Biomechanical analysis-based aerobics athletes’ athletic ability fuzzy comprehensive evaluation

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ABSTRACT

The paper firstly applies Lagrange equations to solve restricted particle kinetic equations, combines with theoretical formulas to analyze athlete hand joint mechanical movement, and combines with shoulder joint, elbow joint mechanical analysis to study on aerobics taking-off, rotation and other motions. Establish fuzzy comprehensive evaluation model, define weights, and then establish fuzzy relation matrix, finally calculate. Result shows that aerobics cooperative ability occupies 30%, innovation attainment occupies 25%, and aesthetic level occupies 18%. Among them, cooperative ability, innovation attainment, and aesthetic level belong to humanistic education and cultivation range, the paper can clearly get that aerobics such event is a kind of sports discipline with stronger cultural atmosphere.

INTRODUCTION

Chinese aerobics undertakings are rapidly developing, research on the aspect of aerobics basic mechanics are fewer; the paper carries out mechanical research on aerobics according to aerobics difficulty rules, until 2000, China totally published above 1000 pieces of aerobics papers and textbooks as well as works, which indicated Chinese research on aerobics was gradually developing, and gradually formed into system. By mechanical researching, it explored inherent law and biological motion law. It included sportsmen movement speed and body each part muscle movement, movement technical expression of technique is equal to action form. As TABLE 1 show.

Secondly, according to international aerobics judgment criterion, as TABLE 2, analyze an aerobics athlete or an aerobics team, utilize evaluation model to calculate.

MODEL ESTABLISHMENTS

By Lagrange equations, the paper gets restricted particle kinetic equations, from which Lagrange function \( L \) is difference generated between system kinetic energy \( K \) and potential energy \( P: L = K - P \)

System kinetic equation is: \( F_i = \frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} \right) \quad i = 1,2, \ldots, n \)

In above formula, \( \dot{q}_i \) is corresponding speed, \( q_i \) is kinetic energy and potential energy coordinate, \( F_i \) is...
the \( i \) coordinate acting force, thigh and shank included angles with coordinate axis are respectively \( \theta_1, \theta_2 \), lengths are respectively \( l_1, l_2 \), distances that arm front and back gravity center position from elbow joint center and knee joint center are respectively \( p_1, p_2 \), thereupon it is clear that arm gravity center coordinate \((X_1, Y_1)\) is:

\[
\begin{align*}
X_1 &= p_1 \sin \theta_1, \\
Y_1 &= p_1 \cos \theta_1, \\
X_2 &= l_1 \sin \theta_1 + p_1 \sin (\theta_1 + \theta_2), \\
Y_2 &= -l_1 \cos \theta_1 - p_1 \cos (\theta_1 + \theta_2)
\end{align*}
\]

Similarly, arm gravity center coordinate \((X_2, Y_2)\) can also be solved. System kinetic energy \( E_k \) and system potential energy \( E_p \) expressions are:

\[
\begin{align*}
E_k &= E_{k1} + E_{k2}, \\
E_{k1} &= \frac{1}{2}m_1p_1^2 + \frac{1}{2}m_2l_1^2, \\
E_{k2} &= \frac{1}{2}m_2p_2^2 + \frac{1}{2}m_1l_1^2 + m_2l_1p_2 \dot{\theta}_2 + m_1l_1p_1 \dot{\theta}_1 + m_1l_1 \dot{\theta}_1 \dot{\theta}_2, \\
E_p &= E_{p1} + E_{p2}, \\
E_{p1} &= \frac{1}{2}m_1g(X_1 - Y_1) - \frac{1}{2}m_2g(Y_2 - Y_1), \\
E_{p2} &= m_2g(Y_2 - Y_1) - \frac{1}{2}m_1g(Y_2 - Y_1)
\end{align*}
\]

Write above formula into Lagrange function expression, by Lagrange system kinetic equation, it can get hip joint and knee joint moment \( M_h \) and \( M_k \) as:

\[
\begin{align*}
M_h &= \begin{bmatrix} M_{h_1} \\ M_{h_2} \end{bmatrix} = \begin{bmatrix} D_{h_1} & D_{h_2} \\ D_{h_2} & D_{h_2} \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} + \begin{bmatrix} P_{h_1} \\ P_{h_2} \end{bmatrix}, \\
M_k &= \begin{bmatrix} M_{k_1} \\ M_{k_2} \end{bmatrix} = \begin{bmatrix} D_{k_1} & D_{k_2} \\ D_{k_2} & D_{k_2} \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} + \begin{bmatrix} P_{k_1} \\ P_{k_2} \end{bmatrix}
\end{align*}
\]

In above formula \( D_{ik} \) is as following result:

\[
\begin{align*}
D_{111} &= 0, \\
D_{222} &= 0, \\
D_{121} &= 0, \\
D_{211} &= m_1l_1p_1 \sin \theta_1, \\
D_{212} &= m_2l_2p_2 \sin \theta_2, \\
D_{221} &= m_2l_2p_2 \sin \theta_2, \\
D_{112} &= -2m_1l_1p_2 \sin \theta_1, \\
D_{212} &= D_{221} = D_{222} = D_{211}
\end{align*}
\]

Combine with theoretical formula, analyze aerobics athlete hand joint mechanical movement, and combine with shoulder joint, elbow joint mechanical analysis.

**Establish moment of momentum theorem model**

When apply mechanical conservation law to solve problems, firstly it should select reasonable research
objects, and make correct force analysis of researched objects, secondly on the basis of force analysis, reference conservation law to check problem, finally according to conservation law, establish equation and solve problems.

Set \( I \) is one rigid body rotational inertia, it suffers moment \( M \) acting, among them, angular accelerated speed \( \beta \) is constant, the rigid body at \( t_1 \) instant angular speed is \( \omega_1 \), rigid body at \( t_2 \) instant angular speed is \( \omega_2 \), it gets: \( M = I \beta = I \frac{\omega_2 - \omega_1}{t_2 - t_1} \)

Deform and get: \( M(t_2 - t_1) = I(\omega_2 - \omega_1) \)

When \( M = M(t) \), it has: \( M(t(t_2 - t_1) = I(\omega_2 - \omega_1) \)

It gets moment of momentum formula, from which \( M(t_2 - t_1) \) is impulsive moment. \( I \omega \) is moment of momentum, from formula, it is clear that rigid impulsive moment variable quantity is equal to moment of momentum variable quantity.

In moment of momentum theorem, time and moment product is equal to impulsive moment; it represents object rotational accumulative effect under external force moment effects. Angular speed and rotational inertia product is state when rigid body rotates. With external force moment increasing and acting time enlarging, rigid body rotational state changes are increasing accordingly.

When human body moves, human body generated rotational inertia is changing, due to rotational variable changes, different time rotational inertia is different, set \( t_1 \) instant rotational inertia is \( I_1 \), \( t_2 \) moment rotational inertia is \( I_2 \), therefore, above formula can be changed as: \( M(t(t_2 - t_1) = I_1 \omega_2 - I_1 \omega_1 \)

For human body sports rules, it should meet:

\( I \omega = 0, \sum M \Delta t = 0 \)

Now it enters into soaring phase, if human body meets: \( I_1 \omega_1 + I_2 \omega_2 = 0 \)

In addition, it should also meet that human body rotates around \( I_1 \omega_1 \), then tennis service sports form is lengthwise relative movement, during sports process, human body moment of momentum vectors sum is 0, according to correlation law, we get that human body will suffer a reactive force that let people to generate moment of momentum, so that reduce sports process strength size, so it is bad for sports stability, but if in sports process, due to body each part suffered active force effects, it causes rotational inertia increasing, so that it will generate an advancing moment of momentum effect, according to energy conservation law, we know that now human body similarly will generate a reactive force effect, so that let human body to move relative to ball, so that increase arm swinging distance, concentrate whole body strength to serve.

In whole sports process, each limb will generate moment that on the opposite direction but size is the same, and every pair can offset, when athlete lands, sole part rapidly lands to support the whole body, and meanwhile it will occur to abdomen contraction, knees bending and others to buffer diminished strength to make preparation for next motion.

In the air, angular speed changes, when moment of momentum remains unchanged, rotational inertia will reduce with angular speed increasing, when moment of momentum remains unchanged, rotational inertia will reduce with angular speed increasing, when athlete jumps and soars, athlete himself can further control rotational angular speed by changing self-rotational inertia. When athlete takes off and arrives at highest point, athlete should try to adjust body stability, let rotational angular speed to reduce as much as possible, now, athlete should raise two legs backward, let gravity center to be far away from rotational axis, and arrive at state of steady movement.

**Fuzzy comprehensive evaluation model summary**

Fuzzy mathematics development has already 40 years history up to now, though is a kind of relative new discipline, it has extremely rich contents in theory, and fuzzy mathematics involves natural science, social science and other disciplines. Due to evaluation is a kind of human thinking process, it is not changing in linear, and fuzzy evaluation matrix is a kind of important evaluation method.

Utilize fuzzy comprehensive evaluation, steps are as following:

1. Establish factor set \( U : U = \{U_1, U_2, \ldots, U_k\} \)
2. Establish judgment set \( V \) (evaluation set);
3. Establish fuzzy mapping from judgment matrix \( U \)
to judgment matrix \( V \), it gets fuzzy relation as matrix \( R \) shows:

\[
R = \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1n} \\
    r_{21} & r_{22} & \cdots & r_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\]

(4) Establish weight set \( A = (a_1, a_2, \cdots, a_n) \), it meets conditions: \( \sum_{i=1}^{n} a_i = 1 \; \; a_i \geq 0 \)

(5) Fuzzy relation \( R \). Every line reflects the line influence factors to object judgment extent, and meanwhile, \( R \) every column reflects the column influence factors to object judgment extent.

\[
\sum_{j=1}^{m} r_{ij} = 1, \; i=1,2,3,\cdots, m
\]

\[
B = A \cdot R
\]

\[
= (a_1, a_2, a_3, \cdots, a_n) \cdot \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1n} \\
    r_{21} & r_{22} & \cdots & r_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\]

\[
= (b_1, b_2, b_3, \cdots, b_n)
\]

In \( V \), fuzzy combination is evaluation set \( B \). Based on above described facts, actual change model is:

As Figure 1 show, it gets fuzzy comprehensive evaluation change model, and can establish corresponding every factor grade evaluation transformation function, evaluation factors \( U_1, U_2, U_3, U_4 \) membership functions can be expressed as following:

\[
\begin{align*}
    u_{*,i}(u_1) &= 0.5(1 - \frac{u_1 - k_1}{k_1 - k_2}), \quad u_1 \geq k_2 \\
    u_{*,i}(u_1) &= 0.5(1 - \frac{k_2 - u_1}{k_2 - k_1}), \quad k_2 \leq u_1 < k_1 \\
    u_{*,i}(u_1) &= 0, \quad u_1 < k_2
\end{align*}
\]

\[
\begin{align*}
    u_{*,i}(u_2) &= 0.5(1 - \frac{u_2 - k_3}{k_3 - k_4}), \quad u_2 \geq k_4 \\
    u_{*,i}(u_2) &= 0.5(1 + \frac{k_3 - u_2}{k_3 - k_4}), \quad k_3 \leq u_2 < k_4 \\
    u_{*,i}(u_2) &= 0.5(1 - \frac{k_4 - u_2}{k_4 - k_3}), \quad k_4 \leq u_2 < k_3 \\
    u_{*,i}(u_2) &= 0.5(1 + \frac{k_3 - u_2}{k_3 - k_4}), \quad u_2 < k_3
\end{align*}
\]

\[
\begin{align*}
    u_{*,i}(u_3) &= 0, \quad u_3 \geq k_4 \\
    u_{*,i}(u_3) &= 0.5(1 + \frac{k_4 - u_3}{k_4 - k_5}), \quad k_4 \leq u_3 < k_5 \\
    u_{*,i}(u_3) &= 0.5(1 - \frac{k_5 - u_3}{k_5 - k_4}), \quad k_5 \leq u_3 < k_4 \\
    u_{*,i}(u_3) &= 0, \quad u_3 < k_4
\end{align*}
\]

\[
\begin{align*}
    u_{*,i}(u_4) &= 0.5(1 - \frac{u_4 - k_6}{k_6 - k_7}), \quad u_4 \geq k_7 \\
    u_{*,i}(u_4) &= 0.5(1 + \frac{k_6 - u_4}{k_6 - k_7}), \quad k_6 \leq u_4 < k_7 \\
    u_{*,i}(u_4) &= 0.5(1 - \frac{k_7 - u_4}{k_7 - k_6}), \quad k_7 \leq u_4 < k_6 \\
    u_{*,i}(u_4) &= 0, \quad u_4 < k_7
\end{align*}
\]

Obtained weighted vector from rank 1 to rank 2: \( \beta = \{\beta_1, \beta_2, \beta_3, \beta_4\} = \{0.4, 0.3, 0.2, 0.1\} \)

\[
U_1^* = U_1 \cdot \beta^T \\
U_2^* = 12, \; U_3^* = 9.7, \; U_4^* = 6, \; \; U_4^* = 5
\]

The paper takes normalization processing: \( U_1^* = 0.35, \; U_2^* = 0.3, \; U_3^* = 0.2, \; U_4^* = 0.15 \)

It gets: \( A = \begin{bmatrix} 0.35 & 0.3 & 0.2 & 0.15 \end{bmatrix} \)

By aerobics performance, it gets remarks membership, as TABLE 5 shows.
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TABLE 3: Aerobics athlete evaluation indicator system

<table>
<thead>
<tr>
<th>Aesthetic level $U_1$</th>
<th>Cooperative ability $U_2$</th>
<th>Physical training $U_3$</th>
<th>Innovation attainment $U_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion aesthetics $u_{11}$</td>
<td>Tactics strategies $u_{21}$</td>
<td>Endurance $u_{31}$</td>
<td>Motion innovation $u_{41}$</td>
</tr>
<tr>
<td>Music aesthetics $u_{12}$</td>
<td>Judgment $u_{22}$</td>
<td>Speed $u_{32}$</td>
<td>Formation innovation $u_{42}$</td>
</tr>
<tr>
<td>Formation design $u_{13}$</td>
<td>Reaction ability $u_{23}$</td>
<td>Strength $u_{33}$</td>
<td>Team shirts, music $u_{43}$</td>
</tr>
<tr>
<td>Team shirts designing $u_{14}$</td>
<td>Competition experiences $u_{24}$</td>
<td>Flexibility $u_{34}$</td>
<td></td>
</tr>
<tr>
<td>Members training $u_{15}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 4: Four kinds of factors importance degree ranking statistics

<table>
<thead>
<tr>
<th>Classification</th>
<th>Rank 1</th>
<th>Rank 2</th>
<th>Rank 3</th>
<th>Rank 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetic level $U_1$</td>
<td>23</td>
<td>7</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Cooperative ability $U_2$</td>
<td>7</td>
<td>18</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Physical training $U_3$</td>
<td>0</td>
<td>9</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Innovation attainment $U_4$</td>
<td>3</td>
<td>0</td>
<td>9</td>
<td>21</td>
</tr>
</tbody>
</table>

TABLE 5: Remarks membership

<table>
<thead>
<tr>
<th>Evaluation way</th>
<th>Set scores interval</th>
<th>0-60</th>
<th>60-80</th>
<th>80-90</th>
<th>90-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>0</td>
<td>0.05</td>
<td>0.9</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.05</td>
<td>0.9</td>
<td>0.05</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Bad</td>
<td>0.95</td>
<td>0.05</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

By one aerobics athlete each indicator obtained evaluation, it gets TABLE 6.

By above model, it gets single layer indicator weight factor fuzzy set:

$U_1^* = \{u_{11}, u_{12}, u_{13}, u_{14}, u_{15}\} = \{0.25, 0.25, 0.2, 0.15, 0.15\}$

$U_2^* = \{u_{21}, u_{22}, u_{23}, u_{24}\} = \{0.54, 0.1, 0.24, 0.14\}$

$U_3^* = \{u_{31}, u_{32}, u_{33}, u_{34}\} = \{0.4, 0.3, 0.1, 0.2\}$

$U_4^* = \{u_{41}, u_{42}, u_{43}\} = \{0.3, 0.4, 0.3\}$

By TABLE 6, and combine with TABLE 3 remarks membership, the paper gets aesthetic level, cooperative ability, physical training, innovation attainment each aspect evaluation set:

$$U_1 = \begin{pmatrix} 0 & 0 & 0.05 & 0.95 \\ 0 & 0 & 0.05 & 0.95 \\ 0 & 0.05 & 0.95 & 0.05 \\ 0 & 0.05 & 0.95 & 0.05 \end{pmatrix}$$

$$U_2 = \begin{pmatrix} 0 & 0 & 0.05 & 0.95 \\ 0 & 0 & 0.05 & 0.95 \\ 0 & 0.05 & 0.9 & 0.05 \end{pmatrix}$$

$$U_3 = \begin{pmatrix} 0 & 0.05 & 0.9 & 0.05 \\ 0.05 & 0.9 & 0.05 & 0 \end{pmatrix}$$

$$U_4 = \begin{pmatrix} 0 & 0 & 0.05 & 0.95 \\ 0 & 0.05 & 0.9 & 0.05 \\ 0 & 0.05 & 0.9 & 0.05 \end{pmatrix}$$

$B_j = A_j \cdot R_j$

Make normalization processing with obtained $B_j$, it gets fuzzy evaluation matrix:

$$B = \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{pmatrix} = \begin{pmatrix} 0.07 & 0.27 & 0.13 & 0.53 \\ 0.1 & 0.4 & 0.5 \\ 0.08 & 0.46 & 0.38 & 0.08 \\ 0.14 & 0.2 & 0.3 & 0.36 \end{pmatrix}$$

It gets comprehensive evaluation value: $Z = U^* \cdot B = (0.18, 0.3, 0.24, 0.25)$
TABLE 6: Aerobics athlete each indicator obtained evaluation value

<table>
<thead>
<tr>
<th>Each layer indicator</th>
<th>Evaluation value</th>
<th>Each layer indicator</th>
<th>Evaluation value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion aesthetics $u_{11}$</td>
<td>Very good</td>
<td>Endurance $u_{31}$</td>
<td>Very good</td>
</tr>
<tr>
<td>Music aesthetics $u_{12}$</td>
<td>Very good</td>
<td>Speed $u_{32}$</td>
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<td></td>
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CONCLUSION

In whole sports process, each limb will generate moment that on the opposite direction but size is the same, and every pair can offset, when athlete lands, sole part rapidly lands to support the whole body, and meanwhile it will occur to abdomen contraction, knees bending and others to buffer diminished strength to make preparation for next motion. In the air, angular speed changes, when moment of momentum remains unchanged, rotational inertia will reduce with angular speed increasing, when moment of momentum remains unchanged, rotational inertia will reduce with angular speed increasing, when athlete jumps and soars, athlete himself can further control rotational angular speed by changing self-rotational inertia. When athlete takes off and arrives at highest point, athlete should try to adjust body stability, let rotational angular speed to reduce as much as possible, now, athlete should raise two legs backward, let gravity center to be far away from rotational axis, and arrive at state of steady movement.

REFERENCE

