Finite Element Analysis of Badminton Engineering Mechanics Driven by Computer-aided Technical Movement

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Abstract. Badminton is a sport carried out relatively well in the sports, recreation, and fitness programs in China. There are many basic batting techniques in badminton. Among them, the technical movements feature the short flight path, straight arc, short time, and fast fall, which are the techniques required for the attack players. Throughout the development history of badminton sports skills and tactics, in the singles and doubles badminton competitions, powerful kill movement techniques, especially back-field movement techniques, are essential means of scoring in the match. In this paper, the computer-based Ariel system and myoelectric telemetry system are used to analyze two technical movements of male players in the badminton team, that is, near-net forehand smash and far-net forehand smash, to lay a foundation for comprehensive quantitative analysis of badminton technical movements while avoiding sports injuries due to irregular movements at the same time. The potential commonalities between different athletes' different technical movements are explored to lay a theoretical foundation for further improving the badminton technical movements.

Keywords: Men, Badminton, Forehand Technical Movement, Finite Element Analysis of Engineering Mechanics, Computer-aided Technical Movement

1. Introduction

The development trend of today's badminton sports techniques is dominated by pulls. Players have fewer and fewer opportunities to obtain technical movements during the match [1-2], and more technical movements become the "lead" for score in matches [3]. Especially in doubles, we can see that technical movement is often the key to determining the initiative of the match. Excellent movement techniques can effectively trap the opponent in passive, disrupt the opponent's footwork, standing, destroy the opponent's tactics, and even score directly. The technical movement is a very energy-consuming technical movement. If it fails to achieve the desired effect, it will make itself passive in the subsequent match [4-5]. In doubles, the number of technical movements is not necessarily proportional to the score.
of technical movements.

In this paper, the engineering mechanics finite element analysis method is used to obtain kinematic data of badminton technical movements, and the energy consumption of the main muscles involved in completing this movement is measured simultaneously. While revealing the basic principles of technical movements, the laws and characteristics of muscle activity of badminton technical movements are analyzed, and the force characteristics of related muscles and critical factors affecting the speed and quality of technical movements are explored when making technical movements. The authors can provide a theoretical basis for improving the technical level and avoiding injuries\(^{[6]}\).

2. Research objects and methods

The research object is three male badminton professional athletes in colleges and universities, and three athletes are proficient in two techniques of forehand and near forehand smash. The PEAK 3D frames were calibrated separately for the site. In the analysis, the calibration is performed according to the athlete's range of motion to ensure that the calibration space can meet the needs of motion analysis. The calibration accuracy is measured to ensure that the accuracy error does not exceed 3\% in meeting the needs of this study. Two Japanese JVC GR-DVL9800sH cameras were used to simultaneously record the athlete's movement techniques video from two fixed points on the field. The smash frequency was 100 Hz, and \( r \) is shown in Figure 1.

The raw materials taken were digitally processed by the software, and the American Ariel motion biomechanics high-speed analysis system was applied, and 22 joint points of the human body model and 25 link control points of the PEAK frame were analyzed. Then the data was processed by the DLT method; the two-dimensional data was converted into three-dimensional data and smoothed by a numerical filtering method. The truncation frequency was 6 during the analysis. The three-axis directions of the movement space are: the movement direction is X, the Y-axis is perpendicular to the X-axis in the horizontal plane, and the Z-axis is perpendicular to the horizontal plane. In the process of parsing the cut image, the right foot off-ground time that can be taken by both cameras is set as the time synchronization point, as shown in Figure 2.

This paper proposes a finite element analysis method for engineering mechanics, which decomposes the real symmetric tensor \( A \) into a linear combination of symmetric unit norm rank tensors.

\[
A = I_1 x_1 \circ x_1 \circ \cdots \circ x_1 + \cdots + I_R x_R \circ x_R \circ \cdots \circ x_R,
\]

\[
= I_1 x_1^d + \cdots + I_R x_R^d
\]  

(1)

Where \( I_1, \cdots, I_R \in \mathbb{R} \) and \( x_1, \cdots, x_R \in \mathbb{R}^e \). Scalar coefficient \( I_1, \cdots, I_R \) identify external products of algorithms for nonlinear systems.

The finite element analysis method of engineering mechanics leads to a tensor that decomposes a symmetric tensor into a limited sum of real numbers of symmetric rank external factors. Afterward, we prove that the finite element analysis method of engineering mechanics is suitable for any tensor sequence through the tensor embedding technique. The first step in the finite element analysis of engineering mechanics is to symmetry (4-way) \( A \in \mathbb{R}^{n \times n \times n \times n} \) reshape to a bi-symmetric matrix.
The eigen-decomposition of $A$ can be calculated as follows:

$$A = \sum_{i=1}^{n^2} \lambda_i v_i \otimes v_i = \sum_{i=1}^{n^2} \lambda_i v_i v_i^T$$

The symmetry of $A$ means the eigenvalues $\lambda_i$ is a real number, and the feature vector $v_i$ is orthogonal. Both eigenvalues and eigenvectors can be calculated by symmetric QR algorithm.

These feature vectors can now be $v_i$ reshape each of them into another bi-symmetric matrix $\bar{v}_i \otimes (v_i)$. That is, the symmetry of $A$ can be expressed as:

$$AP = A$$

Where $P$ is the replacement index $\frac{i_d}{2}, \cdots i_d$ the permutation matrix. Decompose $A$ into:

$$\left(\lambda_1 v_1 v_1^T + \cdots + \lambda_n v_n v_n^T\right)P = \left(\bar{\lambda}_1 \bar{v}_1 \bar{v}_1^T + \cdots + \bar{\lambda}_n \bar{v}_n \bar{v}_n^T\right)$$

Use the feature vector of the $i$-th term $v_i^T \left(i = 1, \cdots, n^2\right)$ Multiply left (Equation 4), assuming $\lambda_i \neq 0$, the following can be obtained:

$$v_i^T \left(\lambda_1 v_1 v_1^T + \cdots + \lambda_n v_n v_n^T\right)P = v_i^T \left(\bar{\lambda}_1 \bar{v}_1 \bar{v}_1^T + \cdots + \bar{\lambda}_n \bar{v}_n \bar{v}_n^T\right)$$

$$\Leftrightarrow \lambda_i v_i P = \bar{\lambda}_i \bar{v}_i$$

$$\Leftrightarrow v_i^T P = v_i^T$$

This means the feature vector $v_i \left(i = 1, \cdots, n^2\right)$ and reformed $\bar{v}_i$ It has different things from $A$. You can also calculate each symmetry $\bar{v}_i$ feature decomposition.

3. Results and analysis

The highest speeds of the upper arm are significantly different between the forehand smash near the net and far from the net. The forehand technical movement in badminton is the force process of the forearm driving the forearm. From Table 1, we can see that the highest speeds of the upper arm and forearm in badminton forehand smash near the net are $2.41 \sim 3.32 \text{m/s}$ and $6.64 \sim 8.87 \text{m/s}$, respectively. The maximum speeds of the upper arm and forearm in badminton forehand smash far from the net are $3.23 \sim 4.72 \text{m/s}$ and $6.99 \sim 8.26 \text{m/s}$, respectively. The speeds of upper arm in the badminton forehand smash near the net are all lower than those far from the net. The running speed and arc of the ball are determined by the angle and speed of the racket at the moment of batting.

In Table 2, we can see that when the athlete is doing a forehand approaching smash movement, the maximum range of the shoulder angle is $168.7 \sim 172.9 \text{°}$, and the maximum range of the shoulder angle
is 109.8° ~ 126.2°. The maximum value of the shoulder angle of forehand smash is significantly larger than that of forehand smash. This requires athletes to raise their elbow joints too high in advance to prepare for technical movements when approaching smash. As forehand smash movement is swift, the elbow joint cannot be raised to a large angle, so the forearm force is required to be swift. Therefore, forearm explosive training is vital when making smash far from the net.

Table 1. Timeline of the movement speed of the upper arm and forearm during the stroke of 3 athletes

| Test subject | Upper arm | Forearm | Upper arm | Forearm |
|--------------|-----------|---------|-----------|---------|
| Test subject | Top speed (m/s) | Corresponding time(s) | Top speed (m/s) | Corresponding time(s) |
| Object 1     | 2.41      | 0.18    | 6.64      | 0.32    |
| Object 2     | 3.32      | 0.23    | 8.87      | 0.36    |
| Object 3     | 3.04      | 0.20    | 7.97      | 0.34    |
| x±s          | 2.92 ± 0.20 ± 0.03 | 0.34 ± 0.02 | 4.14 ± 0.15 ± 0.02 | 0.28 ± 0.04 |
| Note: * means \( P < 0.05 \). |
Table 2. Statistical table of the maximum shoulder angles of two athletes in two technical movements

| test subject | Forehand near smash | Forehand Smash |
|--------------|---------------------|----------------|
| Shoulder angle(°) | humeral angle(°)         |                |
| Object 1     | 168.7               | 126.2          |
| Object 2     | 171.6               | 109.8          |
| Object 3     | 172.9               | 112.6          |
| x±s          | 171.1±2.2           | 116.2±8.8     |

Figure 1. Human motion coordinate diagram

Figure 2. Ariel data processing diagram

In order to obtain better effects of technical movements, athletes must adjust their body posture as early as possible to better force technical movements. The appropriate smash position is also a necessary condition for the effectiveness of technical movements. High-level professional athletes will reach the position of the technical movement before the ball falls so that they have enough time to prepare for the technical movement. Because badminton is a fast-changing sport, it is required to have a certain
concealment in the batting movement. The consistency of the movements is to meet the needs of this point. The preparation postures of the two technical movements are roughly similar, which can make it difficult for the opponent to judge. The course of the ball has the effect of confusing the opponent, increasing the difficulty of the opponent's defense, and enhancing the effectiveness of the offense.

The technical movement is a very complicated technique, which requires coordinating the forces of various joints of the body to work together. In general, the order of power of technical movement techniques is as follows: lower limb kicking, quick take-off, driving waist rotation; using the power of waist rotation to turn the upper body to the net, driving the right shoulder to increase the initial speed of the upper arm. The upper arm is used to drive the forearm to exert force, and use the forearm internal rotation to increase the rotation of the wrist further; at the moment of batting the ball, use the wrist to quickly press down to hit the ball out. The technical movement is a process of force transmission from bottom to top. If the direction of force transmission is not correct or the transmission of force is interrupted, it will affect the final batting effect, resulting in an insufficient speed of technical movement. The most essential technical movement is to obtain the maximum batting speed upon hitting the ball. The previous series of movements are for this purpose, so the force must follow this order.

4. Conclusion

Forehand smash near the net requires the player to have a large commencing height and a high batting point; forehand smash far from the net requires the player to have a relatively small commencing height and a low batting point. At the same time, the upper arm speed of the player for forehand smash far from the net shall be higher than that for forehand smash near the net. Therefore, in the forehand smash training near the net, it is necessary to focus on training the deltoid and pectoralis major that drive the forearm to rotate. The shoulder elbow angle of the badminton forehand technical movement shall be larger than that of the forearm smash far from the net. Hence, when making the forehand smash near the net, it is required to rotate the elbow around the shoulder joint quickly at a large angle in a counterclockwise direction, so that the racket can reach a high batting point. Therefore, in the practice of this movement, it is necessary to focus on training these two muscles.

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