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Based on grey theory optimization model 110-meter hurdles

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ABSTRACT

In order to improve the short stride athletes' technical action and increase competition results, this research first establishes the optimal take-off angle model of hurdles according to the gravity acceleration, resistance coefficient and other factors. And according to the top three achievements of the 1980-2012 period nine Olympic Games men's 110 meters hurdles, it uses gray prediction model to forecast the top three achievements of the next-two Olympic 110-meter hurdles. The results show that the top three achievements of the 2016 Olympic 110 meters hurdles are respectively 12.82 seconds, 13.03 seconds and 13.07 seconds; achievements in 2020 are 12.79 seconds, 13.02 seconds and 13.03 seconds; the achievement of Olympic Games overall is increasing year by year. The research result is conductive to hurdler achievement's improvement, and provides certain scientific basis for its day-to-day training.

KEYWORDS

Gray prediction model;
110-meter hurdles;
Achievements;
Optimal take-off angle.

INTRODUCTION

In the 28th Athens Olympic Games, Chinese athlete Liu Xiang won the men's 110 meters hurdles gold medal by 12.91 seconds equalling the world record. This achievement shocked the world; break the zero record of gold medal in China even Asia men's short stride project. In recent years, more advanced technology is applied to the short stride project making the achievements of short stride project have a new breakthrough. Therefore how to perfect hurdles technical movements more precisely and how to accurately predict the achievement of short stride project in the next few years have important significance.

Previous hurdle research has always focused on the whole process of hurdles, and research on starting and the stride between hurdles has relatively matured. The study on optimal take-off angle of hurdles are mostly macro, there are rarely study that calculate the optimal take-off angle according to athlete's different body characteristics; forecast on results of the 110-meter hurdles are mostly predictions on the future achievements of an athlete. But for hurdlers he not only needs to know his future achievements, but also should know clearly the future of the world's top level athletes, thus can he identify his own position and strive toward an established goal.

This paper first deduces the optimal take-off angle of hurdles on the basis of the gravity acceleration due, resistance coefficient, air density, human body mass, height of the body center of gravity, the frontal area when the human body is upright, the instantaneous horizontal velocity before take-off, take-off distance, the minimum distance from body gravity center to hurdle top, average speed between hurdles, reaction forces of backward kicking and action time of rear kicking and other factors. According to the top three performance of nine Olympic Games men's 110 meters hurdles in the 1980-2012 periods, this paper uses gray forecasting model to predict the top three scores of the future next-two Olympic 110-meter hurdles. Through this research it provides certain basis for the hurdler scientific training and for managers to develop a long-term plan, making modest contribution to the development of China's short stride project.

THE OPTIMAL TAKE-OFF ANGLE MODEL OF HURDLES

The realization of this work supposes the availability of a great number of repetitions of samples responding to the same known theoretical model. In practice, as the theoretical model is

At the moment of taking-off, the human body suffers the impact of the inertia force the reaction force of rear pedal and air resistance. The following is discussion of the impact of these forces on the horizontal velocity.

Inertial force and reaction force of backward pedal:

Before taking-off, the instantaneous horizontal velocity generated by the inertial force is V_0, the reaction force of backward pedal is f, the action time of backward kicking is t, human body mass is m. According to the momentum conservation law, we can see the horizontal velocity of backward kicking generated by reaction force of backward kicking is $V1=\frac{f \cdot t}{m}\cos\alpha$, α is the optimal take-off angle.

Air resistance: since it is very difficult to accurately describe the resistance in the cross-hurdle process when the body posture constantly changes and the speed changes. Therefore, it is necessary to do some simplification[4]. We take the average speed between hurdles V_1 to approximately replace air resistance speed (the human motion speed). By this time the air resistance to human body is $f=-c\rho A_0 V_1^2\cos\alpha$.

Wherein A_0 are the frontal area of the human body, $\rho=0.001293g/m^3$ and the action time of the air resistance is:

$$t=\frac{S_1}{V_1}=\frac{S_0-h_0\cos\alpha}{V_1} \quad (1)$$

Therefore, the final velocity generated by the air resistance is:

$$V_2=\frac{-c\rho A_0V_1^2\cos(S_0-h_0\cos\alpha)}{mV_1}=-\frac{1}{m}c\rho A_0V_1(S_0-h_0\cos\alpha)\cos\alpha \quad (2)$$

Therefore obtain the average speed of the air resistance:

$$V_x=-\frac{1}{2m}c\rho A_0V_1(S_0-h_0\cos\alpha)\cos\alpha \quad (3)$$

From the above analysis, the total average speed when the human body steps over the hurdle:

$$V=V_0+V_1+V_2$$

$$V=V_0+\frac{1}{2m}(2ft-c\rho A_0V_1S_0)\cos\alpha-\frac{1}{2m}c\rho A_0V_1h_0\cos^2\alpha \quad (4)$$

Therefore the time from human body center to over the hurdle is:

$$t_1=\frac{2m(S_0-h_0\cos\alpha)}{2mV_0+(2ft-c\rho A_0V_1S_0)\cos\alpha-c\rho A_0V_1h_0\cos^2\alpha} \quad (5)$$

Thus we can obtain the free fall distance h_2:

$$h_2=\frac{1}{2}gt^2\text{(Stride over the hurdle)} \quad (6)$$

Assume that point P is the center of body gravity, then:

$$\tan\alpha=\frac{h_1+h_2+h-h_0\sin\alpha}{S_0-h_0\cos\alpha} \quad (7)$$

Namely,

$$\tan\alpha=\frac{1}{S_0}(h_1+h_2+h) \quad (8)$$

Substitute equation (5) and (6) into above equation. After arrangement the optimal take-off angle satisfies the following equation:

$$A\cos^4\alpha+B\cos^3\alpha\sin\alpha+C\cos^3\alpha+D\cos^2\alpha\sin\alpha+ E\cos^2\alpha+F\cos\alpha\sin\alpha+G\cos\alpha+H\sin\alpha+T\tan\alpha+K=0 \quad (9)$$

The above equation is the optimal take-off angle equation. The coefficients *A,B,C,D,E,F,K,T* are function of human quality parameters m, h_0, A_0, dynamic stereotype parameter V_0, S_0, h_1, f, t and hurdle height h, they are:

$$A=-(h_1+h)\alpha^2$$

$$B=S_0\alpha^2$$

$$C=2(h_1+h)\beta\alpha$$

$$D=-2S_0\beta\alpha$$

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$$E = 2(h_1 + h)mV_0\alpha - (h_1 + h)\beta^2 - \frac{2m^2h_0^2}{g}$$

$$F = S_0\beta^2 - 2mV_0S_0\alpha$$

$$G = \frac{4m^2}{g}S_0h_0 - 4mV_0(h_1 + h)\beta$$

$$H = 4S_0mV_0\beta$$

$$K = -4(h_1 + h)m^2V_0^2 + \frac{2m^2S_0^2}{g}$$

$$T = 4S_0m^2V_0^2$$

And:

$$\alpha = c\rho A_0V_1h_0$$

$$\beta = 2f \cdot t\frac{\alpha}{h_0}$$

ACHIEVEMENT FORECAST OF THE NEXT-TWO OLYMPIC 110-METER HURDLES

Introduction to grey prediction model

The grey prediction model was first found in the book gray system theory of Deng-ju Long Professor. The basic principles of the method is: first accumulate raw data, form one-time accumulated series, establish the model based on the cumulative series, predict the follow-up value of the cumulative series through the model, and do regressive restoration to the prediction value of the cumulative series, thereby obtain the prediction value of the original series. Specific modeling steps are as follows:

Suppose original data sequence $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$, *n* is the number of data.

(1) Conduct accumulation on the original data sequence to weaken volatility and randomness of the random sequence, and obtain the new data sequence $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$, including:

$$x^{(1)}(t) = \sum_{k=1}^{t} x^{(0)}(k),\ t = 1,2,\cdots,n$$

$$x^{(1)}(t+1) = \sum_{k=1}^{t+1} x^{(0)}(k),\ t = 1,2,\cdots,n$$

(2) Establish the first-order linear differential equations of $x^{(1)}(t)$ on $x^{(1)}(t)$:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = u$$

(3) Therein,are undetermined coefficients, respectively, called the development coefficient and gray actuating quantity. The effective range of *a* is (-2, 2), and denote the matrix constructed by, *a*, *u* is $\hat{a} = \begin{pmatrix} a \\ u \end{pmatrix}$.

As long as figure out parameters *a*, *u* then $x^{(1)}(t)$ can be calculated, and find the future predicted value of $x^{(0)}$.

(4) The mean value generation B and constant term vector Y_n of accumulated generating data, namely:

$$B = \begin{bmatrix} 0.5(x^{(1)}(1) + x^{(1)}(2)) \\ 0.5(x^{(1)}(2) + x^{(1)}(3)) \\ 0.5(x^{(1)}(n-1) + x^{(1)}(n)) \end{bmatrix} \quad Y_n = (x^{(0)}(2), x^{(0)}(3), \cdots, x^{(0)}(n))^T$$

(5) Use the least squares method to solve the gray parameter $\hat{a}$, then:

$$\hat{a} = \begin{pmatrix} a \\ u \end{pmatrix} = (B^TB)^{-1}B^TY_n$$

(6) Substitute gray parameter $\hat{a}$ into $\frac{dx^{(1)}}{dt} + ax^{(1)} = u$, and solve $\frac{dx^{(1)}}{dt} + ax^{(1)} = u$, get:

$$\hat{x}^{(1)}(t+1) = \left(x^{(0)}(1) - \frac{u}{a}\right)e^{-at} + \frac{u}{a}$$

As $\hat{a}$ is the approximation calculated by the least squares method, so $\hat{x}^{(1)}(t+1)$ is an approximate expression. In order to distinguish from the original sequence $\hat{x}^{(1)}(t+1)$, therefore it is referred to as $\hat{x}^{(1)}(t+1)$.

Discrete function expression $\hat{x}^{(1)}(t+1)$ and $\hat{x}^{(1)}(t)$, and do subtraction of the two in order to restore the original sequence $\hat{x}^{(0)}$ and $\hat{x}^{(0)}(t+1)$ get approximate data sequence $\hat{x}^{(0)}(t+1)$, which is shown as follows:

$$\hat{x}^{(0)}(t+1) = \hat{x}^{(1)}(t+1) - \hat{x}^{(1)}(t)$$

Test the established gray model, the steps are as follows:

(1) Calculate the residual $e^{(0)}(t)$ and relative error $q(x)$ between $x^{(0)}$ and $\hat{x}^{(0)}(t)$:

$$e^{(0)}(t) = x^{(0)} - \hat{x}^{(0)}(t)$$

$$q(x) = \frac{e^{(0)}(t)}{x^{(0)}(t)}$$

(2) Seek the mean value $x^{(0)}$ of original data and

variance s_1.

(3) Calculate the average value $\bar{q}$ of $e^{(0)}(t)$ and the residual variance s_2.

(4) Calculate the variance ratio $C = \frac{s_2}{s_1}$.

(5) Calculate the small error probability $P = P\{|e(t)| < 0.6745 s_1\}$.

(7) Carry through predictions using the model:

$$\hat{x}^{(0)} = \left[\hat{x}^{(0)}(1), \hat{x}^{(0)}(2), \cdots, \hat{x}^{(0)}(n), \hat{x}^{(0)}(n+1), \cdots, \hat{x}^{(0)}(n+m)\right]$$

Performance forecast of the next two Olympic 110-meter hurdles

Use MATLAB and gray prediction model to forecast performance data of the 1980-2012 Olympic 110-meter hurdles gold, silver and bronze; the original data and predictive value are shown in TABLE 1 below:

TABLE 1 : The original data and predictive value of the 1980-2012 Olympic 110-meter hurdles gold, silver and bronze

Year	Gold medal	Silver medal	Bronze medal
1980	13.39	13.4	13.44
1984	13.2	13.23	13.4
1988	12.98	13.28	13.38
1992	13.12	13.24	13.26
1996	12.95	13.09	13.17
2000	13	13.16	13.22
2004	12.91	13.18	13.2
2008	12.93	13.17	13.18
2012	12.92	13.04	13.12
2016	12.82	13.03	13.07
2020	12.79	13.02	13.03

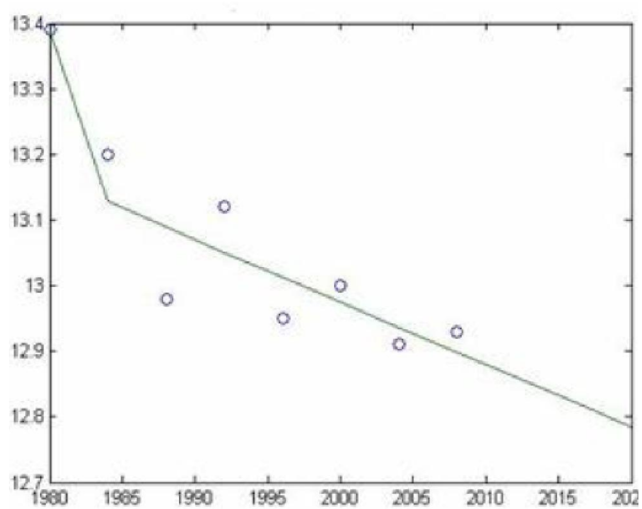

Figure 1 : Change curve of successive gold medal achievement

The overall change trend of gold, silver, and bronze medalist' previous, present and future achievements are shown in Figure 1, Figure 2 and Figure 3 below:

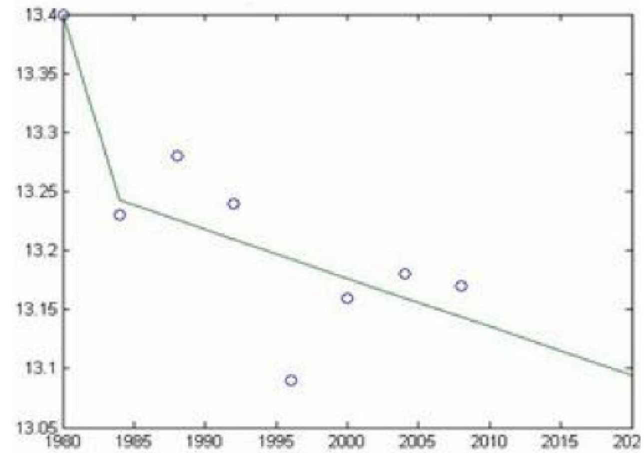

Figure 2 : Change curve of successive silver medal achievement

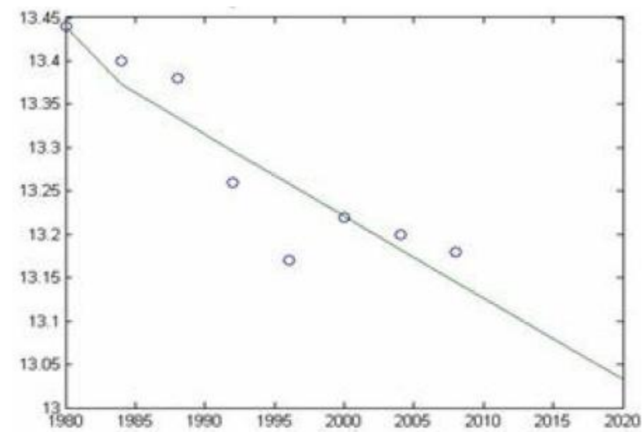

Figure 3 : Change curve of successive bronze medal achievement

CONCLUSIONS

(1) This paper establishes the optimal take-off angle model of hurdles. This model overall considers the gravity acceleration due, resistance coefficient, air density, human body mass, height of the body center of gravity, the frontal area when the human body is upright, the instantaneous horizontal velocity before take-off, take-off distance, the minimum distance from body gravity center to hurdle top, average speed between hurdles, reaction forces of backward kicking and action time of rear kicking and other factors; for different athletes we can use the model to calculate the optimal take-off angle

suited to their own characteristics, which is in favor of the increasing of hurdles athletes' achievements.

(2) This paper uses gray prediction model to forecast the gold, silver and bronze medals' achievements of 2016 and 2020 two-session Olympic men's 110 meters hurdles, finding that the Olympics achievements in general has increased annually, which requires hurdles coaches and athletes to improve training effect in the day-to-day training, and to improve their performance through a variety of scientific approaches in order to have certain competitiveness in the future competitions.

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