Dynamic Analysis of sprint burst based on coupled Fuzzy Control

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Abstract: The dynamic analysis of sprint burst based on coupled fuzzy control is studied. Through theoretical analysis and computer vision simulation, the detailed data are obtained and applied to sprint training. Computer simulation technology is used under the computer vision simulation platform, the dynamic model of sprint burst movement is analyzed, and the dynamic mathematical model of sprint explosive force joint is constructed. The limb mechanical characteristic parameters under sprint burst action are obtained. Based on the coupling control method, the characteristic analysis and information parameter estimation of sprint burst dynamics are carried out. The sprint starting model and sprint model are constructed respectively. The mathematical modeling and lower extremity mechanical analysis of two sprint burst motion modes are carried out. The torque of bone and joint is calculated, and the theoretical calculation value and simulation value are obtained. Finally, the visual simulation of sprint burst mechanics is carried out with ADAMS software, and the simulation values and theoretical values of the characteristic parameters of sprint burst dynamics are obtained, and the comparative analysis is realized. Through the simulation results, the optimal power model control under sprint burst mode can be realized. The research results will provide effective theoretical guidance for sprint training, optimize the training methods and improve the training effect.

1. Introduction
In sprint training and sports, the explosive power of lower extremities is very important to achieve excellent sports results. Nowadays, there are many forms of sports. However, for most sports such as track and field, basketball, football badminton and so on, it is necessary to have strong explosive power of lower limbs in order to obtain the magic weapon of winning. Therefore, in order to achieve twice the result with half the effort in sprint training, it is necessary to analyze the principle and model of human lower extremity power from the point of view of human lower extremity dynamics theory, give full play to the potential of human sports, and constantly create new human sports records in sports[1].

At present, the theoretical analysis of lower extremity power in human motion is still in its infancy, and the research on human kinematics starts late, and because of the limitation of subject integration, the dynamic analysis of human lower extremity power model is worth referring to. Traditionally, the dynamic analysis of human lower extremity dynamics is mostly focused on human rehabilitation, robot design and other research fields. However, because the dynamics analysis of lower extremity can rationally and quantitatively understand the transmission performance of human momentum in lower extremity sports, the power of lower extremity will be the key to affect sports performance, so the study of sprint burst dynamics analysis has important application value in sprint training[2]. Moreover,
with the development of computer simulation technology, especially with the advent of ADAMS software, it is possible to effectively simulate and analyze human motion mode in computer vision mode. Adams software, that is, mechanical system dynamics automatic analysis (Automatic Dynamic Analysis of Mechanical Systems) is the most extensive mechanical system motion model simulation software in the world, users can use Adams to establish and test virtual prototype on computer. Realize the simulation of fact reproduction and understand the motion performance of complex mechanical system design. In this paper, ADAMS software is applied to the analysis of human lower extremity dynamic motion model, and the computer simulation is carried out in computer vision mode, which makes the analysis of sprint burst dynamics more scientific and accurate\cite{3}.

In short, this article will study that problem of the analysis of the motion mechanics of the sprinter based on the coupled fuzzy control, and through the theoretical analysis and the computer visual simulation, the detailed data is obtained and applied to the sprint training. The computer simulation technology is adopted, under the computer vision simulation platform, the running mechanics model of the sprinting explosion is analyzed, the dynamic mathematical model of the sprinting force acting joint is carried out, and the mechanical characteristic parameters of the limb under the action of the sprinting explosion are obtained, analysis of the best mode of force of the sprinting force\cite{4}. In the model construction, the dynamic model of the sprinting in the sprinting model and the sprinting mode is respectively constructed, and the mathematical modeling and the mechanical analysis of the lower limbs are carried out on the two kinds of sprinting motion patterns, and the moment of the bone joint is calculated, and the theoretical calculation value and the simulation experimental value are obtained. Finally, the dynamic visual simulation is carried out by using the ADAMS software, and the best force model control in the running mode of the sprinting burst can be realized through the simulation results, and the research results will provide effective theoretical guidance for the training of the sprints, optimize the training mode and improve the training effect.

2. Modeling and analysis of burst dynamics of sprint
When the human body carries on the sprint burst movement, it is mainly supported by the lower limbs to carry on the sagittal movement in the sagittal plane movement\cite{5}. In order to grasp the principle and characteristics of the sprint burst movement scientifically and rationally, it is necessary to model and analyze the sprint burst dynamics. The mathematical expression of the dynamic model of sprint burst can be expressed as follows:

\[ M(\theta)\ddot{\theta} + C(\theta, \dot{\theta}) + G(\theta) = T_i + T_u \]  \hspace{1cm} (1)

In the formula, \( \theta \) is the angle between lower extremity support of sprint burst exercise, \( T_i \) is the torque acting on joint, \( T_u \) action and exoskeleton torque, human body movement is, through the best force model theory, \( T_u \) tends to 0, so that human motion is to receive the best help combination. Based on the above principles, combined with sports practice, this paper constructs the sprint starting model and sprint mode dynamics model respectively in the model construction. The mathematical modeling and lower extremity mechanics analysis of two kinds of sprint burst motion modes are carried out, the torque of bone and joint is calculated, the theoretical calculation value is obtained, and the simulation experiment is carried out\cite{6}.

2.1. Dynamic analysis of lower extremity in starting mode of sprint
The explosive force action joint of sprint can be understood as 7 connecting rod model structure, which is bipedal, calf, thigh and upper limb\cite{7}. The schematic diagram of the stress decomposition structure of the 7 connecting rod model is shown in figure 1.
Fig. 1 Dynamic analysis model of sprint burst under starting mode of sprint

Let the coordinates in the world coordinate system \( O_{xyz} \) of supporting ankle joint be \((x_a, 0)\), sprint burst movement each limb part rod center of mass \( G_i(x_i, z_i) \), is:

\[
\begin{align*}
  x_0 &= x_a + a \\
  x_1 &= x_a + a_i \sin q_i \\
  x_2 &= x_a + l_i \sin q_i + a_2 \sin q_2 \\
  x_3 &= x_a + l_i \sin q_i + l_2 \sin q_1 + a_3 \sin q_3 \\
  x_4 &= x_a + l_i \sin q_i + l_2 \sin q_2 + a_4 \sin q_4 \\
  x_5 &= x_a + l_i \sin q_i + l_2 \sin q_3 + l_4 \sin q_4 + a_5 \sin q_5 \\
  x_6 &= x_a + l_i \sin q_i + l_2 \sin q_2 + l_4 \sin q_3 + l_6 \sin q_5 + a_6 \sin q_6 \\
  z_0 &= 0 \\
  z_1 &= a_i \cos q_i \\
  z_2 &= l_i \cos q_i + a_2 \cos q_2 \\
  z_3 &= l_i \cos q_i + l_2 \cos q_2 + a_3 \cos q_3 \\
  z_4 &= l_i \cos q_i + l_2 \cos q_3 + l_4 \cos q_4 + a_4 \cos q_4 \\
  z_5 &= l_i \cos q_i + l_2 \cos q_3 + l_4 \cos q_4 + l_6 \cos q_5 + a_5 \cos q_5 \\
  z_6 &= l_i \cos q_i + l_2 \cos q_2 + l_4 \cos q_3 + l_6 \cos q_5 + a_6 \cos q_6 
\end{align*}
\]

As a result, the kinetic energy of sprint burst is as follows:

\[
K = \frac{1}{2} \sum_{i=0}^{6} \left[ I_i \dot{q}_i^2 + m_i (\dot{x}_i^2 + \dot{z}_i^2) \right] 
\]

In the above formula, \( I_i \) is the moment of inertia of sprint burst motion.

The potential energy of sprint burst is as follows:

\[
P = \sum_{i=0}^{6} m_i g z_i 
\]

According to the Lagrange function of sprint burst movement:

\[
L = K - P 
\]

The Lagrange dynamic equation of lower extremity power motion is obtained as follows:

\[
\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = T_i, \ (i = 1, 2, \ldots, 6) 
\]

According to Cartesian spatial trajectory tracking theory, the spatial trajectory matching mode of sprint burst joint is obtained by using inverse kinematic transformation, and the rotation angle of
adjacent joint nodes in sprint starting mode is represented by inverse kinematic transformation:

$$\theta_i = q_i, \theta_2 = q_1 - q_2, \theta_3 = q_2 - q_3, \theta_4 = q_4 - q_3, \theta_6 = q_6 - q_4$$

According to the above, the mass matrix of the lower extremity is represented by $M$, and the gravity vector is represented by vector $G$. Combined with the angle transformation model of Cartesian, the transformed Lagrangian equation is obtained as follows:

$$D(\theta)\ddot{\theta} + C(\theta, \dot{\theta}) + G(\theta) = \tau$$

(8)

Wherein, $\tau = [\tau_1, \tau_2, ..., \tau_i]$, $\tau_1$, $\tau_2$ and $\tau_3$ are the ankle joint, knee joint and hip joint, respectively, and $\tau_i$ and $\tau_j$ are the driving force moments of sprint burst movement, respectively.$^{[8]}$

2.2. Dynamic analysis of lower extremity in sprint mode

On the basis of the dynamic analysis of sprint burst under the above one-leg support mode, the lower extremity dynamic model under sprint mode can be analyzed by the same reason. The mass $m_{L3}$ on the left leg of sprint burst movement and the quality $m_{R3}$, acting on the right leg. Through the relationship between the centroids distance and the coordinate axis, the relationship between $m_{L3}$ and $m_{R3}$ of sprint burst motion can be calculated as follows:

$$x_{L3} = l_3 \sin \theta_1 + l_3 \sin(\theta_1 - \theta_2) + \alpha_3 \sin(\theta_2 - \theta_3) - \alpha_0$$

(9)

$$x_{R3} = \alpha_0 - l_3 \sin \theta_4 + l_3 \sin(\theta_4 - \theta_5) - \alpha_3 \sin(\theta_5 - \theta_6)$$

(10)

$$m_{L3} = \frac{x_{L3}}{\alpha_3}$$

(11)

$$m_{R3} = m_{L3} + m_{R3}$$

(12)

Based on the above four formulas, the values of $m_{L3}$ and $m_{R3}$ of sprint burst can be calculated. Referring to the calculation method in the motion model of fuzzy coupling control mode in the previous section, the kinetic energy expression of the left leg in sprint mode is obtained as follows:

$$K = \frac{1}{2} \sum_{i=0}^{2} [I_i \dot{q}_i^2 + m_i (\dot{x}_i^2 + \dot{z}_i^2)] + \frac{1}{2} (I_{L3} \dot{q}_{L3}^2 + m_{L3} (\dot{x}_{L3}^2 + \dot{z}_{L3}^2))$$

(13)

Wherein, $I_i$ is the moment of inertia of the rod around the center of mass in the body part of the sprint burst movement. Similarly, according to Cartesian spatial trajectory tracking theory, the trajectory matching mode of sprint burst motion is obtained by using inverse kinematic transformation, and the rotation angle relationship of adjacent joint nodes in sprint mode is obtained as follows:

$$q_i = \theta_i, \quad q_2 = \theta_1 - \theta_2, \quad q_3 = \theta_2 - \theta_3 + \theta_6$$

(14)

By using the coupling fuzzy control method, the potential energy expression of the left leg of sprint burst motion is obtained as follows:

$$P = \sum_{i=0}^{2} (m_i g z_i) + m_{L3} g z_{L3}$$

(15)

Similarly, through the following formula group, the driving force moment of each joint burst in sprint burst is obtained. Lagrange dynamic equation is as follows:

$$\frac{d}{dt} \left[ \frac{\partial L}{\partial \dot{\theta}_i} \right] - \frac{\partial L}{\partial \theta_i} = \tau_i, \quad i = 1, 2, 3, \quad L = K - P$$

(16)

According to the coordinate transformation analysis of the right leg model of sprint burst movement in the world coordinate system, the kinetic energy expression of the right leg of sprint burst motion is obtained as follows:

$$K = \frac{1}{2} (I_{R3} \dot{q}_{R3}^2 + m_{R3} (\dot{x}_{R3}^2 + \dot{z}_{R3}^2)) + \frac{1}{2} \sum_{i=1}^{5} [I_i \dot{q}_i^2 + m_i (\dot{x}_i^2 + \dot{z}_i^2)]$$

(17)

The potential energy of the right leg of sprint break out is as follows:

$$P = \sum_{i=1}^{5} (m_i g z_i) + m_{R3} g z_{R3}$$

(18)

$$P = \sum_{i=1}^{5} (m_i g z_i) + m_{R3} g z_{R3}$$

(18)
Instead of Lagrange dynamic equation, the burst driving force of each joint of the right leg of sprint can be calculated. The equation is as follows:

\[
\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{\theta}_i} \right) - \frac{\partial L}{\partial \theta_i} = t'_i, \quad i = 3, 4, 5, \quad L = K - P
\]  (19)

3. Simulation experiment and result analysis

On the basis of the above software platform construction and data import, the simulation experiment, system test and data analysis are carried out. The simplified computer vision simulation system of sprint burst dynamics analysis is obtained by using ADAMS software, and the interface of sprint burst motion simulation test is shown in figure 2.

Fig. 2 Computer vision simulation system for dynamic analysis of sprint burst based on ADAMS

For the simulation experiment of angle and dynamics analysis of each joint, according to the space limit, this paper only lists the simulation results under sprint, and obtains the torque value of each joint of sprint burst movement by MATLAB programming. As shown in figure 3, the figure shows only the limb mechanical characteristic parameters under the action of left leg ankle sprint burst and the limb mechanical characteristic parameters under the action of knee sprint burst. Figure 3 shows the simulation value and theoretical value of the torque simulation data of each joint of both legs under the condition of sprint. Through the form of data analysis, it has important theoretical value for guiding sports.

(a) Theoretical calculation and simulation values of limb mechanical characteristic parameters under the action of sprint burst

(b) Theoretical calculation and simulation values of mechanical characteristic parameters of knee joint and limb

Fig. 3 Estimation of physical parameters of lower extremities in sprint model
4. Conclusions
In this paper, the dynamic analysis of sprint burst based on coupled fuzzy control is studied. Through theoretical analysis and computer vision simulation, the detailed data are obtained and applied to sprint training. Using computer simulation technology, under the computer vision simulation platform, the dynamic model of sprint burst movement is analyzed, the dynamic mathematical model of sprint explosive force joint is constructed, the limb mechanical characteristic parameters under sprint burst action are obtained, and the best force mode of sprint explosive force is analyzed. In the construction of the model, the starting model of sprint and sprint model are constructed respectively, and the mathematical modeling and lower extremity mechanics analysis of two kinds of sprint burst motion modes are carried out, the torque of bone and joint is calculated, and the theoretical calculation value and simulation value are obtained. Finally, the dynamic visual simulation is carried out with ADAMS software, and the simulation values and theoretical values of the characteristic parameters of sprint burst are obtained, and the comparative analysis is realized. Through the simulation results, the optimal power model control under sprint burst mode can be realized. The research results are of great practical significance in providing effective theoretical guidance for sprint training, optimizing training methods and improving training effect.

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