)^{-1} K^T V_E$$

And calculate X direction speed fitted equation linear coefficient. Similarly, it can get speed in Y and Z directions speed fitted equation linear coefficients, and furthermore it can calculate relative experience calculation return speed expression:

$$V_E = \begin{pmatrix} v_{E1x} \\ v_{E1y} \\ v_{E1z} \end{pmatrix} = \begin{pmatrix} \beta_{x0} & \beta_{x1} & \beta_{x2} & \beta_{x3} & \beta_{x4} \\ \beta_{y0} & \beta_{y1} & \beta_{y2} & \beta_{y3} & \beta_{y4} \\ \beta_{z0} & \beta_{z1} & \beta_{z2} & \beta_{z3} & \beta_{z4} \end{pmatrix} \begin{pmatrix} 1 \\ \Delta x \\ \Delta y \\ \Delta z \\ v_{2xy} \end{pmatrix}$$

Return speed weighted calculation

Due to simplified physical model and experience data model's calculation on return speed have their own drawbacks, in order to make up for the two methods deficiency, combine with the two advantages, adopt dynamic weight method to proceed with return speed calculation, realize dynamic weighted return speed computational method is as following:

$$v_f = \eta_b v_b + \eta_E v_E$$

$$\eta_b + \eta_E = 1$$

Among them, v_f represents after weighting final return speed calculated value, η_b, η_E respectively represent two computational methods' weights sizes. And weight value is changing, it needs to give initial conditions' weight value in the beginning, and then analyze actual drop point and expected drop point errors sizes and self adjustment weights values sizes by robot actual combats experiences data accumulation, so that let return speed more correct.

CONCLUSIONS

The paper on the basis of physical model and experience model, it proposes a kind of new dynamic weight value return speed computational method, weighted combines simplified physical model computational method with experience data computational method to calculate tablet tennis robot return speed. And by analyzing drop point and predicted point fall values, adjust the two methods weights values in calculating return speed. It realizes weights dynamic forms and ensures return speed accuracy.

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