

Target Movement Research Based on Spearman's Rank Correlation Analysis and Ridge Regression: Key Identification, Patterns, and Prediction

Jiaqi Lin*

Taizhou Vocational College of Science & Technology, Taizhou, China

* Corresponding author: Jiaqi Lin (Email: 15067273316@163.com)

Abstract: This paper proposes a research methodology for the long jump that integrates kinematic analysis with statistical modeling. It focuses on determining the timing of takeoff and landing, analyzing the movement patterns during the flight phase, and investigating the relationship between influencing factors and performance outcomes, including predictive capabilities. First, using key foot joints as the core, precise timing of takeoff and landing is determined by calculating average vertical foot velocity and position. This is combined with three-tier dynamic indicators—displacement, velocity, and acceleration—along with quantifying fluctuation thresholds across phases to obtain critical timing parameters for athletes. Second, treating athletes as point masses, a projectile motion model is constructed. The flight phase is divided into ascent, apex, and descent stages. The movement patterns of parameters such as center-of-mass trajectory and joint angles are analyzed, comparing differences in movement characteristics among athletes. Finally, a Spearman rank correlation analysis model identifies 33 features significantly correlated with performance. Ridge regression then addresses multicollinearity among features and quantifies each factor's contribution to performance, enabling the construction and validation of a long jump prediction model. This model accurately captures critical movement nodes, clarifies movement patterns, effectively screens core influencing factors, and reliably predicts long jump performance while resolving multicollinearity issues, yielding robust analytical results.

Keywords: Spearman Rank Correlation Analysis, Ridge Regression, Dynamic Indicator Calculation.

1. Introduction

This paper focuses on analyzing key phases in the long jump, quantifying performance-influencing factors, and developing predictive models. By integrating kinematic analysis with statistical modeling, it aims to uncover movement patterns and establish a performance forecasting system. First, centering on key foot joints, this paper calculates the vertical average position and velocity of the foot. Using second-order forward difference to compute acceleration, this paper quantifies signal fluctuation thresholds for each phase, precisely pinpointing takeoff and landing moments to derive critical timing parameters for athletes [1][2]. Second, the flight phase is segmented into ascent, apex, and descent. A point-mass projectile model analyzes the center-of-mass trajectory, calculating joint angles and trunk inclination angles. By comparing athlete movement variations, the influence of leg efficiency and trunk stability is clarified [3][4]. Finally, Spearman's rank correlation analysis first screens 33 features significantly correlated with performance. Ridge regression then addresses multicollinearity and quantifies feature contributions to build and validate a performance prediction model [4-6]. Experimental results demonstrate this method's ability to accurately identify critical movement moments, reveal aerial patterns, and pinpoint core factors through predictive modeling. The consistent outcomes with actual performance provide support for optimizing long jump technique.

2. Takeoff/Landing Moment Determination and Airborne Motion Law Analysis

2.1. Determination of Takeoff and Landing Timing and Motion Process Analysis

Taking key foot joints as the core analysis subjects, this approach identifies functionally relevant features—such as velocity and acceleration metrics—and integrates them with a multi-indicator threshold fusion system. This enables precise localization of takeoff and landing moments while establishing clear temporal boundaries for subsequent analysis of the motion trajectory from takeoff to landing.

2.1.1. Calculation of Average Foot Velocity and Position

In kinematic analysis, the change in the vertical direction is the core for determining take-off and landing. Since the foot does not fluctuate much during the jump preparation phase, the average position of the foot is chosen as the determination point.

Based on the selected average foot position, the overall average vertical position $Y(t)$ of the foot at frame t is constructed. To reflect the vertical motion trend of the foot, the velocity in the vertical direction is defined as $v_t = \frac{Y_t - Y_{t-1}}{\Delta t}$, where the numerator represents the height difference of the average foot position between frame t and frame $t-1$, and the frame time $\Delta t = 0.33$. The point where the vertical velocity increases sharply is very likely to be the take-off point.

2.1.2. Calculation of Dynamic Indicators Based on Dynamics

The essence of take - off and landing involves abrupt changes in the vertical motion state of the foot. From the preparatory movements before takeoff to the aerial phase, through maintaining suspension in midair, and finally to landing, the entire process involves complex dynamic changes. Therefore, three - layer dynamic indicators of displacement, velocity, and acceleration are selected for calculation, so as to comprehensively describe motion characteristics from different dimensions and more accurately determine the take - off frame and landing frame.

Acceleration is a direct indicator reflecting the force state in the vertical direction and can reflect the magnitude of take - off and landing. It is calculated using the second - order forward difference. Thus, the vertical acceleration at frame t is:

$$a_t = \frac{v_t - v_{t-1}}{\Delta t} = \frac{y_t - 2y_{t-1} + y_{t-2}}{(\Delta t)^2} \quad (1)$$

According to the solved value, the motion state can be judged. If $a_t > 0$, it may be the take - off phase, where an upward accelerating force is generated.

Based on this, by defining the normal fluctuation range of each phase and determining the threshold, the upper and lower limits of normal fluctuations in each phase are quantified for determination, so as to confirm whether the foot is out of the sequence interval.

1. In the preparation phase, the first 10 frames are taken as normal fluctuations. The maximum value of the signal in this phase is taken as the upper fluctuation limit. If it exceeds this limit, it means leaving the static state: $\Delta Y_{pre} = \max \{\Delta Y_t | t \in [1, 10]\}$. If $\Delta Y_t > \Delta Y_{pre}$, it indicates that the displacement exceeds the normal fluctuation.

2. The normal fluctuation in the take - off phase is a small - amplitude acceleration before force application. This paper can take the transition frame $t = 11$, and 1.5 times is taken as the upper fluctuation limit: $\Delta Y_{takeoff} = 1.5\Delta Y_{11}$. If

$\Delta Y_t > \Delta Y_{takeoff}$, it indicates that the displacement exceeds the threshold range.

3. The normal fluctuation in the landing phase should satisfy the stable displacement or velocity during falling. 0.2 times is taken as the lower fluctuation limit. If it is lower than the lower limit, it means touching the ground: $\Delta Y_{land} = 0.2\Delta Y_{peak}$ ($\Delta Y_{peak} = \Delta Y_{max}$). If $\Delta Y_t < \Delta Y_{land}$, it indicates exceeding the range.

Based on the above theory, the key time parameters of two athletes are obtained as in the Table 1:

Table 1. Key time parameters for the two athletes

Athlete	Take-off Moment	Landing Moment	Airborne Time
Athlete 1	The 120th frame (3.96s)	The 140th frame (4.62s)	0.66s
Athlete 2	The 162nd frame (5.35s)	The 180th frame (5.94s)	0.59s

2.2. Analysis of Movement Law in Stages of Airborne Phase

After determining the moments of an athlete's take - off and landing, according to the preprocessed coordinates of key points, the airborne law is analyzed by dividing into the ascending period, the highest point, and the descending period, and multiple kinematic parameters such as the center of - gravity trajectory and joint angles are calculated to analyze the characteristics of movements in the air.

2.2.1. Stage Division and Time Characteristics

The airborne phase of long jump can be simply described by a kinematic model. The athlete as a whole is regarded as a particle, and the movement of the center of gravity is regarded as projectile motion, which satisfies uniformly accelerated linear motion in the vertical direction. So, the trajectory of the center of gravity is a standard parabola, and the trajectory of the airborne phase is described based on this. The following Figure 1 is the center - of - gravity trajectory diagram of the athlete:

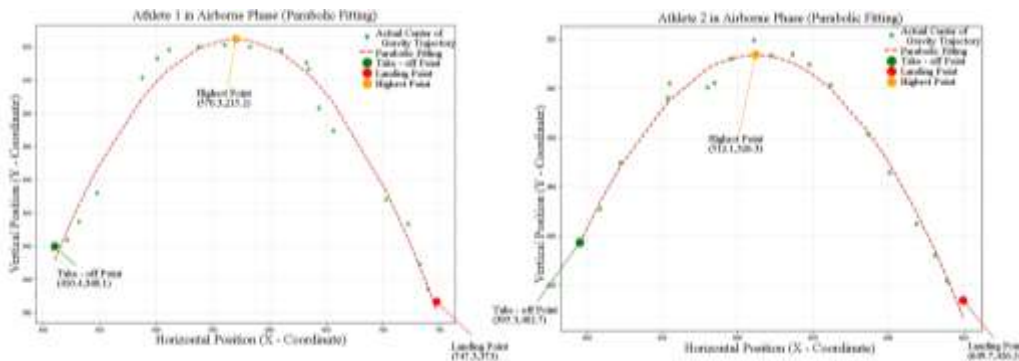


Figure 1. Center of gravity trajectory diagram for Subject 1 and Subject 2

From the Figure 1, the three stages can be analyzed intuitively. The parabola first rises and then falls, and the vertex is the only extreme point. Therefore, the airborne process can be clearly divided into three stages: ascending period, the highest point, and descending period.

2.2.2. Movement Law in Ascending Period ($t_0 \sim t_{peak}$)

The core feature of the ascending period is that the vertical

velocity gradually transitions from a negative value at touchdown to 0. The posture adjustment in this stage directly affects the height of the jump. Combined with the displacement data of foot key points, the law is derived. The calculation of the knee joint angle is the included angle between the two vectors from the hip joint to the knee joint and from the ankle joint to the knee joint.

Athlete 1 shows a stable upward trend of the center of

gravity in the ascending period. The knee joint angle gradually extends from about 120° – 140° at take - off to 170° – 175° at the highest point, and the trunk forward tilt angle is maintained at about 10° – 15° . This posture not only ensures the force - exerting efficiency in the vertical direction but also reduces the unnecessary loss of horizontal velocity, reflecting good take - off posture control.

Athlete 2's vertical change of the center of gravity in the ascending period is relatively gentle. The trunk forward tilt angle gradually increases from 110° – 130° at take-off to 165° – 170° , and the lifting degree is slightly smaller than that of Athlete 1.

Based on this, Athlete 1 has higher leg extension efficiency, and the vertical lifting amplitude is a little higher than that of Athlete 2, which provides a vertical height basis for extending the airborne time. Moreover, Athlete 1 also has better joint coordination, and the stability of the trunk reduces the loss of vertical force. However, Athlete 2 disperses the leg extension force due to the forward tilt of the trunk, resulting in insufficient vertical lifting.

2.2.3. Movement Law at the Highest Point (t_{peak})

Athlete 1's center of gravity continues to rise slightly at this stage, accounting for about 52.5% of the estimated maximum vertical displacement range of the airborne trajectory. The knee joint angle moderately decreases to 135° , and the trunk forward tilt angle is basically maintained at 30° . Through subtle posture adjustment, kinetic energy is stored for the horizontal displacement in the descending period, showing typical transition characteristics of the airborne posture.

When Athlete 2 is at the highest point, the center of gravity is significantly higher than the take-off point, which compensates to a certain extent for the insufficient vertical

displacement in the ascending period. Moreover, the knee joint angle is 125° , which is close to that of Athlete 1, but the trunk forward tilt angle is still maintained at 36.5° . A larger forward tilt may affect the balance control in the air and increase the adjustment difficulty in the landing phase.

2.2.4. Movement Law in Descending Period ($t_{\text{peak}} \sim t_1$)

The center of gravity of Athlete 1 descends in the vertical direction, and the knee joint bends greatly, with the angle decreasing from 162° to 135° , forming sufficient buffer space. At the same time, the trunk forward tilt angle stabilizes at 28.9° , which is beneficial for the balance of the center of gravity and the fixation of the distance during landing.

The vertical descending value of the center of gravity of Athlete 2 is smaller, and the descending amplitude is also smaller than that of Athlete 1. Combined with the steepness feature of his trajectory, it is inferred that the vertical height at landing is closer to the highest point. At the same time, the

knee joint angle bends from 155.2° to 109.7° , and the bending degree is not as sufficient as that of Athlete 1, which may lead to insufficient landing buffer and increase the impact load on the lower limb joints.

2.3. Long - Jump Process Law

The following Figure 2 is a diagram of the ankle height changes of Athlete 1 and Athlete 2. It can be found that Athlete 1 stored energy many times before take - off, and the curve rose and fell repeatedly. After take - off, the ankle height quickly climbed to the peak, and the interval from the take - off frame to the falling frame was long, with a long airborne time. Finally, the landing curve quickly became stable, indicating that the lower limbs buffered the impact force more efficiently and controlled the posture more effectively during landing, and could stabilize the body quickly.

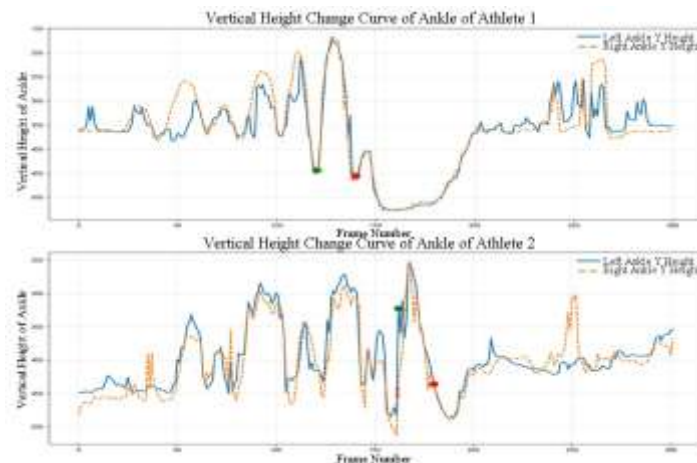


Figure 2. Ankle vertical height variation curve

Observing the curve of Athlete 2, the ankle height changes more scattered before take - off, the height peak after take - off is lower, and the airborne time is short. Moreover, after landing, the ankle height still fluctuates slightly and repeatedly, reflecting the different movement habits and lower limb control characteristics of different people.

3. Long-Jump Performance Influencing Factor Analysis and Prediction Model Construction

3.1. Establishment of Spearman Rank Correlation Analysis Model

To explore the strength and direction of the correlation between each potential influencing factor X_i and long - jump performance Y , a Spearman rank correlation analysis model is established. Its core is to calculate the Spearman rank correlation coefficient r_s between each influencing factor X_i and performance Y . The calculation formula of this coefficient is as follows:

$$r_s = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2 - 1)} \quad (2)$$

Among them, n is the number of athletes, and d_i represents the ranking difference of the i -th athlete in the two variables of factor X and performance Y (that is,

$$\beta^{ridge} = \arg \min_{\beta} \left\{ \sum_{i=1}^n \left(Y_i - \beta_0 - \sum_{j=1}^p \beta_j X_{ij} \right)^2 + \lambda \sum_{j=1}^p \beta_j^2 \right\} \quad (4)$$

First, Spearman correlation calculation is carried out, and then a ridge regression model is constructed for the selected features to solve the regression coefficients.

3.2. Model Solution and Evaluation

3.2.1. 6.3.1 Solution of Spearman Rank Correlation Analysis

Based on Spearman rank correlation analysis, the

$$d_i = \text{rank}(X_i) - \text{rank}(Y_i).$$

Through Spearman correlation analysis, a batch of variables significantly related to long - jump performance is initially screened out, and the cognition of monotonic correlation between each factor and performance is established.

Let the long - jump performance of the i -th athlete be Y_i , and the independent variable be a p -dimensional feature vector $\mathbf{X}_i = (X_{i1}, X_{i2}, \dots, X_{ip})^T$ including kinematic indicators and physical indicators. Then the ridge regression model can be expressed as:

$$Y_i = \beta_0 + \sum_{j=1}^p \beta_j X_{ij} + \varepsilon_i \quad (3)$$

Among them, β_0 is the intercept term, $\beta_j (j=1, 2, \dots, p)$ is the regression coefficient corresponding to the physical indicator, and ε_i is the random error term. Ridge regression estimates parameters by minimizing the following objective function:

correlation coefficients and their significance (p -value) of all features with long - jump performance are calculated.

Taking $p < 0.05$ as the significance standard, 33 features significantly related to performance are screened out, and their correlation coefficients and p -values are shown in Table 2:

Table 2. 33 characteristics significantly associated with academic performance

Feature Name	Correlation Coefficient	p-value	Feature Name	Correlation Coefficient	p-value
Hip Joint Flexion	0.0945	0.6068	Visceral Fat	0.2382	0.1893
Knee Joint Flexion	-0.2363	0.1930	Moisture Content	0.5880	0.0004
Ankle Joint Flexion	-0.3383	0.0582	Bone Mass	0.5043	0.0033
Trunk Forward Tilt Angle	-0.2341	0.1973	Basal Metabolism	0.6778	0.000020
Muscle Explosive Power	0.3367	0.0595	Fat Mass	0.7275	0.000002
Muscle Explosive Power	0.3367	0.0595	Fat Mass	0.7275	0.000002
Arm Whip-like Swing Angle	-0.1731	0.3434	Muscle Rate	0.5868	0.0004
Arm Whip-like Swing Force	0.4022	0.0225	Skeletal Muscle Mass	0.6296	0.0001
Heel-to-Ground Angle	-0.3000	0.0953	Moisture Mass	0.7410	0.000001
Airborne Time	-0.2907	0.1066	Protein Mass	0.6077	0.0002
Age	0.6098	0.0002	Standard Body Weight	0.7410	0.000001
Gender	0.7380	0.000001	Body Weight Control	-0.6579	0.000043
Height	0.7410	0.000001	Fat Control	-0.8742	<0.0000001
Body Weight	0.7892	<0.0000001	Protein Rate	-0.5714	0.0006
Nutritional Status	-0.7858	<0.0000001	Fat - Free Mass	0.7410	0.000001
Body Type	-0.7858	<0.0000001	Body Score	0.9098	<0.0000001
Body Fat Rate	0.5317	0.0017	Performance	1.0000	<0.0000001
Muscle Mass	0.7410	0.000001	/	/	/

Combined with the key factors from Spearman correlation

analysis, it can be seen that the standing long - jump

performance is mainly affected by the following factors: Muscle explosive power — the stronger the explosive power, the better the long - jump performance; The force of arm swing provides additional forward momentum for the body, improving the take - off effect; Height and weight, as physical foundations, have a significant positive impact on performance; A too high body fat percentage will reduce the power - to - weight ratio, increase invalid load, and significantly weaken take - off efficiency.

3.2.2. Solution and Evaluation of Ridge Regression Analysis

To accurately quantify the independent contribution of each factor to the long - jump performance and build a stable and reliable prediction model, the Ridge Regression method is introduced. Ridge regression can effectively handle the problem of multicollinearity and identify the core factors affecting long - jump performance.

The finally obtained ridge regression coefficients are shown in Table 3:

Table 3. Key coefficients of ridge regression coefficients

Feature	Coefficient	Feature	Coefficient
Trunk Forward Tilt Angle	-0.013994	Bone Mass	-0.032165
Muscle Explosive Power	0.020045	Basal Metabolism	0.079457
Arm Whip - like Swing Angle	-0.050999	Fat Mass	0.061959
Arm Whip - like Swing Force	0.057218	Muscle Rate	0.119788
Heel - to - Ground Angle	-0.001024	Skeletal Muscle Mass	0.050968
Airborne Time	-0.128005	Moisture Mass	0.071887
Age	0.005498	Protein Mass	-0.011364
Height	-0.020507	Standard Body Weight	-0.020041
Body Weight	0.059412	Body Weight Control	-0.209261
Body Fat Rate	0.038537	Fat Control	-0.159329
Fat - Free Mass	0.057672	Protein Rate	-0.084130
/	/	Body Score	0.145787

The larger the absolute value of the coefficient, the stronger the influence intensity of the feature on the performance; a positive coefficient indicates a positive promoting effect on the performance, while a negative coefficient indicates a negative restrictive effect. Among the features with a relatively strong positive influence, the regression coefficient of body score is close to 0.15, which is the feature with the most significant promoting effect on performance. Among the features with a relatively prominent negative influence, the absolute value of the regression coefficient of body fat control amount is relatively large, indicating that excessive body fat

will restrict the long - jump performance.

3.3. Analysis Results of Key Points

Combining the analysis logic of physical characteristics and posture parameters, posture parameters are the direct dynamic influencing factors of performance. The coordinates of the body's center of gravity reflect the airborne height and body balance, and the average height of the hands reflects the swing amplitude and force rhythm. The motion sequences of athletes before and after adjusting their long - jump postures are selected, and the results are shown in Figure 3:

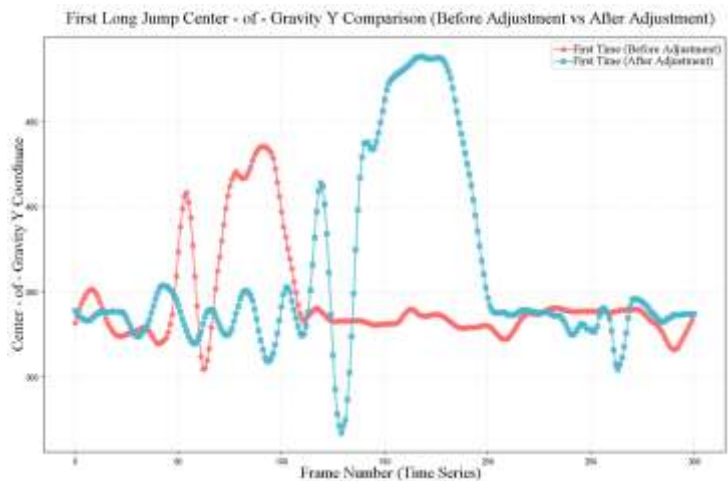


Figure 3. Comparison diagram of body center of gravity y adjustment before and after adjustment

After adjustment, the airborne peak value of the body's center of gravity is significantly higher. The peak value after adjustment is nearly 480, and that before adjustment is about 430. Moreover, the height of the center of gravity is more stable during the airborne phase. This indicates that after posture optimization, the body's airborne ability and airborne posture control ability are enhanced, laying a foundation for the improvement of long - jump performance.

Similarly, the height peak value of hand swing after adjustment (nearly 540) is much higher than that before adjustment (about 470), and the swing rhythm is more coherent. The rising segment of the curve after adjustment is smoother, and the peak value lasts longer.

3.4. Long-Jump Performance Prediction Model Construction and Mathematical Implementation Based on Ridge Regression

A long - jump performance prediction model is constructed based on the ridge regression algorithm. Key features such as

muscle explosive power and airborne time are introduced. Through regression coefficients, the problem of multicollinearity among features is effectively solved, and the long - jump performance of Athlete 11 is predicted.

As shown in Table 4, it is the prediction result for 8 key parameters. Based on the current values of Athlete 11, within the range of the optimization target, a reasonable adjustment direction is given:

Table 4. Comparison of power load forecasting of 403 line

Key Parameter	mean	std	Athlete 11's Current Value
Arm Whip - like Swing Force	38.28	2.57	31.5
Airborne Time	1137.5	319.32	720
Trunk Forward Tilt Angle	28.04	3.0443	20.81
Knee Joint Flexion	0.26	0.029	0.21
Muscle Explosive Power	30.63	2.505	25.2
Hip Joint Flexion	402.5	130.79	280
Ankle Joint Flexion	146.44	6.95	154.14
Arm Whip - like Swing Angle	75.72	5.76	66.31

The actual take - off moment of Athlete 11 is the 178th frame, the landing moment is the 189th frame, the airborne time is 0.36s, and the final long - jump performance is 1.03m, which is in line with the deduction of the above theory.

4. Conclusions

This paper proposes a long jump research framework integrating kinematic dynamic analysis with Spearman rank correlation and ridge regression. This framework accurately identifies critical movement moments, systematically analyzes movement patterns, and reliably predicts performance, providing quantitative support for optimizing long jump technique. First, focusing on key foot joints, it combines vertical velocity and acceleration metrics with fluctuation thresholds for each phase to precisely locate takeoff and landing moments, capturing key parameters during movement and resolving ambiguity in phase segmentation. Second, the flight phase is subdivided into ascent, apex, and descent segments. A point-mass projectile model analyzes center-of-mass trajectories, integrating joint angles and other parameters to reveal how leg extension efficiency and trunk stability influence aerial posture. Third, Spearman's rank correlation identifies 33 features significantly correlated with performance. Ridge regression then addresses multicollinearity among these features, quantifying each's contribution to performance outcomes. Finally, the performance prediction model constructed within this framework demonstrated practical validity, with predicted results aligning with actual 1.03m performance. Future research may expand the sample size to enhance

analytical precision.

References

- [1] Ling Regression Models Based on Functional Principal Differential Equations and Principal Components: Theory and Applications
- [2] Liang Wanzong. Analysis of Technical Movements and Teaching Exploration in Standing Long Jump [J]. Henan Education (Basic Education Edition), 2025, (06): 84-85. DOI: CNKI:SUN:TECH.0.2025-06-037.
- [3] Han Bingnan, Li Chao. Study on the Work Characteristics of the Takeoff Leg and the Movement Characteristics of the Center of Gravity During the Takeoff Phase of Long Jump Athletes [J]. Journal of Guangzhou Sport University, 2015, 35(05): 88-91. DOI:10.13830/j.cnki.cn44-1129/g8.2015.05.023.
- [4] Gao Haiyan, Zhang Yue. Ridge Regression Model Based on Functional Principal Differential and Principal Components and Its Application [J]. Journal of Lanzhou University of Arts and Sciences (Natural Science Edition), 2023, 37(06): 17-24. DOI: 10.13804/j.cnki.2095-6991.2023.06.006.
- [5] Shi Jian, Zhang Shilin, Fan Zuosong, et al. Research on TBM Net Excavation Rate Prediction Model Based on Ridge Regression Analysis [J]. Research on Urban Rail Transit, 2025, 28(06): 37-42+53. DOI: 10.16037/j.1007-869x.20230594.
- [6] Yang Pan, Lu Lu, Wang Jibao, et al. Application of Spearman's Rank Correlation Coefficient Method Based on Principal Component Analysis in Water Quality Analysis of the Yangtze River Mainstream [J]. Environmental Engineering, 2019, 37(08): 76-80. DOI:10.13205/j.hjgc.201908014.