Human body moderate training control method based on flexible mechanical characteristic analysis

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Abstract: It has important application value to the human body moderate training control in the sports training guidance and the sports training big data analysis and so on. Aiming at the problem that the current master-slave arm motion data acquisition method is not accurate enough for human body moderate training and control, a human body appropriate training control method based on flexible mechanical characteristics analysis is proposed. Firstly, the flexible mechanical data analysis and kinematic attitude space reconstruction of human body are carried out. Then the motion state equation is constructed to sample the human body moderate training control attitude data and analyze the fusion of flexible mechanical features. The human body moderate training control is realized. Finally, the simulation results show that the modeling method has good stability, high accuracy of mechanical parameter estimation, and good reconstruction ability for human movement, such as running, jumping, gymnastics and so on, and the simulation results show that the modeling method has good stability and accuracy for human body moderate training and control, and the accuracy of mechanical parameter data estimation is high.

1. Introduction

Human motion is a complex system analysis of flexible mechanics. The modeling and analysis of human motion will have important application value in guiding sports training, computer game development, virtual reality simulation, film and television special effect performance, and so on. The modeling process of human motion is the process of data analysis and extraction of mechanical information of human motion. By capturing flexible mechanical data of human body, feature compression, information retrieval and reconstruction are carried out. To realize the synthesis and editing of human motion process, to achieve the purpose of bone reconstruction of human movement, and to study the appropriate training control method of human body are also of great significance in guiding sports rehabilitation training [1].

Traditionally, the key frame information extraction method combined with motion image analysis is used to realize the moderate training control of human body, for example, the key frame information extraction method is the key frame information extraction method, and the motion image analysis is used to realize the appropriate training control. Using curve simplification method, the process of human body motion is regarded as a key characteristic point tracking process of a motion trajectory curve, and the bone segment curve of human motion is a behavior track in high dimensional space, and the hierarchical curve method is used to reconstruct the behavior [2]. Some achievements have been achieved, but this method needs to set the resolution threshold between the key frames. Under the disturbance of large motion characteristics, the error of human motion reconstruction is larger and the effect of proper training and control of human body is poor. In order to overcome the disadvantages of the traditional
method, aiming at the poor accuracy of the current key frame motion data acquisition method for human body moderate training control, this paper proposes a human body appropriate training control method based on the analysis of flexible mechanical characteristics. Firstly, the flexible mechanical data analysis and kinematic attitude space reconstruction of human body are carried out. Then the motion state equation is constructed to sample the human body moderate training control attitude data and analyze the fusion of flexible mechanical features. Finally, the simulation experiment is carried out. The conclusion shows the superior performance of this method in improving the accuracy and rationality of human body moderate training control.

2. Data analysis of flexible mechanics of human body

2.1. Collection and representation of flexible mechanical data of human body

The flexible mechanics analysis method is used to control the human body moderate training. Firstly, the data collection of human flexible mechanics needs to be carried out. Compared with the commonly used methods of human flexible mechanics data collection, such as ASF/AMC (Acclaim Skeleton File/Acclaim Motion Capture data), BVH, HTR and so on[3]. Because of the nonlinear characteristics and random distribution of human flexible mechanical data, this paper adopts the file format of ASF/AMC to express the flexible mechanical data of human body[4]. The biosensor installed on the human body and the vibration sensor are used to collect the information, and the motion state information of the biosensor installed on the human body at the time of \( \mathbf{a}_k = [a_x \ a_y \ a_z]^T \) is output as \( \mathbf{b}^c_k = \begin{bmatrix} a_x \ a_y \ a_z \end{bmatrix}^T \). Using accelerometer and magnetometer to calculate the position and attitude information of the human body, the output of the position and attitude information is \( \mathbf{b}^e_k = \begin{bmatrix} m_x \ m_y \ m_z \end{bmatrix}^T \), and the attitude angle output is \( \mathbf{r}_g = [0 \ 0 \ -g]^T \). If the reference coordinate system is a geodetic coordinate system (regardless of the magnetic deflection angle), then under the action of the gravity vector and the geomagnetic vector, in the high-dimensional space of the biological motion of the human body, the accurate attitude estimation can be achieved. The mechanical measurement data of human motion are respectively \( \mathbf{r}_m = [h \cos \alpha \ 0 \ -h \sin \alpha]^T \), where \( g \) is the absolute value of gravity acceleration, \( h \) and \( \alpha \) are the follow-up errors of sensor data with geomagnetic dip angle, respectively.

When the human body is walking, jumping, gymnastics and so on, a closed set of spatial motion equations of the flexible mechanics of the human body is obtained as follows:

\[
\begin{align*}
    m \frac{dV}{dt} &= P \cos \alpha - X - mg \sin \theta \quad (1) \\
    mV \frac{d\theta}{dt} &= P \sin \alpha + Y - mg \cos \theta \quad (2) \\
    J_x \frac{d\omega_x}{dt} + (J_y - J_z) \omega_y \omega_x + J_y (\omega_y^2 - \omega_z^2) &= M_x \quad (3) \\
    \frac{dx}{dt} &= V \cos \theta \\
    \frac{dy}{dt} &= V \sin \theta \quad (5) \\
    \frac{d\theta}{dt} &= \omega_z \quad (6) \\
    \alpha &= \theta \quad (7) \\
    \delta_c &= f(\epsilon_c) \quad (8)
\end{align*}
\]

Where, \( \theta \) is the jumping angle of human motion, which is expressed as the angle between velocity vector and vertical line of human body in the process of jumping movement, and \( \alpha \) is the pitch...
anteverversion angle of human body in running movement, and the angle between longitudinal axis and vertical inclined plane of human body movement. GS is the vertical migration of human body in gymnastic movement, and the angle between the projection of velocity vector of human motion centroid and X axis in the state space of human body motion vector. The characteristic equation of spatial distribution of human body motion is constructed by the above mentioned equation. According to the data acquisition of flexible mechanics of human body, the characteristic equation of data capture of flexible mechanics under walking, jumping and gymnastics movement is described as follows:

Walking:

\[
\begin{align*}
    mV \dot{\theta} \cos(\sigma) &= F_y, \\
    J_x \dot{\omega}_x + (J_y - J_z) \omega_y \omega_z &= M_y, \\
    \phi &= \theta + \alpha
\end{align*}
\]

Jump:

\[
\begin{align*}
    -mV \dot{\sigma} &= F_z, \\
    J_x \dot{\omega}_y + (J_z - J_y) \omega_z \omega_x &= M_z, \\
    \phi &= \sigma + \beta
\end{align*}
\]

Gymnastics:

\[
J_x \dot{\omega}_x + (J_z - J_y) \omega_y \omega_z = M_z
\]

Based on the above principles, the collection and characteristic analysis of human flexible mechanical data are carried out.

2.2. Space reconstruction of Kinematic posture of human body

According to the above equations of human motion and the results of data acquisition, the kinematics and posture space reconstruction of human body motion is carried out, and the observation equation of flexible mechanics data for human body moderate training under global search is obtained as:

\[
\begin{align*}
    q_{k+1} &= \Phi_k q_k - \frac{\Delta t}{2} \Xi_k \delta b_{k+1}^x \\
    0 &= H_{k+1} q_{k+1} - \frac{1}{2} \Xi_1 b_{k+1}
\end{align*}
\]

Where, \( k \) is the sampling time, \( q \) is the quaternion of the output vector, \( \epsilon \) is used to output the attitude information of the human body motion attitude equation. In order to ensure

\[
\begin{align*}
    \begin{bmatrix}
        \dot{\omega} \\
        \dot{q}
    \end{bmatrix} &= \begin{bmatrix}
        -\frac{1}{r} \epsilon \\
        -\frac{1}{r} \sigma \\
        -\frac{1}{r} \theta \\
        0
    \end{bmatrix} + \frac{1}{2} q \otimes b^x
\end{align*}
\]

In the equation, \( \overline{\omega} = [0 \ \omega]^T \) is the quaternion of the output vector, \( \epsilon \) is respectively used to output the attitude information of the human body motion attitude equation. In order to ensure
the linearity of the observation equation, the captured data of human flexible mechanics, $b_{k+1}^a$ and $b_{k+1}^m$. QUEST algorithm or Gauss-Newton iterative algorithm, are obtained by quadratic filtering.

The error analysis is carried out by reading the sensor data worn on the human body, and the Kalman equation for obtaining the human motion characteristic information in the observation space is obtained by the method of kinematics and attitude space reconstruction. The Kalman equation is as follows:

$$ q_{k+1} = \Phi q_k + \frac{N}{2} z_k^e $$

$$ b_{k+1}^e = \left[ C^e(q_{k+1}) \right] \left[ r_{e,i} \right] + v_{e,i+1} $$

$$ b_{k+1}^m = \left[ C^m(q_{k+1}) \right] \left[ r_{m,i} \right] + v_{m,i+1} $$

(14)

In the equation, $C^j(q_{k+1})$ is the state estimation of attitude information in reference coordinate system, and $v_{k+1}^a$, $v_{k+1}^m$ are the error of attitude change in the course of motion under the action of gravity acceleration vector.

3. Realization of human body moderate training control

3.1. Proper training of human body controls the reconstruction of mechanics

During the process of motion, the attitude will change constantly, so it is necessary to carry on the appropriate training control to realize the mechanical reconstruction of the attitude information [7]. When the human body is in the state of non-acceleration, the motion capture data is represented as:

$$ M = \{f_1, f_2, \ldots, f_{n-1}, f_n\} $$

(15)

Where, $f_i, i = 1, 2, \ldots, n$ represents the four-element vector in the process of human motion. The GS is the timing position transmitted through a sensor that is worn on the human body. The human motion data obtained from each sampling point is expressed as follows:

$$ f_i = \{p(i), q_1(i), q_2(i), \ldots, q_m(i)\} $$

(16)

Where, $p(i)$ is the flexible mechanical characteristic information of human moving bone in $i$ frame, that is, the translation between the points of force. The change of attitude information of $q(i)$ bone segment of $i$ frame, when $\Phi_i = I_4$ is arbitrary attitude. The Euler angle method is used to calculate the attitude angle $\Phi_i = I_4$, in which $I_4$ is a 4-order unit matrix.

Linear interpolation method is used to fit and interpolate the flexible mechanical data of human body:

$$ p(t) = \frac{t-t_1}{t_2-t_1} p(t_1) + \frac{t-t_2}{t_2-t_1} p(t_2) $$

(17)

In which $t_1 < t < t_2$. $t$ is the estimation error of attitude angle between $t_1$ and $t_2$ time. The fitting equation of reconstruction interpolation is obtained by the following iterative equation:

$$ K_{k+1/k+1} = \rho_k m_{k+1} \Phi_i K_{i+1} \Phi_i^T + \frac{1}{m_{k+1}} \delta K $$

(18)

Where

$$ \delta K = \left[ S - \sigma I \quad z \right] \left[ z^T \right] $$

(19)

$$ m_k = \sum_{i=1}^{n} a_i, \quad m_{k+1} = m_k + \delta m_{k+1} $$

(20)

$$ \sigma = \frac{1}{m_k} \sum_{i=1}^{n} a_i b_i r_i^T, \quad B = \frac{1}{m_k} \sum_{i=1}^{n} a_i b_i r_i^T $$

(21)
$$S = B + B^r, \quad z = \frac{1}{m_i} \sum_{i=1}^{n_i} a_i (b_i \times r_i) \quad (22)$$

If the mechanical decomposition of the human body is nonlinear in the attitude transformation process, the mechanical decomposition process of the human body attitude transformation using the fourth-order Runge-Kutta method is expressed as two units quaternion by the above decomposition process of $q_i(t_1) = [w_1, x_1, y_1, z_1]$ and $q_i(t_2) = [w_2, x_2, y_2, z_2]$, $\theta$ is the angle between the sample bone points, expressed as:

$$\theta = \arccos(w_1w_2 + x_1x_2 + y_1y_2 + z_1z_2) \quad (23)$$

Then, $q_i(t)$ is obtained by spherical linear interpolation:

$$q_i(t) = \text{slerp}(q_i(t_1), q_i(t_2), t) = \frac{\sin(1-t)\theta}{\sin \theta} q_i(t_1) + \frac{\sin t\theta}{\sin \theta} q_i(t_2) \quad (24)$$

The attitude transformation information output by linear interpolation of $0 < t < 1$, sphere can reasonably reflect the flexible mechanical information of human body motion, thus realizing the mechanical reconstruction of human body proper training control\textsuperscript{[8]}.  

3.2. Human body moderate training control and quality evaluation

The reconstruction error is used to represent the constraint index of human body proper training control. The reconstruction error is the average motion vector metric of the original motion sequence and the reconstructed motion sequence. The original motion fragment $om$, with n frame data is calculated by using accelerometer and magnetometer, and the sample points of bone flexibility mechanics of $om$ are calculated. The motion data interpolation fitting method is used to reconstruct the reconstructed motion fragment $rm$. Consider the difference in the rate of each part of the limb\textsuperscript{[9]}. Let $n$ be the original motion sequence and the reconstructed motion sequence respectively, and the sequence length of the joint force moment is all $n$. The human body mechanics reconstruction error is defined as:

$$D(om, rm) = D_s(om, rm) + uD_v(om, rm) \quad (25)$$

Where, $D_s(om, rm)$ describes the position error relative to the world coordinate system during human motion, $D_v(om, rm)$ indicates the difference of joint rate, and $u$ is the updated step size. According to previous experiments, the percentage of joint velocity difference is very small\textsuperscript{[10]}, therefore, this paper sets it to 1, from which the reconstructed flexible mechanical equation of human body proper training control is obtained as follows:

$$d(om^i, rm^i) = \sum_{j=1}^{n} w_j \|om^j - rm^j\|^2 \quad (26)$$

$$D_s(om, rm) = \frac{1}{n} \sum_{i=1}^{n} d(om^i, rm^i) \quad (27)$$

$$D_v(om, rm) = \frac{1}{n} \sum_{i=1}^{n} \left| d(om^{i-1}, om^i) - d(rm^{i-1}, rm^i) \right| \quad (28)$$

Where, $d(om^i, rm^i)$ represents the stability parameters of the first frame of the original state of motion under the dynamic acceleration motion. $i$ is the weight of moving joint $om^i$ in stable state, which represents the importance of joint $G$. The coordinate position of the vs joint in frame I of the motion model reconstructed by $rm^i$.

4. Simulation analysis

The experiment is carried out with Matlab and ADAMS software. The experiment is carried out on a PC with Intel Pentium 42.6 GHz CPU,3 GB memory, and the accelerometer is used respectively.
Vibration sensors and mechanics sensors are worn on the human body to collect the original flexible mechanics, and the human body is properly trained and controlled by walking movement, jumping movement and gymnastic movement. The local geomagnetic field intensity is set to 5000 for the maximum number of iterations of $h = 0.45 \text{ gauss}$. According to the above simulation environment and parameter setting, hierarchical curve fitting method, frame sequence reconstruction method, genetic algorithm and this method are used to control the moderate training of human body. The results are shown in figure 1-3.

Figure 1. Results of modeling human walking motion

Figure 2. Results of modeling jump motion

Figure 3. Results of modeling gymnastics
The analysis shows that the original motion can be reconstructed by using this method, and the boundary frame can be extracted accurately by this method, which makes the difference between the original motion and the reconstructed motion small. Figure 4 describes the convergence error curves of different methods for human body moderate training control. The quantitative analysis shows that the error of this paper is much lower than that of the traditional method, and the optimal reconstruction error is obtained. It shows that this method is reasonable for human body moderate training control.

![Convergence Error Curves](image)

**Figure 4. Error curve of human motion reconstruction**

5. Conclusions
By capturing flexible mechanical data of human body, feature compression, information retrieval and reconstruction, the synthesis and editing of human motion process can be realized, and the aim of proper training and control of human body can be achieved. In this paper, a method of human body moderate training control based on flexible mechanical characteristics analysis is proposed. Firstly, the flexible mechanical data analysis and kinematic attitude space reconstruction of human body moderate training are carried out. Then the motion state equation is constructed to sample the attitude data of human moderate training control and analyze the fusion of flexible mechanical characteristics. Finally, the simulation experiment is carried out. The results show that the modeling method has a good stability for human body moderate training control. The accuracy of mechanical parameter data estimation is high, and the reconstruction ability of human movement such as running, jumping, gymnastics and so on is better, which shows a higher application value.

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