2009 Second International Symposium on Knowledge Acquisition and Modeling

Modeling of Human Body for Animation by Micro-sensor Motion Capture

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Abstract—**We present a human motion model and animation for micro-sensor motion capture system. It consists of a sensor data-driven layered human motion model and an animation method using polygon group to achieve skin deformation. This method is based on biomechanics. The joints of human body were categorized according to the motion characteristics. Motion parameters estimated from sensor data are used to control the movement of human skeleton model and the deformation of skin model, and consequently reconstruct the human body motion in real-time animation. The experiments have shown that the proposed model is suitable for sensor data-driven virtual human in real time animation.**

Keywords-human model; quaternio; movement reconstruction; micro sensor; real-time animation

1. INTRODUCTION

Modeling and animation of virtual humans has been an important research goal in computer graphics. Good models of the virtual human are thus very useful for a variety of applications, for example, movie special effects, user interfaces and games, etc. However, modeling of the virtual humans is extremely difficult due to the complexity of its shape, joint structure, and deformation. Much progress has been made in the various fields that contribute to the realization of virtual humans. The Web3D Union proposed H-Anim standard used in Network Virtual Environment. However, it is often difficult to meet the requirements. Chadwich proposed the Multi-level model[1], which can be used to construct a realistic three-dimensional human model[2]. However, it is not suitable for real-time applications such as games due to the large computation required at present. In this paper we present the full procedure of the creation of a life-like virtual human, from modeling and texturing to animation, and propose a method of constructing a sensor data-driven layered human motion model to realize the human motion capture and reconstruction.

In order to produce a highly realistic skinning deformation, researchers have made a number of skinning deformation methods. Weighted pose space deformation (WPSD) can generate high quality skinning with a limited number of sample pose[3]. Though it can generate an accurate skinning, it requires more computation than the Pose space deformation (PSD)[4], since joint distances are computed independently for each vertex. As such, this method is not suitable for real-time application. Skeleton subspace deformation (SSD) compute lower and is suitable for real-time application[5]. In this paper we propose the Polygon grouping method to achieve skinning deformation.

The contents of this paper are arranged as following: Section 2 describes the method of constructing a sensor data-driven layered human motion model; the process of movement reconstruction is presented in Section 3; the 4th section shows the experiments; Section 5 is the summation of this article.

2. HUMAN MODEL

Setting up a human model for micro-sensor motion capture system. We propose a modeling method of layered human motion model. Our method consists of the following three steps: first, according to H-Anim standard, we construct the layered human skeleton model; second, construct the dynamic model of the human body and restrict the degree of freedom of joint; third, use the polygon mesh method to model the human skin.

2.1 Human skeleton model

Based on the H-Anim standard, we constructed the skeleton model of virtual human. The human model contains 1 center of gravity, 21 segments and 17 joints. Segments are linked by joints. We use the nested joints to describe the hierarchical structure of skeleton model and use the sacrum as the center of gravity of human, which is on the bottom of the spine and is commonly considered as the root joint of the whole human model. From the root to upward and downward parts we establish a tree skeleton model. Each joint is the child node of another joint, except root joint. The tree structure is shown in Figure 1. In order to use sensor data to drive the human body motion in real-time animation, we assume each segment of human body is simple rigid geometry, which doesn't change shape during animation.

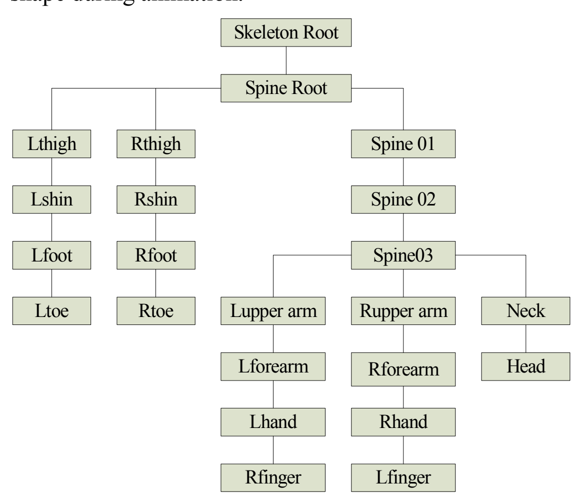

Figure 1 The human skeleton model

2.2 Dynamics model

Human skeleton model is formed by the nested joint, so adjacent two joints constitute a linkage device. We use the arm as an example to analyze the movement of the linkage. The arm contains shoulder joint, elbow joint and wrist joint. In our model, each joint has a local coordinate system, the X-axis point to the child joint. This linkage has 7 DOF which shoulder joint has 3 DOF, elbow joint has 2 DOF and wrist has 2 DOF. We use a series of rotation

978-0-7695-3888-4/09 $26.00 © 2009 IEEE
DOI 10.1109/KAM.2009.174

parameters to denote the change of the 7 DOF (v_1, v_2, v_3, v_4, v_5, v_6, v_7), Figure 2 shows the dynamic model of arm. The dynamic equation of arm can be formulized as follows:

$$M_{shoulder} = rot(x_{shoulder}, v_1)rot(y_{shoulder}, v_2)$$
$$rot(z_{shoulder}, v_3)tran(d_x, d_y, d_z) \quad (1)$$

$$M_{elbow} = rot(z_{elbow}, v_4)rot(x_{elbow}, v_5)$$
$$tran(d_x, d_y, d_z) \quad (2)$$

$$M_{wist} = rot(z_{wist}, v_6)rot(x_{wist}, v_7)$$
$$tran(d_x, d_y, d_z) \quad (3)$$

M_{shoulder}、M_{elbow} and M_{wist} can separately represent the transformation matrix of shoulder joint, elbow joint and wrist joint. *Rot(•)* stands for the rotation operation and the relative rotation angle can be given in the form of the quaternions which are provided by micro-sensor, *tran(•)* is translation operation which can be given by the coordinate transform. x, y and z stand for the local coordinate axis of joint, d_x、d_y and d_z stand for the displacement of the shoulder joint in the world coordinate system. According to the forward dynamic model, we can estimate the position of elbow joint and wrist joint by the rotation and translation under the local coordinate system of shoulder joint, elbow joint and wrist.

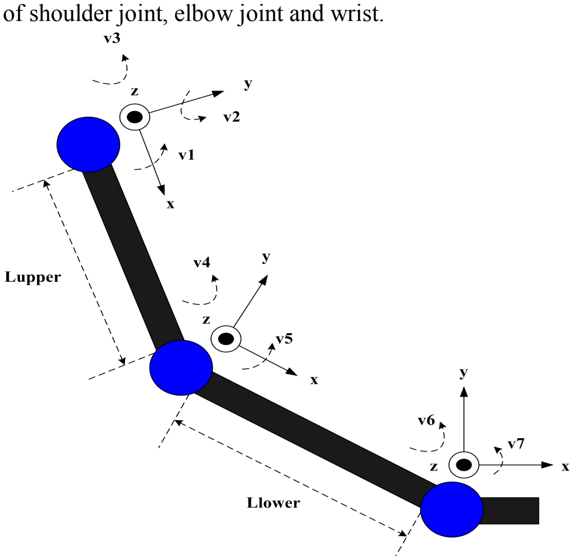

Figure 2 Dynamic model of the arm

If the length of the upper arm was L_{upper} and the length of forearm was L_{lower} , the initial position of shoulder joint is $P_{shoulder}(0)=(0,0,0,0)$, the initial position of elbow joint and wrist are $P_{elbow}(0)=(L_{upper},0,0,0)$, $P_{wist}(0)=(L_{lower},0,0,0)$. The initial translation of shoulder joint is $T_{shoulder}(0)=(0,0,0,0)$. The positions of the three joints at time T are represented as below:

$$P_{shoulder}(t) = T_{shoulder}(t) \cdot P_{shoulder}(0) \quad (4)$$

$$P_{elbow}(t) = q_{shoulder}(t) \otimes P_{elbow}(0) \otimes q^*_{shoulder}(t)$$
$$\cdot \mathrm{T}_{shoulder}(t) \quad (5)$$

$$P_{wist}(t) = q_{shoulder}(t)q_{elbow}(t) \otimes P_{wist}(0)$$
$$\otimes q^*_{elbow}(t)q^*_{shoulder}(t) \cdot \mathrm{T}_{shoulder}(t) \quad (6)$$

Where, q is the quaternion which is provided by the information processing, $\otimes$ is the multiplication of quaternion.

Given the above framework, we can compute the positions of all joints. Movements of the humanoid joints will cause the movement of associated *end-effector*, we need to compute the position vector of the *end-effector*. We can obtain angule and position values of joint connecting *end-effector* by using forward kinematics. The conversion formula is as follows:

$$dS = J_s(\theta)d\theta \quad (7)$$

$$J_s(\theta) = [\xi_1 \quad \xi_2 \quad \xi_3 \quad \cdots \quad \xi_n] \quad (8)$$

$$\xi_i = \begin{bmatrix} \alpha_i \times (M(i)P_n^i) & \beta_i \times (M(i)P_n^i) & \gamma_i \times (M(i)P_n^i) \\ \alpha_i & \beta_i & \gamma_i \end{bmatrix} \quad (9)$$

Where, dS is a six-dimensional vector of the *end-effector*, which include three-dimensional line speed and three-dimensional angle speed; θ is rotation angle ; n is the number of joint from root node to the end of the limb; $J_s(\theta)$is the Jacobin matrix, α_i, β_i, γ_i are the column vector of matrix $M(i)$ of i^{th} joint in world coordinate system. P^i_n is the position of i^{th} joint in local coordinate system.

2.3 The skin model

We use polygon mash to compose human skin model. According to the features of the human motion capture and reconstruction, we proposed the polygon group method for skin deformation. This method is based on SSD arithmetic. It divides the polygon mesh into planar polygon and surface polygon. The planer polygon meshes are attached on the segment of human so that it can move with bone and there is no deformation, such as finger, head which have no sensor data to drive their skin's deformation. The surface polygon meshes are attached on a group of joints and they can deform when the bone moved, such as, the upper arm, forearm which can deform when the relative joints moved. So this method increases the processing speed of human model and it also ensures the deformation effect of skin in human animation.

3. THE RECONSTRUCTION OF HUMAN MOTION

3.1 Motion parameters conversion

In the motion reconstruction, each segment of human model has a channel receiving the motion parameters information and this motion parameters is quaternion. These information are transformed into rotation angle information and position information in channel. The conversion formula is as follows:

Supposed that the quaternion of bone channel is $Q = (q_1,q_2,q_3,w)$, $v = (q_1,q_2,q_3)$ is rotation axis vector, w is rotation angle.
Quaternion normalized:

$$Norm(Q) = sqrt(w^2 + q_1^2 + q_2^2 + q_3^2) \quad (13)$$

$$Normlize(Q) = Q / Norm(Q) \quad (14)$$

Supposed that normalized quaternion $Normlize(Q) = (x,y,z,w)$,

$$\theta = 2\arccos w \quad (15)$$

$$\alpha_x = x / \sin(\theta / 2) \quad (16)$$

$$\alpha_y = y / \sin(\theta / 2) \quad (17)$$

$$\alpha_z = z / \sin(\theta / 2) \quad (18)$$

Where, $Normlize(Q)$ is a normalized quaternion，θ is rotation angle，a_x，a_y，a_z is rotation axis.

3.2 Motion posture reconstruction

3.2.1 Skeleton model motion

In real-time reconstruction of human motion posture, we define three nested coordinate system: the world coordinate system, the human coordinate system and the joint local coordinate system. Joint movement is divided into rotation and translation in the relative local coordinate system. So the human posture’s change can be represented into the accumulation effect of joint movements. Adjacent joint coordinate system is shown in Figure 3.

According to the position vector of the joint local coordinate system, we can obtained the position vector of child joint in the world coordinate system, the transformation formula is as follows:
Supposed that joint O_i is child joint of joint O_{i-1}, the rotation matrix of joint O_i is Rii-1under local coordinate system of joint O_{i-1}, the matrix of O_i in O_{i-1} joint local coordinate system show as follows:

$$M_i^{i-1} = \begin{bmatrix} R_i^{i-1} & P_i^{i-1} \\ 0 & 1 \end{bmatrix} \quad (19)$$

The matrix of joint O_i in the world coordinate system:

$$M(i) = \prod_{i=1}^{n} M_i^{i-1} \quad (20)$$

The transformation matrix of O_i show as follows:

$$M_{local}(i) = \begin{bmatrix} R_{local}(i) & 0 \\ 0 & 1 \end{bmatrix} \quad (21)$$

The new position of O_i in the world coordinate system

$$P_{final}(i) = M(i) M_{local}(i) P_{inital}(i) \quad (22)$$

Where， n is the number of joint from root node to joint O_i, $R_{local}(i)$is rotation matrix of O_i

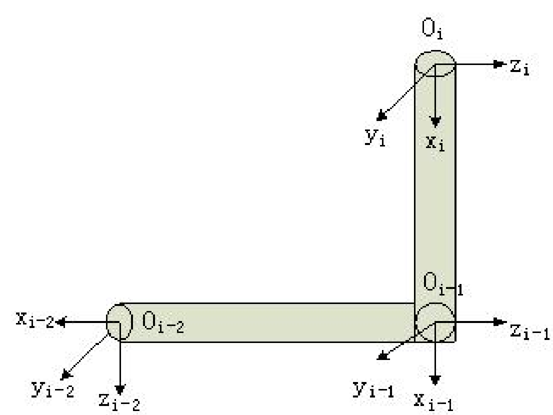

Figure 3 Adjacent joint coordinate system

3.2.2 Skin deformation

Skin model is attached to skeleton model, so that the movements of skeleton drive the skin deformation. The skin model is composed by polygon. Deformation of skin model uses SSD algorithm and the deformation formula is as follow:

Suppose the mesh vertex P of the surface polygon attach to the joint n, the inverse transform matrix of the i^{th}

joint in the initial pose is $M_{ref}^{-1}(i)$, the transform matrix of the i^{th} joint is $M_{quat}(i)$, the transform matrix of P under the i^{th} point can be represented as follow:

$$M(i) = w(i) M_{quat}(i) \cdot M_{ref}^{-1}(i) \qquad (23)$$

The summation of weight value of P is 1.

$$\sum_{i}^{n} w(i) = 1 \qquad (24)$$

The position of P in the world coordinate system after transform can be represented as follows:

$$P_{final} = \sum_{i=1}^{n} w(i) M(i) P_{inital} \qquad (25)$$

Where, n is the number of joints which can impact the vertex of skin, $w(i)$ is the right value of vertex P on the i^{th} joint.

4. EXPERIMENTS AND PERFORMANCE EVALUATION

In order to reconstruct the human motion in real-time animation, we have developed a human model to capture and reconstruct human motion. Once the micro sensors capture the information of motions from real people, human model must keep in consistent with the pose of real people. In the experiments, we put ten micro sensors on the upper body to capture the movement information. The frequency of sensor is 100Hz/s. This experiment is finished on the personal computer which CPU is AMD Ath.64 TK55 and EMS memory is 1G. The speed of the real-time animation is 30 frame/second and the delay time is 23ms. Each sensor captures the movement information of its relative segment. All the movement information is imported into the human model, and then he human model reconstructs the human motion in real-time animation. Figure 4 is the screenshot of the processes of human motion capture and reconstruction. The experimental results show that a sensor data-driven layered human motion model can reconstruct the movements of real people exactly.

5. CONCLUSION

Here we have presented a method of constructing a layered human motion model on the basis of the modeling method of surface model. This method suits the needs of micro-sensor human motion capture, and it also can well present the biomechanics of human motion. Because the surface model does not concern the structure of anthropotomy, this paper proposed a method of polygon group on the basis of SSD arithmetic. It speeded up the processing of human motion reconstruction and skin deformation. The experiments shown that it can reconstruct the pose of human motion with good accuracy. Future research will be on better skin model and skin's deformation algorithms.

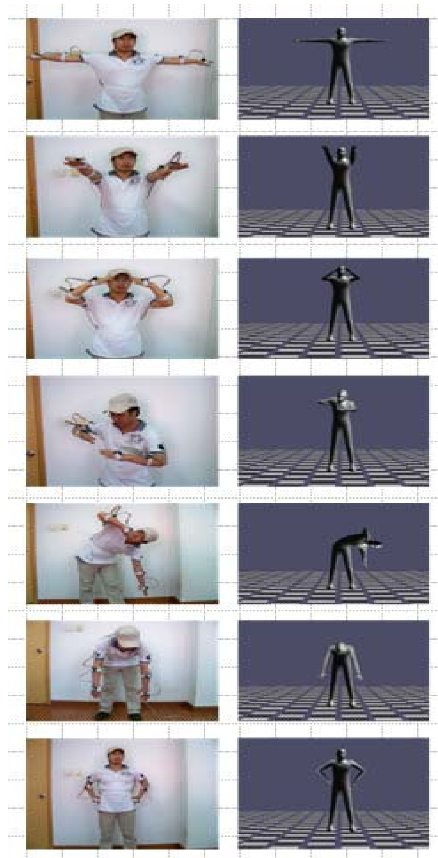

Figure 4 human motion capture and reconstruction

ACKNOWLEDGEMENT

The work is partially supported by the project under the China-Singapore Institute of Digital Media. The authors acknowledge the support by the members of SNARC, especially, Chen Jiang, for his support of hardware platforms.

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