SHAPE AND MOTION MODELING OF THE HUMAN HAND USING RANGE DATA

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ABSTRACT

This paper describes a new approach for modeling of human hands by considering the dynamics and the natural constraints of hand motion as well as hand shape. The hand model consists of a dynamic model and a surface model. The dynamic model is used to generate the posture of the hand. One can generate natural hand posture even when there are only a few of the hand parameters given. The surface model is used to generate the hand shape based on the posture generated by the dynamic model. The surface model is built based on the digitized 3D shape of a real hand.

1 INTRODUCTION

This paper describes a 3D hand model that can be used to make computer graphics(CG) animation and many other applications such as hand shape recognition. Using CG, one can create images of various objects from their 3 dimensional models. However, it is difficult to obtain the motion information from moving objects, and to synthesize the information without significant artifacts is not an easy job either. Therefore, it is difficult to create CG animation using CG technology that looks natural. The above is also true in the case of human hand. Human hand has over ten joints and they can move freely, thus a hand can give uncountable number of postures and generate complex movement.

Recently, motion captors such as data gloves have been widely used to capture the motion sequence of the hand that can be used for hand animation. Although the hand animation generated in this way is smooth and natural, it can only replay the recorded hand motion, thus it can not be used in a computer synthesized hand animation system. Even there are many degrees of freedom in a human hand, the fingers' motions are not completely independent [2, 3]. The angle of each finger joint is influenced by the angles of the neighboring joints and the adjacent fingers' joints. We explore the motion constraints between the joints We then use this information to build a dynamic model to describe the natural hand motions. When we want to generate a particular posture of hand, we give "force" to the finger to be moved. The postures of one or several of the fingers with given "force" are first determined with the model. The postures of the rest fingers are then computed with the dynamic model by using the information of the determined posture. The proposed model can also be used to predict the posture of the whole hand when only part of the information of the fingers is available. The unknown posture parameters of the hand can be determined by the known parameters and the dynamic model by considering the "inner force" between fingers.

A skin model of the hand is also built for generating images of a hand that looks real. The hand skin is modeled as a continuous surface which covers the whole hand. The initial shape of the skin model is constructed based on the 3-D shape data of a real hand and is represented as a polygonal model. The skin shape of a given posture is produced by deformation of the initial one. Once the hand posture is determined by the dynamic model, the posture parameters are used to adjust the positions of the control points of the surface model to generate the shape of the surface of the hand.

2 POSTURE DETERMINATION PROCESS

As we know, each joint in a hand can not move independently. There are some rules in the motion of bending fingers. And the motion of each finger also influences the motion of others. We utilize this natural characteristics of human hand as constraints in order to generate lifelike hand motion with few inputs. In this section, we describe the input system which can keep the natural skeletal posture by generating inner forces automatically when user gives few inputs to the system.

The dynamic model consists of a skeleton model and a inner force energy. Skeleton model is represented by many sticks with joints and some virtual springs, which determine the stiffness of each joint of fingers. Inner forces between joints and fingers are derived from a inner force energy.

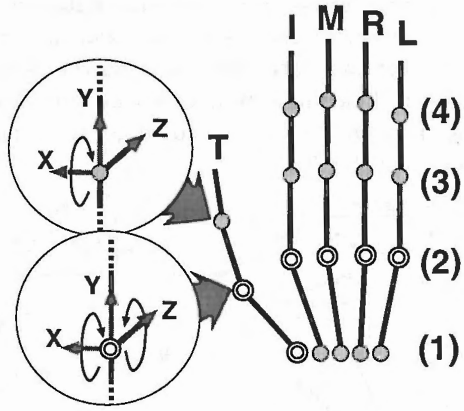

Figure 1. Skeleton model

We model the hand skeleton with rigid links and joints. State variables are joint angles which determine the posture of a hand.

There are five fingers in a hand, they are T(Thumb), I(Index), M(Middle), R(Ring) and L(Little). Each finger has several joints, where it is three for Thumb or four for the rests. The angle between j-th link and $(j-1)$-th link belonging to the finger k is expressed as $\theta^k_{(j)}$, which is used as a state variable of this system. We assume that joint(1) of Thumb and joint(2) of all fingers have two degrees of freedom (rotational components around x and z axis), and the other joints have only one(rotational component around x-axis)(Fig.1).

2.1 System Equation

We give a virtual spring in each degree of freedom of joint(Fig.2). State variables are determined by equilibrium between the elastic force of virtual spring and the input force. This is expressed as the following equation.

$$K\,\boldsymbol{\theta} = \boldsymbol{\tau}, \qquad (1)$$

$\boldsymbol{\theta}$	:	state variable vector
$\boldsymbol{\tau}$	:	input force vector
K	:	stiffness matrix

where the matrix K is diagonal matrix which represents stiffness of virtual springs. Stiffness matrix K can indicates easiness to bend each joint of fingers.

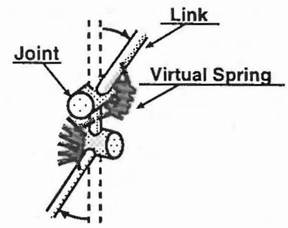

Figure 2. Virtual spring

2.2 Natural Posture

Here, the natural posture of the hand is defined as the equilibrium state of the dynamic model of the hand. The inner potential energy of the dynamic system is defined by the following equation.

$$J = \frac{1}{2}\,\Theta^T W\,\Theta, \qquad (2)$$

where $\Theta = A\boldsymbol{\theta}$ which is a linear combination of $\boldsymbol{\theta}$, the state variables. The component of W express the gains of inner forces. The inner force vector $\boldsymbol{\tau}_c$ is derived by partial differentiation of energy J by state variable vector $\boldsymbol{\theta}$ as the following.

$$\boldsymbol{\tau}_c = -\left(\frac{\partial J}{\partial \boldsymbol{\theta}}\right) \qquad (3)$$

$$= -\left\{\left(\frac{\partial J}{\partial \boldsymbol{\theta}^T}\right) + \left(\frac{\partial J}{\partial \boldsymbol{\theta}}\right)^T\right\}$$

$$= -(A^T W A)\,\boldsymbol{\theta} \qquad (4)$$

2.3 Determination of Hand Posture

We call the user inputs as direct inputs, and the inputs which keep natural skeleton posture as inner inputs. Total inputs to the system are the sum of these two inputs as the following.

$$\boldsymbol{\tau} = \hat{\boldsymbol{\tau}} + \boldsymbol{\tau}_c \qquad (5)$$

$\hat{\boldsymbol{\tau}}$	:	direct input force vector
$\boldsymbol{\tau}_c$	:	inner input force vector

Once direct inputs are given to some joints, the state of the inner force energy J is changed because J is a function of $\boldsymbol{\theta}$. In order to get the equilibrium state of a whole hand posture inner forces work on each joint. So the direct input force vector can be sparce one, that is there is no need to give direct inputs as many as degrees of freedom of a whole hand.

State variable vector $\boldsymbol{\theta}$ in a equilibrium state is determined by the following equations.

$$\left\{\begin{array}{rcl} K\,\boldsymbol{\theta} & = & \boldsymbol{\tau} \\ \boldsymbol{\tau} & = & \hat{\boldsymbol{\tau}} + \boldsymbol{\tau}_c \end{array}\right. \qquad (6)$$

$$\Downarrow$$

$$(K + A^T W A)\,\boldsymbol{\theta} = \hat{\boldsymbol{\tau}} \qquad (7)$$

2.4 Determination of Energy Parameters

The parameters in the equation(7) are determined using the captured motion data of a real hand. We use a video camera to capture the image sequence of the hand motion. The calibration of the camera is done before we capture the images. We attached tiny color markers on the each joint of a hand. The angle of each joint is obtained from the positions of the markers extracted from the image sequence.

We draw line segments connecting the markers in each image and calculate the angles at the joints. We get sequences of joint angles and then estimate the parameters in equation(7) by fitting a linear function to the angle sequence of each relational joints pair. We grab 10 to 30 images of finger motion for one cycle of flex and extension. The result of the estimation of the linear function give the values of the components of matrix A in the equation (7).

At the same time, the dispersion of the linear approximation is also estimated. The weight parameters w_k of constraints in the matrix W are calculated as the normalized values of the dispersion of the linear approximation as following,

$$w_k = \frac{\sum_i^n l_i^2}{n\ w_{max}}. \qquad (8)$$

l_i	:	Euclidean norm between data point and estimated line
n	:	number of data
w_{max}	:	maximum value of w_k

3 SURFACE GENERATION

The 3D surface model of the hand is generated based on a digitized 3D shape information of a real human hand. The surface model is a polygon based model. To make it useful, we combine the polygon model with the skeleton model, so we can generate the continuous surface of the hand when we change the posture of the hand skeleton.

3.1 Range Data

We measured the 3D shape of a replica of a hand made of plaster. We used a laser range-finder with linear motion platform to obtain shape data set of the palm and the back side separately. Each range data set is composed of 512×512 3-D points. The hand shape is extracted by removing data of motion platform with a proper threshold of height value.

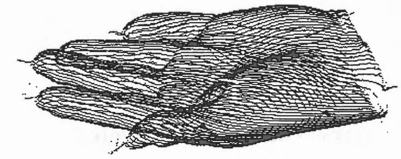

Figure 3. Shape data

We attached 9 markers to the replica before measurement. We transformed the back side data set to the coordinate system of the palm side, and adjusted the 3D positions of two data sets based on the position of the markers included in both data set by minimizing the quadratic error. In this way, we could get the range data of a whole hand(Fig.3).

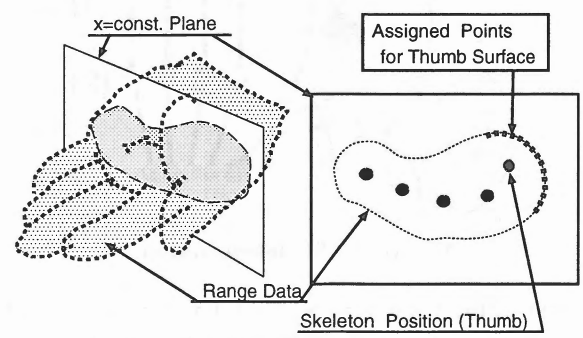

Figure 4. Procedure to get the polygon vertices

In order to deform the hand surface properly according to a given posture of the hand skeleton, we need to establish the relationship between the range data and the skeleton model indicating which point of the range data belongs to which link of the skeleton model.

At first, we assign a hand posture that is same as the one of the digitized hand of the skeleton model, and settle the skeleton model into the digitized 3D shape of the hand manually. As described in the previous subsection, the data set of the digitized hand shape is composed of the palm side data and back side data. We need to transform the back side data to the coordinate system of the palm side in order to obtain the range data of the whole hand. After this process, the scanning lines of palm side and back side will become unaligned. We construct the polygon model to describe the hand surface as following(also see Fig.4).

1. Settle 50 section planes ($x = const.$ plane in the world coordinate).
2. Project all points of range data onto the nearest section plane.
3. Assign the projected points to the nearest link on each section plane.
4. For each group of the projected points belonging to the same link, transform the coordinate of each point to a polar coordinate system, where the origin is set at the link. In order to create the polygon

vertices, we first select the points with the maximum angle θ_{max} and the one with the minimum angle θ_{min}. Then we create 10 new points of which angles have even intervals, as following.

$$\theta_i^* = \theta_{min} + \frac{(\theta_{max} - \theta_{min})}{10} i \qquad (9)$$
$$(i = 0, 1, 2, \cdots, 9)$$

To obtain the radius value of each newly created points, we find out two nearest original points, one has angle greater than θ_i^*, (r_b, θ_b) another has angle less than θ_i^*, (r_a, θ_a). Then the radius of the newly created point is calculated by linear interpolation as following,

$$r_i^* = r_a + \frac{r_b - r_a}{\theta_b - \theta_a}(\theta_i^* - \theta_a). \qquad (10)$$

After setting the skeleton model into range data and 50 section planes manually, the polygon vertices are automatically produced.

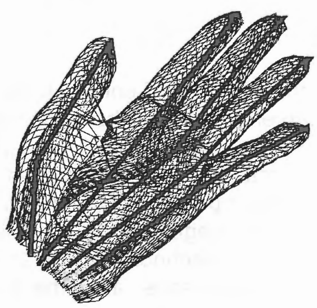

Figure 5. Wire framed model

4 EXPERIMENT

In order to evaluate the effectiveness of the proposed hand model. We built a simple GUI to allow a user to assign the desired angles of the joints, and a model renderer to generate the hand images as well as the hand model itself. At first, we input the sequence of the angles of the joints we want to move. The angles of the joints that we did not give are determined by the dynamic model. After that hand surface is generated with the surface model based on determined the angle of the joints, which is then sent to model renderer to generate the hand animation. The system is implemented on a SGI *Indigo*[2] workstation.

The hand surface is composed of about 8000 triangle meshes. The posture of the state without inputs is shown in fig.4. Two example frames of the generated hand animation are shown in fig.5 and fig.6, where we only assigned the angles of the joints of the thumb and the middle finger.

5 CONCLUSIONS

We introduced dynamics to a human hand model by using virtual springs and a inner force energy in a skeleton model. We also built a surface model of hand based on 3D shape measurement data and photo-realistic hand can be synthesized with the model. The natural posture of a hand is defined as the equilibrium state of the dynamic model, which can express the complicated effects of the interference between finger motions. The desired natural posture of the hand can be generated by only assigning key angles to a few joints. The experiment showed that the hand animation can be designed easily and the generated hand animation is natural and smooth.

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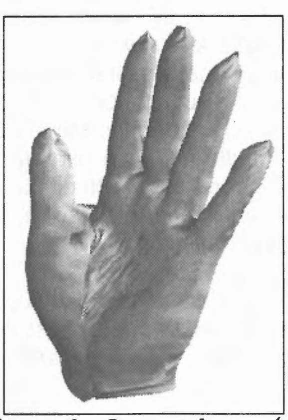

Figure 6. Outout image(1)

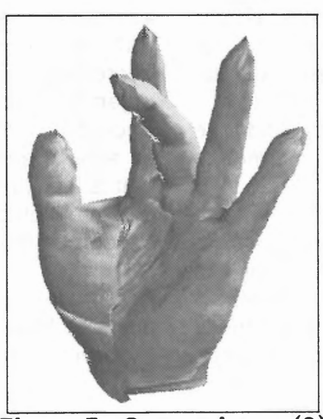

Figure 7. Output image(2)

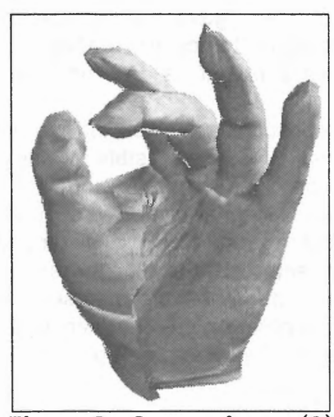

Figure 8. Output image(3)