Computer Aided Action Simulation of Exploring Aerobics Athletes

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Abstract. There are few researches on the motion simulation of aerobics athletes. In order to improve the efficiency of aerobics training, this topic conducted research on human geometric modeling and motion synthesis through in-depth analysis of aerobics exercise system. Firstly, by analyzing the characteristics of real human body structure, this paper established a parametric whole-body geometry model based on human anatomy and anthropometry. Then, based on the analysis of the human motion system, a hierarchical motion model was established, and the joint motion was mathematically modeled. In addition, through the establishment of the anatomical-based joint coordinate system and the analysis of the motion capture data, the kinematics and dynamics parameters were solved. Finally, the simulation of human motion synthesis was realized under the condition of space mechanics balance constraint.

Keywords: computer aided; aerobics athlete; motion simulation; human body model
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1 INTRODUCTION

At present, the research on aerobics is only for a high-level athlete or aerobics participant to carry out a simple action analysis and analysis of a single link or a certain muscle group, which only analyzes the relevant motion technology features one-sidedly, lacks the systematic technical action model, and cannot comprehensively grasp the laws of motion technology. With the development of computer technology and the emergence of simulation technology, relevant software can be used to establish related sports action models and computer-assisted analysis of aerobics movements. In the research process of aerobics simulation, how to make the simulation model more natural has always been the difficulty that people have overcome. Computer-aided technology can design and analyze some methods that allow computers to learn autonomously, learn actions, and drive virtual human movements.

In recent years, with the continuous development of virtual reality technology, virtual human technology has attracted many scholars and organizations at home and abroad as an important branch and has conducted in-depth exploration and research in their respective virtual human application fields. Famous foreign teams include: MTRALab of the University of Montreal, the Human Body Modeling Center of the University of Pennsylvania, Carnegie Mellon University's graphic studio and its established NaturalMotin, Stuttgart Fraunhofer Institute's virtual reality research laboratory Fábio Angioluci Diniz Campos, Physiology, Yijie Z, Mu, Ming L Ltd., Michigan State University's ergonomics center, ANYBODYTechnology. The research results include virtual human expressions [1], movements [2], costumes [3], and hairstyles [4], all of which have achieved good results. Makhni E C et al [5] focused on the in-depth analysis of the movement characteristics of the human arm and shoulders. In order to reduce the algorithm operation time and achieve the effect of the model real-time reaction to the control parameter change, polynomial is used to express the behavior state of the muscle, and good results are obtained. Murray J J ,et al. [6] solved the problem that traditional methods need to perform large-scale inverse kinematics calculations in a given time series by using nonlinear programming and recursive Newton's and Euler equations to calculate gradients, so that kinematic parameters can be quickly obtained from motion data. Martin S A et al. [7] conducted an in-depth study of the reaction force model in the case of providing only joint kinematic parameters and providing foot pressure at the same time, and verified it in ANYBODY, which provides great convenience for the analysis of ground forces in some scenarios where the force pad is not suitable. Zich C et al. [8] studied the muscle system and proposed a virtual muscle control model based on the physiological shape of the muscle. Moreover, they applied the research results to the bionics field and achieved good results in controlling the robot arm. David P D D C et al. [9] established a new musculoskeletal model of the human hand for the lack of robustness of the current control algorithm and predicted the movement of the hand and wrist joints through the EMG signal.

The virtual person is a comprehensive representation of the human body's geometric and motion characteristics in the three-dimensional environment built by the human body [10]. The geometric surface features of the human body are extremely complex and very irregular, and the surface features of each body segment are very different, so it attracts many researchers to invest in this work. According to the user's orthogonal photos, Bowman T G et al. [11] customized the human body model that meets the requirements of the apparel industry by extracting the three-dimensional feature parameters of the human body. Cameron P W et al. [12] obtained a human body model with different shapes by using manual methods to modify the parameters. Yang D et al [13] used Kinect to obtain human body model data, extracted the feature points of the scanned image to complete the local matching of adjacent frames, and then performed global optimization to obtain the human body model through continuous iteration. Mcpherson A L [14] used the three-dimensional modeling software Maya to establish a virtual human model with a two-layer structure of skin layer and bone layer. The skin layer of the model consists of 6478 points and 7053 faces, and the bone layer contains 30 bone segments. Narra N et al [15] established a three-dimensional human skeleton model by extracting human body characteristic parameters in the video sequence. Schilaty N D et al. [16] used the American virtual human male CT data to establish a human upper limb model, which simplified 26 muscles into 42 action lines for upper limb weight-bearing muscle dynamics studies. Graham S [17] established a human upper limb model containing 50 muscles and conducted research in the field of ergonomics. Wang T et al [18] established a three-dimensional model of bone tissue based on the frozen human slice data obtained from the “China Visualization Man” project provided by Chongqing Third Military Medical University. Guillochon M uses the international anthropometric data and hierarchical modeling method to construct a two-layer virtual human model with bone layer and skin layer, which realizes virtual human character modeling [19].

The paper mainly studies the human motion simulation system in fluid environment, and further improves the simulation performance and effect on the basis of implementation and puts forward some innovative techniques. The core of this paper is divided into the establishment of human motion model, human body fluid interaction simulation and human path planning, and on this basis, the human motion simulation system is established.

2 RESEARCH METHOD

2.1 Human motion model

So far, the research on system simulation of multi-rigid body motion has been mature. The main methods are: Lagrangian dynamics, Newton Euler equation, variational method, Kane method and so on. Among them, the Lagrangian dynamic equation is a system equation about the binding force. There are two main types of this method: the first type of Lagrangian equation and the second type of Lagrangian equation. The first category applies to both complete and non-complete systems, and the second category applies only to complete systems. The generalized coordinates of the method require an auxiliary constraint equation to obtain an efficient solution. The form of the Lagrangian dynamics function is simple and easy to implement with the program, and the dynamics provides the force mode, the inertia matrix and the system structure, but the calculation of this method is large [20].。

The topological relationship of the human body model system is generally composed of a set of rigid body models according to a certain structure, such as: the head, the body, the limbs, the hands, the feet, etc., and the connection between the rigid bodies can be connected by a spring -damper. The motion of each rigid body needs to be converted to generalized coordinates. This requires the Jacobian matrix of spatial transformation. The degree of freedom of human body converted into generalized space is generally $10 \sim 200$, which depends on the accuracy of the human body model.

We assume that a part of the model is $a_i\left(i=1,2,\cdots,n\right)$, its centroid position is $p_i\left(x_i,y_i,z_i\right)^T$ in human body local coordinates, and the relative angle between each part is $q_i\left(\alpha_i,\beta_i,\varphi_i\right)^T$. When a generalized coordinate system is established, the position of the human body part in the coordinate system is described as $g_i\left(p_i^T,\mathrm{q}_i^T\right)^T$. The angular velocity of the rigid body a_i has the following expression (1).

$$w_i=\begin{pmatrix} \sin\theta & \sin\varphi & 0 & \cos\theta \\ \cos\theta & \sin\varphi & 0 & \sin\theta \\ \cos\varphi & & 1 & 0 \end{pmatrix} \tag{1}$$

Among them, the first term of formula (1) is the rotation matrix of the model. If we consider the spatial transformation relationship between the world coordinate system and the generalized coordinate system, the kinetic energy expression of the model (2) is following:

$$T_i=\frac{1}{2}r_i^T m_i r_i+\frac{1}{2}w_i^T I_i w_i \tag{2}$$

In formula (2), r_i is the position of the model in local coordinates, w_i is the angle of rotation of the model in local coordinates, m_i is the mass matrix of the model, and I_i is the inertia matrix of the model as it rotates. The formula (1) is substituted into the formula (2) to obtain the Euler expression (3) of the formula.

$$T_i=\frac{1}{2}r_i^T m_i r_i+\frac{1}{2}p_i^T a_i I_i a_i p_i \tag{3}$$

In the generalized coordinate system, the Lagrangian equation (4) that constitutes the rigid body part of the human body is as follows.

$$\frac{d}{dt}\begin{bmatrix}\left(\frac{\partial T}{\partial r}\right)^T\\ \left(\frac{\partial T}{\partial p}\right)^T\end{bmatrix}-\begin{bmatrix}\left(\frac{\partial T}{\partial r}\right)^T\\ \left(\frac{\partial T}{\partial p}\right)^T\end{bmatrix}-\begin{bmatrix}\phi_{r_i}^T\lambda\\ \phi_{p_i}^T\lambda\end{bmatrix}=\begin{bmatrix}Q_{r_i}\\ Q_{p_i}\end{bmatrix} \tag{4}$$

In the formula, $\lambda(\lambda_1,\lambda_2,\cdots,\lambda_n)$ is the Lagrange multiplier matrix, Q_{r_i} and Q_{p_i} are the force matrix in the generalized coordinate system of displacement and rotation, and $\phi_{r_i}^T$ and $\phi_{p_i}^T$ are the partial derivative of the first term of the equation to the generalized coordinates. The expression of the angular momentum matrix in the generalized coordinate system is set to: $\eta_i=\frac{\partial T_i}{\partial q_i}=a_i^T I_i a_i p_i$. Since there is $\frac{d}{dt}\left[\left(\frac{\partial T_i}{\partial r_i}\right)^T\right]=m_i\ddot{r_i}\left(\frac{\partial T}{\partial r_i}\right)^T=0$, the formula (4) can be transformed into the formula (5).

$$\begin{cases} m_i\ddot{r_i}+\phi_{r_i}^T\lambda=Q_{r_i}\\ \eta_i-\frac{\partial T_i}{\partial q_i}+\phi_{p_i}^T\lambda=Q_{p_i}\end{cases} \tag{5}$$

Considering the human body model formula, formula (5) is expressed in matrix form as equation (6).

$$\begin{cases} M\ddot{r_i}+\phi_{r_i}^T\lambda-Q_{r_i}=0\\ \dot{\eta}-\frac{\partial T}{\partial p}+\phi_p^T\lambda-Q_p-0\\ \eta-A^T JAp\geq 0\end{cases} \tag{6}$$

Equation (6) is a complete system equation. For this type of dynamic equation, Gear is more effective, and a stable iterative format can be obtained, which is suitable for solving sparse coupled nonlinear equations and non-rigid differential equations.

2.2 Tree structure of human body model

The method of 3D geometric representation refers that the basic geometry is used to construct a human body model in three dimensions. Common models are solid models and surface models.

The construction principle of a solid model is to use a simple set of entities to represent the structure and shape of the body. The collection of these entities is made up of a large number of basic geometries (such as ellipsoids, spheres or cylinders, etc.). It uses a method of hidden surface display. The establishment of the solid model is relatively long and complicated because the size and position of each geometric element are sequentially arranged according to the structure of the human anatomy. A major advantage of the solid model is the ability to handle edge collisions.

The body is composed mainly of bones, and each bone abstracts it into a combination of a joint and a chain, which is called as Hinge body. Because the movement of the human body is very complicated, in order to improve the real-time performance of the simulation, the structure of the human body model needs to be simplified. The model of the human body is composed of 11 hinge bodies.

Degree of freedom (DOFs) indicates the type of rotation of the hinge body. The rotation of each bone of the human body is different, and the rotation of the hinge body is also different. It is divided into the following types:

One dimension: x, y, z type;

Two dimensions: xy, xz, yx, yz, zx, zy;

Three dimensions: xyz, xzy, yxz, yzx, zxy, zyx.

The dimension represents the local rotation ability of the hinge body. For example, the hand joint is 3 dimensions, and the knee joint is 1 dimension. This information is configured in an external file (such as an xml file), and we need to build different information about the joints at different locations when loading the model.

The schematic diagram of the hinge body is shown in Figure 1.

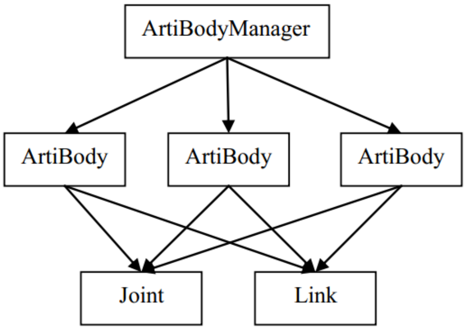

Figure 1: Schematic diagram of the relationship between the hinges.

A joint together with a chain form a hinge. The hinge body manager is primarily responsible for managing the simulation and update of each hinge body. The memory allocation of the hinge body is distributed in the form of a dynamic array, that is, a certain amount of hinge body is pre-allocated. If the actual number of treatments of the model is allocated, it is redistributed, which can reduce the consumption time of the program when loading and releasing resources to a certain extent. The interface is shown in Table 1.

Hinge body manager interface definition	*Interface description*
Upload	upload data
AddArtiBodyInfo	Adding a hinge
ConnectLink	link
StartSimulate	simulation

Table 1: Interface of the hinged body manager.

As shown in Fig. 2 and Fig. 3, the structure of the human body is composed of a series of sub-chain movements, and the movement of each sub-chain is mutually restrained. The information of the sub-chain includes: position, line speed, angular velocity, direction, external force (gravity, fluid force), parent chain and sub-chain information. Without a suitable data structure to manage and store this complex information, it would be difficult to achieve effective control of each sub-chain. In this paper, we choose to use a tree structure, and we use the waist of the human body as the root node to construct the link relationship of all the sub-chains.

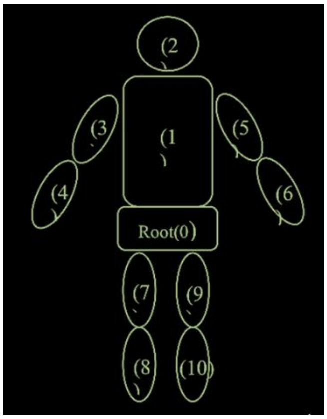

Figure 2: Hinge body model of human body.

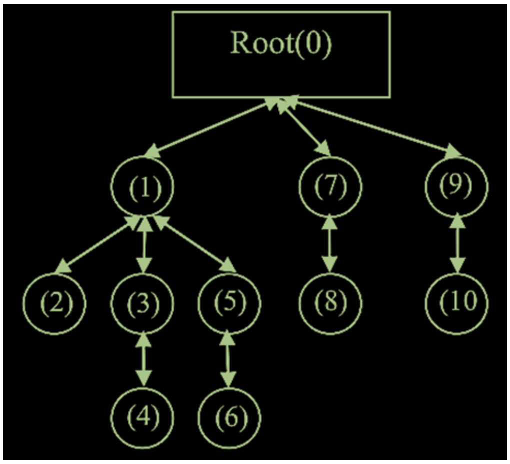

Figure 3: The tree structure of the human body.

Figure 3 shows the XML configuration information. It is worth noting that after determining the parent-child relationship of the child chain, the root node is the parent node of all the child chains and is the node in the world coordinate system that identifies the position and direction of the human body movement. Moreover, it is fixed in the local coordinates of the human body, and the position and direction are not updated.

The model has 11 hinges and 24 degrees of freedom, the root node is the parent of all nodes, and the root node remains motionless during local motion. There are two types of commonly used three-dimensional human models: one is the standard mesh model. It treats each joint as a unit and stores its corresponding vertex information, texture information, material information, and corresponding transformation matrix. Therefore, changing the transformation matrix in the mesh model can affect all the vertices in this part, and the degree of action on each vertex is the same. The other is the skinned mesh model, which uses a different storage method than the standard mesh model, and the skinned mesh model specifies its skeleton. Each bone in the mannequin has a corresponding set of specific sets of vertices. For example, in a palm bone, a collection of vertices corresponding to the palm of the model. Similarly, relative to a series of vertices in a standard mesh model, the vertices in the skinned mesh are assigned to different bones belonging to them according to the set of different vertices. Unlike a standard grid, its vertices can belong to all bones connected to it. For example, the apex of the place where the thigh and the calf meet will be controlled by the transformation matrix of the thigh and the calf. The following mainly introduces the principle of the role of the model transformation matrix in the skinned mesh.

As shown in Figure 4, the topmost coordinate system represents the world coordinate system. The mesh of the upper limb model is divided into three parts, namely the upper arm, the lower arm and the hand. The bones are determined in the Mesh of the upper arm, the lower arm and the hand in turn, so that the three segments of the figure can be formed. Each vertex in the character mesh has its own local coordinates, and the local coordinates of each vertex constitute the mesh object data in the file. On each bone, the coordinate system belonging to the bone is established. During the movement of the bone, the coordinate system of the bone changes with the movement, but the coordinates of the vertices on the skin do not change.

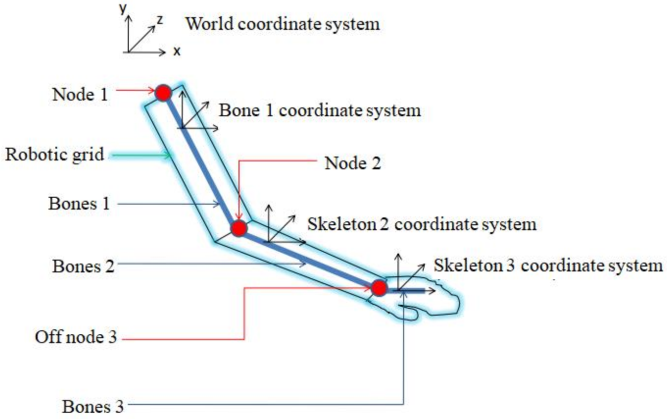

Figure 4: Schematic diagram of the transformation of the skinned mesh model.

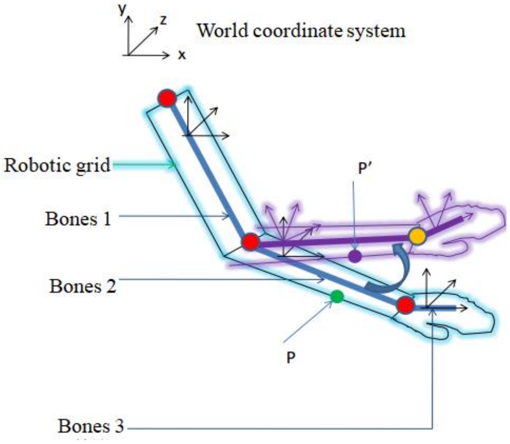

Figure 5: Schematic diagram of the transformation of the skinned mesh model.

The coordinates of the P point in the coordinate system of the skeleton 2 as shown in Fig. 5 do not change during the movement of the arm. All bones will have their own skeleton matrix. A folding matrix is a transformation matrix among Frame objects with hierarchical relationships in a .X file. Using the skeletal matrix, the coordinates of the vertices of the skeletal skin and the world coordinates in the skeletal coordinate system can be calculated.

3 SYSTEM CONSTRUCTION

In the construction of the 3D model, the software used in this paper is 3Ds MAX software. It specifies the format and design criteria of the file. In the process of model animation implementation, the human body model needs to be controlled through an external interface, and the software interface and its versatility will be encountered. Microsoft's DirectX-defined .X file can store 3D model information to solve this problem, Moreover, the DirectX SDK development library has its associated functions available to us. The model in the .X file can be edited with the C# language. DirectX's proficiency and in-depth study of the rules of three-dimensional modeling enables it to control and edit three-dimensional models flexibly.

In the process of DirectX development, it is divided into two parts: the runtime library and the development library. The runtime library provides support for DirectX program running, and the development library SDK is necessary for DirectX program compilation. Direct3D (D3D) is part of DirectX and is a set of 3D graphics programming interfaces developed on Windows systems. The relationship between Direct3D, Windows image device interface GDI, and hardware is shown in Figure 6.

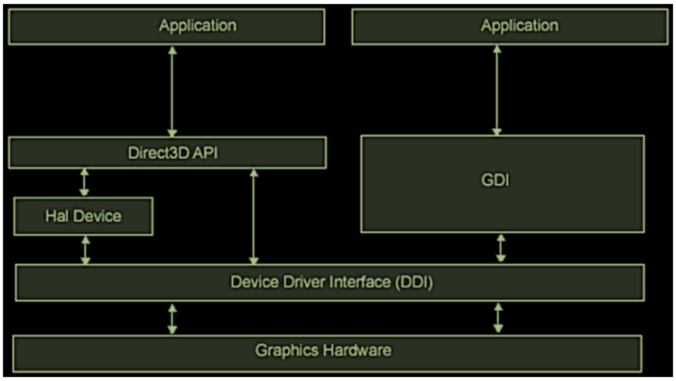

Figure 6: Relationship between Direct3D with Windows components and hardware.

DirectX has the following components: DirectX Graphics (including DirectDraw & Direct3D), DirectInput, DirectSound, AutoPlay, DirectPlay, Direct3D, DirectSetup, and more.

The indirect reading method is to convert the *.3ds file of the model into a standard mesh file by using the conversion tool. For this article, it is converted to the .X human body model. The mesh file contains attribute information. Then, the interface function of DirectX is used to read the material, texture, vertex and other information of the model in the mesh from the converted X file, so that the model can be rendered. In the case of several cases, the method we use is to convert the file format. Generally, we will use the Conv3ds.exe soft-change tool provided by D3D to convert the 3D MAX created model file *.3ds into the *.x file we need. Alternatively, we will use the DX8ISDK extras _ Direct3d.exe tool provided in the DirectX SDK to convert the 3DS model file created in 3D MAX to a *.x file. The model in 3DS MAX is shown in Figure 7. The .x model after indirect reading in Directx is shown in Figure 8:

The real-time motion control process of virtual human has the following main steps:

(1) Initialization of the system. First, 11 inertial sensors are bound at the key positions of the human body to complete the standard initialization posture, as shown in Figure 9. The system will initialize the relative rotation matrix between the sensor and the human bone according to the standard posture of the human body.

Figure 7: 3ds max human body model.

Figure 8: Human body model after reading in Directx.

Figure 9: Initialization pose.

(2) Human motion capture. The human body will make the desired action in the process of motion capture, and the system will collect the attitude data during the motion in real time, so as to achieve the purpose of real-time human motion simulation.

(3) Reproduction of human movements. After the motion capture is completed, the system can save the acquired human motion data, and use these data to simulate the motion reproduction of the virtual human model for the research and analysis of human kinematics.

4 ANALYSIS AND DISCUSSION

Human motion synthesis technology uses the knowledge of human anatomy, computer graphics, human kinematics, computer science and many other disciplines, so the technology is challenging and complex. Because this technology not only has theoretical research value but also has great commercial value, it has attracted many domestic and foreign institutions and human motion simulation enthusiasts to invest in this research. At present, it has been widely used in game production, film and television entertainment, rehabilitation training, sports and other fields. In this paper, a computer-aided human geometry model is established, then a hierarchical motion model of the human body is established, and the human joint motion type is mathematically modeled. Finally, through the analysis of the motion capture data, the calculation of multi-rigid kinematics and dynamic parameters is carried out. The effective joint motion constraint mechanism is obtained by applying the space mechanics balance constraint, and the human motion synthesis simulation is realized.

Figure 10: Motion Simulation Recognition.

(1) This paper establishes a human body geometry model based on anatomy. At present, scholars at home and abroad mainly aim at a specific part of the human body (such as the upper limbs and shoulders) and are closer to the real structure of the human body. However, there is a lack of simulation of human body geometry model based on anatomy. Since the shape of the human body is not the same, in order to reduce the complexity of the simulation, the main structure is unified into a straight-line segment to represent.

(2) In this paper, the human body motion system is hierarchically represented, and the joints are classified according to the degree of freedom. At the same time, the motion of the joint is mathematically modeled, and the rotation matrix of the joint around the coordinate axis and any axis is deduced in detail. The rotation of the joint around the coordinate axis is represented by a matrix, and the rotation of the joint around any axis is represented by a quaternion.

(3) In this paper, a local coordinate system is established for the main joint points by selecting anatomical feature points. By selecting the feature points at the joint, the origin of the local coordinate system and the direction of the coordinate axis are determined, and the local coordinate system of the wrist joint, the elbow joint, the shoulder joint, the hip joint, the knee joint and the ankle joint is established.

(4) On the basis of completing the construction of the human geometric model and the motion model, the motion capture data is analyzed and matched with the human geometric model, and then the inverse rotation kinematics is used to solve the rotation angle of the joint. Moreover, the dynamics formula is used to calculate the dynamic parameters. Finally, the effective joint motion constraint mechanism is obtained by applying the space mechanics balance constraint, and the human motion synthesis simulation is realized.

5 CONCLUSION

The application of motion capture technology has made virtual human motion control technology more and more mature, which makes up for the shortcomings of traditional control technology. This paper mainly describes the computer-assisted aerobics athletes' motion capture technology, and on the basis of these theoretical knowledge, this paper basically realizes the simulation of the virtual human real-time action. Firstly, after summarizing and analyzing the advantages and disadvantages of various methods related to human body motion capture, this paper selects an inertial sensor with low cost, high precision and easy to carry as a motion data acquisition device for simulating human motion capture system. Although this article has basically completed the basic application of real-time control of human motion posture, it is not ideal for some complex and difficult sports. In addition, the PC software can only perform 3D animation display and basic motion analysis such as acceleration and angular velocity. To this end, future research work can be further developed, and the current mature mobile positioning technology can be applied to the study of more complex behavior recognition in human body.

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