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# Display of Virtual Hand and Establishment of Behavior Databases Based on 3dsMax and OpenGL

Xu Chao, Li Yunlong, Zhou Dongxiang and Cai Xuanping

College of Electronic Science and Engineering, National University of Defense Technology

Changsha 410073, China

Email: xuchao_1986@126.com

**Abstract**. Virtual-hand technology is one of the most important applications in Virtual Reality. It has offered great potential to create aeronautic training and medical treatment. In this paper we present a method of establishing a virtual-hand model in segments with 3dsMax software based on the structure and motion model of human hands, and realize the display and control of human hands in virtual environment by exploiting OpenGL. A behavior database of virtual hand is then established, and the relationship between serial numbers and behavior parameters is confirmed. This method decreases the data in telecommunication and improves the accuracy and real-time capacity in displaying and controlling virtual hand in a long distance. The experiments demonstrate the validity of the system.

**Keywords:** Virtual hand; 3dsMax modeling; OpenGL; Behavior database; Behavior parameters;

## 1. Introduction

In recent years, with the rapid development of Virtual Reality (VR), virtual-hand technology has been one of the hot topics in the domain of human-computer interaction. As one important part of virtual reality, virtual-hand technology exploits computers to establish virtual-hand model in virtual environment. Operators convey the information of human hand to the virtual-hand model established in virtual environment via peripheral equipment, in order to control the motion of human hand and then to get feedback for realizing the human-computer interaction.

Yang Wei [1] presented a method of virtual-hand interaction based on dynamic simulation, which implemented grasp operation for the virtual-hand effectively, but lack of fidelity interfered with its accuracy and authenticity. Zhu Jie [2] exploited an approach of skinned mesh to establish virtual-hand model, and settled joint fragments combined with weights theory, improving the accuracy to a great extent. However, both of them did not consider how to satisfy the validity and real-time capacity in the display of virtual hand under remote control. In this way, remote control can effectively improve the status of virtual hand in the field of human-computer interaction.

The implementation of display and remote control in virtual hand has brought forward a higher requirement for the quality of telecommunication. Poor quality and loaded data may interfere with the real-time capacity, and even arouse sequence chaos. Therefore, it is essential to improve communication quality and reduce data quantities during the course, in order to maintain the stability and real-time capacity.

The exact display of virtual-hand gestures is determined by their behavior parameters. In the process of telecommunication, transferring behavior parameters directly often requires large data quantities, which may lead to the loss of data. To solve this problem, this paper presents a method of establishing a behavior database of virtual hand, and links certain serial numbers to the behavior parameters. In this way, it is necessary for remote receivers to receive the numbers, in order to display corresponding gestures. This method can substantially reduce the data quantities and improve the stability and real-time capacity in the remote control. The basic flow of remote control of virtual hand is illustrated in Fig. 1. This system can realize the display and control of virtual hand by inputting external parameters.

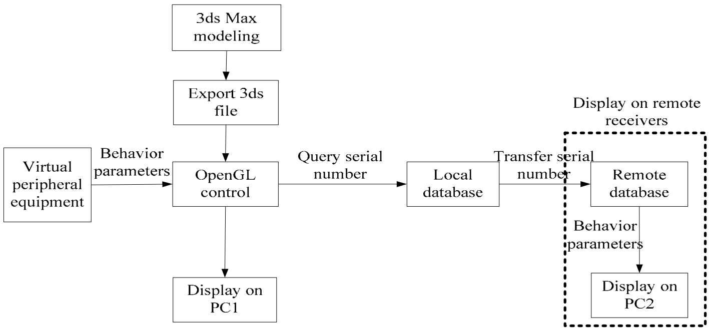



Fig.1. Basic flow

## 2. Structural Characteristics and Kinematics Theory of Hand

### 2.1. Anatomical Structure of hand

Fig. 2 shows a picture of anatomical structure of human hand [3]. The hand consists of one palm and five fingers, and the Metacarpal (including four joints) constitutes the major part. Five fingers are thumb, index finger, middle finger, ring finger and little finger, of which the basic structures are nearly the same except for thumb. Each finger is made up of three knuckles and joints respectively. Thumb is different from the other four fingers. It consists of only two knuckles (Interphalangeal and Metacarpophalangeal). As Metacarpal has a strong movement capability, in this sense, thumb can also be regarded as three joints, that is, Interphalangeal, Metacarpophalangeal and Trapeziometacarpal.

According to the anatomical structure of human hand, if 4 Metacarpals can be regarded as a whole, the hand then can be described consisting of 16 rigid parts. The movement characteristics of simplified model and their degrees of freedom (DOF) of joints are illustrated in Table Ⅰ [4]. The sum of DOF of all the joints is 23. Therefore, the motion states of hand can be controlled by inputting 23 external parameters.

Table 1. Simplified hand joints and motion characteristics

| Joint Name | DOF | Number | Motion |
|---|---|---|---|
| Interphalangeal | 1 | 9 | Flexion |
| Metacarpophalangeal | 2 | 5 | Flexion, Abduction |
| Trapeziometacarpal | 2 | 1 | Flexion, Abduction |
| Wrist | 2 | 1 | Flexion, Abduction |

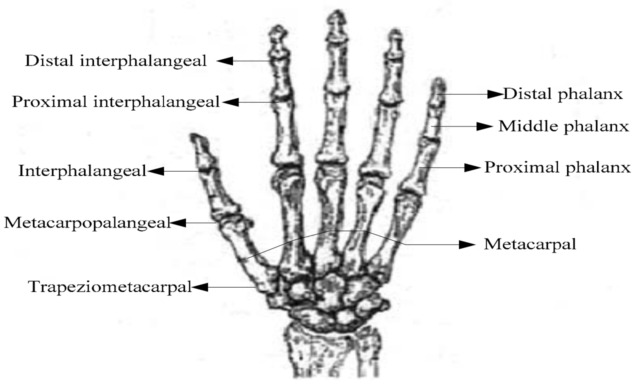



Fig.2. Anatomical structure of human hand

## 2.2. Kinematics Theory of Human Hand

Simplified model of human hand motion is shown in Fig. 3. As the standard system describing the whole movements of hand, the world coordinate system (denoted by $T_0$) is defined to have the same orientation as the wrist locates. The local coordinate system is then defined on each joint of index finger, in which the origin is located at the middle of the joint, X-axis points towards right, Y-axis points towards upwards, and Z-axis points towards viewers. This forms a right-handed coordinate system with a positive rotation about the axis in the anticlockwise direction.

In this figure, arrows show the directions of movements. The rotation and translation of joints are implemented based on the local coordinate systems. When fingers rotate or translate, the local coordinate system will carry corresponding operations. In addition, $T_1$ is defined as the local coordinate system of palm, which is coincident with $T_0$; $T_2$, $T_3$ and $T_4$ are local coordinate systems of proximal phalanx, middle phalanx and distal phalanx, and their Y-axis are coincident with each other; $L_1, L_2, L_3$ represent the lengths of their knuckles (proximal phalanx, middle phalanx, and distal phalanx). The relationship between local coordinate system and world coordinate system can be denoted by homogeneous transformation matrixes [5].

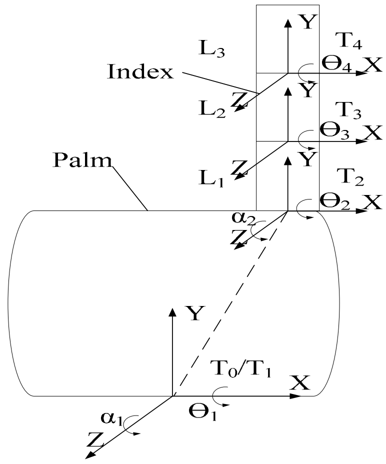



Fig.3. Simplified model of human hand motion

According to the simplified model of human hand motion in Fig. 3, we can deduce the homogeneous matrixes for geometric transformation extending each local coordinate system to world coordinate system.

Compared to the world coordinate system, the homogeneous transformation matrix $T_0^1$ describing the wrist revolving $\theta_1$ on its X-axis and $\alpha_1$ on its Z-axis can be given by:

$$T_0^1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_1 & -\sin\theta_1 & 0 \\ 0 & \sin\theta_1 & \cos\theta_1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\alpha_1 & -\sin\alpha_1 & 0 & 0 \\ \sin\alpha_1 & \cos\alpha_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

If $\cos$ and $\sin$ are replaced by $c$ and $s$, then the equation can be given by:

$$T_0^1 = \begin{bmatrix} c\alpha_1 & -s\alpha_1 & 0 & 0 \\ c\theta_1 s\alpha_1 & c\theta_1 c\alpha_1 & -s\theta_1 & 0 \\ s\theta_1 s\alpha_1 & s\theta_1 c\alpha_1 & c\theta_1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Similarly, given that the translation vector extending from coordinate $T_2$ to coordinate $T_1$ is $(a,b,c)$, compared to the coordinate system of wrist $T_1$, the homogeneous transformation matrix $T_1^2$ describing the proximal phalanx of index finger revolving $\theta_2$ on its x-axis and $\alpha_2$ on its z-axis can be given by:

$$T_1^2 = \begin{bmatrix} C\alpha_2 & -S\alpha_2 & 0 & a \\ C\theta_2 S\alpha_2 & C\theta_2 C\alpha_2 & -S\theta_2 & b \\ S\theta_2 S\alpha_2 & S\theta_2 C\alpha_2 & C\theta_1 & c \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

Then, the homogeneous matrix $T_2^3$ extending from local coordinate system $T_3$ to local coordinate system $T_2$ can be given by:

$$T_2^3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C\theta_3 & -S\theta_3 & L_1 \\ 0 & S\theta_3 & C\theta_3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

The homogeneous matrix $T_3^4$ extending from local coordinate system $T_4$ to local coordinate system $T_3$ can be given by:

$$T_3^4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C\theta_4 & -S\theta_4 & L_2 \\ 0 & S\theta_4 & C\theta_4 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

The relationship between local coordinate systems and world coordinate system for each point can be given by:

$$p = T_1 \cdot T_2 \cdot T_3 \cdots T_n \cdot p' \quad (6)$$

In this equation, $p$ denotes the coordinates of each point under world coordinate system while $p'$ denotes the coordinates under local system coordinate. In the model, $p'$ is defined as $p' = (0, L_3, 0, 1)^T$.

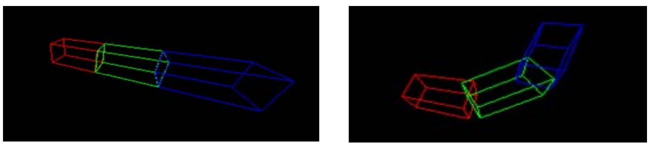
According to the movements of human hand, every angle of joints can be obtained. The homogeneous matrixes $T_0^1, T_1^2, T_2^3, T_3^4$ then can be deduced. The coordinates of each point is unchangeable in local coordinate systems. So if the local coordinates of each point are given, their world coordinates can be calculated, and the exact position of such points then can be located in virtual environment.

# 3. Establishment and Control of Virtual-hand Model

## 3.1. Drawing Virtual-hand Model in Segments by 3ds Max

As OpenGL can not provide high-level instructions in the respect of establishing 3D model, but takes vertexes as graphic elements, and then creates lines and polygons. Figures are composed of such basic elements. This method is flexible for simple and regular objects, but requires loads of work in establishing complex models. Besides it is easy to go wrong when some good visual effects are required. With 3ds Max, human hand modeling, texture mapping and rendering can be directly implemented, accompanying high efficiency and visual effects. However, OpenGL is much easier in controlling virtual model. Combined with their advantages, this paper introduces a method of establishing model by exploiting 3ds Max, and then realizes the real-time control of 3D model by reading 3ds files with OpenGL program, which improves the efficiency of modeling.

According to the method, the coordinates of each point are firstly extracted. Their world coordinates are then calculated based on kinematics equation. Finally the transformed gestures are drawn with OpenGL. However, it will come out joints fragmentation during the finger motion, which is shown in Fig. 4. The initial state of one finger is shown in Fig. 4(a), and two adjacent joints are connective closely with each other. When the joints are at the flexion state, the phenomenon of joints fragmentation will appear at the junction of two joints, which is shown in Fig. 4(b).



a b

Fig.4. Sketch map of joints fragmentation

To resolve the problem, each critical point can be connected by exploiting cubic polynomial track programming, to realize the smooth movement in joints [6]. But this method requires loads of work and complex calculation.

This paper adopted a way of drawing virtual-hand model in segments to resolve above problem. According to the characteristics of human hand, it is firstly divided into 16 independent parts, and then to establish models for individual part. The whole hand model is lastly established by joining each part together, which is shown in Fig. 5. To resolve joints fragmentation, each joint can be drawn into a knob embedded into its adjacent module.

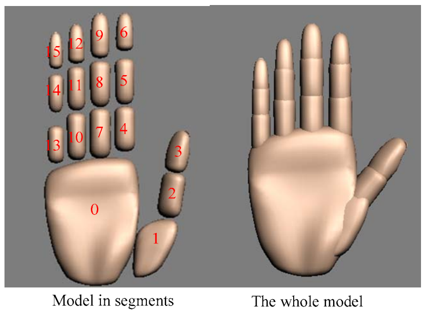



Fig.5. Virtual-hand model

As the data in 3ds files are orderly stored in chunks, and each takes up a separated storage space, the modules are established in the order of their serial numbers in Fig. 5, realizing the transformation for data blocks. In this case, the translation and rotation for each data block can be transformed into corresponding operation on the module. Thereby the real-time control to each point is transformed into corresponding operation to blocks. This method improves the efficiency of model controlling, but demands a high standard of drawing, especially in the joints. It still needs more remedy and verification to achieve a good visual effect.

### 3.2. Display and Control in OpenGL

In the OpenGL, glTranslatef() and glRotatef() are defined as the translation and rotation functions. glTranslatef() denotes multiplying current matrix by the translation matrix, glRotatef() denotes multiplying current matrix by the rotation matrix, rotating around the line (from origin to target) in the anticlockwise direction. In the progress of control, glTranslatef() is firstly used to translate each module to the origin of world coordinate system, glRotatef() is then used to control exact rotation angles, glTranslatef() is again utilized to translate the module back to its former position, thus realizing the rotary motion. Make clear of the subordinate relationship among different modules when these two functions are utilized to control the movements of each module, and guarantee that both of them are acted on corresponding module-view matrix to display exact gestures.

## 4. Establishment of Behavior Databese

In this paper, the real-time display and control are fulfilled by inputting external parameters, and different virtual gestures are also displayed by inputting different angle parameters, which lacks real-time capacity and practicality. To improve the real-time interaction between real hand and virtual one, a total series of behavior database can be established, in which different numbers are allocated to corresponding parameters desired from every gesture. In such case, the real-time display of virtual hand is implemented by matching the movement parameters required from data gloves with the data in the database. Provided that realizing human-computer interaction between two PCs, it is only need to transfer corresponding numbers of different gestures. This will reduce the transfer data and improve the stability and real-time capability effectively during the interaction.

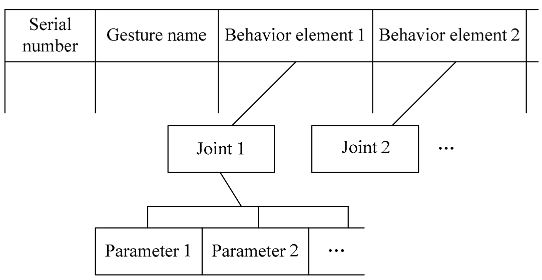



Fig.6. Sketch map of behavior database

It is shown in Fig. 6 that the purpose of establishing behavior database is to complete a one to one mapping from gestures to a behavior table. The behavior table consists of serial numbers, gesture names and a series of behavior elements which are composed of movement parameters of each joint. The detailed transfer process between two computers (PC1 and PC2) works as follows. Firstly, obtain corresponding serial numbers from the database of PC1 by matching the data from data gloves. Secondly, transfer the numbers to the database of PC2, and find their behavior parameters. Lastly, the gesture is displayed on the screen of PC2.

The behavior database is established for the requirements of users. Once established, the database can be used repeatedly in a long term. Besides, users can modify any gesture as required, which means that they can add new gestures or delete old ones to raise the utilization rate of the system.

It is important to integrate the virtual model into actual conditions, which means to consider about the constraints in each joint.

# 5. Experimental Results

## 5.1. Results of Virtual Hand Modeling

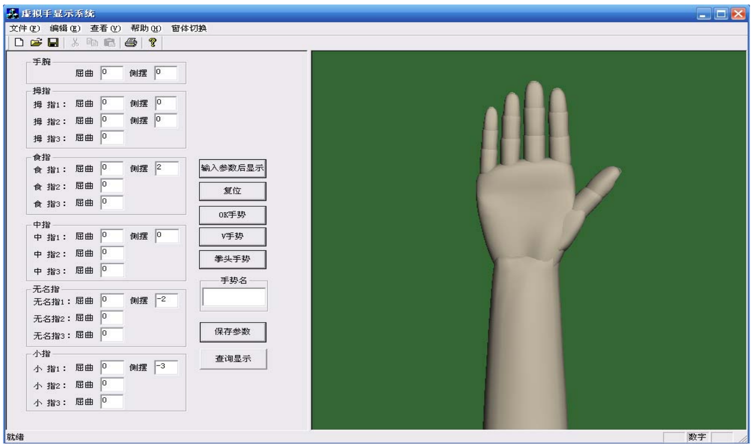



Fig.7. Display of virtual-hand model

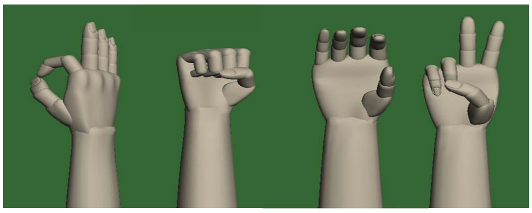
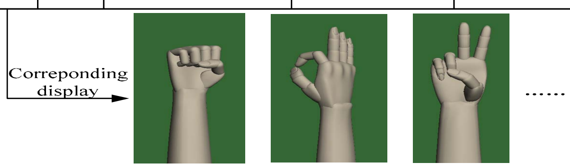


Fig.8. Display of virtual hand in different parameters

As is shown in Fig. 7, various gestures can be displayed by inputting different parameters on the interface, and the rotation of the whole model can be implemented by dragging mouse. The movements of virtual fingers are flexible and accurate, and coincide with the law of kinematics. Four different gestures are shown in fig. 8. Besides, the method of drawing in segments has basically resolved joints fragmentation, and displayed a vivid motion picture in virtual environment.

| Serial number | Name | Palm | Thumb | Index | Middle | ······ |
|---|---|---|---|---|---|---|
| 0001 | fist | 0.0 0.0 | 40.0 20.0 0.0 60.0 70.0 | 90.0 -5.0 90.0 90.0 | 90.0 0.0 90.0 70.0 | ······ |
| 0002 | OK | 0.0 0.0 | 28.0 18.0 0.0 20.0 40.0 | 35.0 67.5 45.0 80.0 | 0.0 0.0 0.0 0.0 | ······ |
| 0003 | V | 0.0 0.0 | 60.0 25.0 5.0 50.0 40.0 | 5.0 -10.0 0.0 0.0 | 10.0 0.0 0.0 0.0 | ······ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |




0001 0002 0003

Fig.9. An example of behavior database

## 5.2. A Modeling Case of Database

As is shown in Fig. 9, a behavior database of one to one mapping among the serial number, gesture name, and relevant parameters is established. Behavior parameters are the angles of each joint in certain motion states. Different gestures obtain different parameters. For some certain gestures, their behavior parameters are not always unchangeable. Even one person may produce different behavior parameters, despite the same gestures in different time, let alone different persons. Therefore, large quantities of behavior models are needed to improve the accuracy in displaying virtual hands. Besides, hand motion has to be constrained to delimit the range of movements of fingers, in order to avoid unreasonable gestures [7]. This is the key of establishing behavior database.

This experiment searches serial numbers in a database of 1 million records with hardware configuration of Intel(R) Core(TM) i3 2.93GHz CPU and Intel(R) Graphics Media Accelerator HD card. The whole time from collecting parameters to virtual-hand display is about 10ms when we use a network with the data transmission rate of 100Mbps (98% of the network are used), which can satisfy the requirements of real time. And the time of transmission process is less than 1ms due to the fact that we only transfer the serial numbers.

Therefore, the experiment demonstrates that the method based on behavior databases can realize the remote display of virtual hand effectively.

# 6. Conclusion

This paper presents a method of displaying and controlling of virtual hand based on behavior database, which reduces the delay time in displaying virtual hand, and promotes the efficiency of human-computer interaction. Due to the interference of behavior quantities and parameters of database, there are still some deviations in the course.

In the coming research, more attention should be focused on the establishment of database. For example, adding more virtual gestures can improve the completeness of behavior database. In the next step, the model will be calibrated and some unreasonable parameters of the database will be modified, in order to make the display of virtual hand more vividly and authentically.

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