Parametric 3D Hand Model

Maria Isabel Saludares, Rowel Atienza
Electrical and Electronics Engineering Institute
University of the Philippines, Diliman
Quezon City, Philippines
Email: mis.saludares@gmail.com

Abstract — In virtual reality, particularly in gaming applications, the hands used are generic representations that move using a controller. An individualized hand representation can create a more immersive experience. If the hands being controlled by the user are similar with his, the interaction with the virtual world is more effective and meaningful. We present a parametric 3D human hand model from Leap Motion sensor’s data. Piecewise geometric 3D shapes, such as ellipsoid and truncated elliptic cone, are used to generate the 3D hand. The dimensions of the hand are obtained from the Leap Motion sensor and used as parameters to make the 3D hand model.

Keywords – Virtual reality, Graphics, Modeling, 3D hand model

I. INTRODUCTION

Hand is mainly used as an interface for interaction including object handling and communication. Analysis of the kinematics and appearance of the human hand is significant in the fields such as hand surgery, human-computer interaction (HCI), and computer animation. In computer graphics, a more immersive experience in virtual reality is achieved when one directly interacts with the virtual world using body movements such as moving objects using hands. Gaming applications use generic hand representations (pre-loaded 3D hand models) that move using a controller. Using this technique may degrade the experience depending on the model representation used.

Individualized hand representation can create a more immersive experience, since it can provide a more effective means of interaction with the virtual world. To achieve this, an optimized, person-specific, realistic hand model has to be constructed, and be manipulated in real-time using a sensor that can capture its movement. Rendering a realistic 3D hand is dependent on the sensors used to capture the appearance such as size, shape, color, and creases and how these can be modeled. Animating the hand model is dependent on the sensor’s accuracy in capturing its minute movements. And finally, as an interface, the hand model must be optimized for fast, real-time rendering. In this paper we present a parametric 3D hand model that uses piecewise geometric shapes to programmatically create basic hand shapes. Given that the human hand has known basic anatomical features such as the fingers and the palm, hand geometry can be used in making its generic shape. It is more lightweight to re-create the hand from mathematical representations since it reduces loading time and footprints of applications, as well as the amount of work for graphic artists in creating individualized hand models. In this paper, we present a preliminary work on creating a fully-parametric 3D hand model without traditional graphics pipeline integration.

II. MESH GENERATION AND MODELING

Mesh is a discretized representation of an object into simple shapes such as tetrahedra and triangles [1]. It is composed of vertices and triangles dependent on the object’s form, shape, and nature. The triangles are defined by its three corner vertices and referencing shared vertices can create the surface of a solid object.

The triangles are enough to define the shape of an object as shown in Figure 1(a)-1(b). However, additional information such as texture and lighting is also necessary for rendering. Normal vector is supplied to each vertex to be shaded correctly for lighting. The normals at corners of the mesh’s triangles are simply perpendicular to the plane of their triangle. A uniform shading for each triangle creates an effect of having sharp edges applicable to objects such as a cube [2]. Normals are then interpolated across the triangles to create a smooth shading to approximate curved surfaces.
In addition to normals, textures are added to re-create finer details on the surface. Texture is similar to an image overlaid and stretched on the object’s mesh. For each triangle, a texture image corresponding to the finer details of the object is mapped on the mesh triangle [2]. Therefore, instead of simulating finer details on the mesh which would require thousands of triangles (high-poly) as shown in Figure 1(c), a whole texture map is wrapped to fit each mesh triangle to produce a visual representation similar to its original counterpart with fewer triangles (see Figure 1(d)).

For deformable objects, it is also important to take into account the nature of its surface relative to its kinematics to properly simulate its deformation. The quality of the mesh can influence on the accuracy and optimization in generation and simulation. Therefore it is important to take into account the nature of the object when constructing its 3D model.

The hand is a movable and deformable object therefore representing it in graphics requires a generated mesh that takes into account its complex shape associated with many degrees of freedom (DOF), skin deformation related to its underlying skeleton, hand creases, and skin color. The hand’s muscles and tendons underlying the skin significantly contribute to skin deformation [3] while the joint-bone structure is related to hand creases [4].

Sueda (2008) presented an automatic technique for generating the motion of subcutaneous tendons and muscles by integrating traditional animation pipeline with a novel biomechanical simulator [3]. The system computes the muscle activations in order to drive the movement of the hand. However it lacks details such as skin creases of joints, and palm. Rhee (2006) on the other hand focused on using the surface appearance of the hand in order to create its 3D model [5]. The details such as creases and skinning properties were incorporated. This is significant in creating a visually realistic model of the hand but requires substantial pre-processing using computer-vision techniques. Vaillant (2014) introduced implicit skinning that uses geometric method for real-time skin deformation with contact modeling given a 3D model of the hand [6]. MacLeod (2014) presented an individualized human CAD model that automatically creates the mesh from anthropometric and scan data [7]. Bogo’s (2015) method on the other hand, estimated 3D geometry and appearance of the human body from the monocular RGB-D video [8]. They introduced a parametric 3D model, called Delta, which can be adjusted based on the features obtained from the video. A three-dimensional hand model using 3D stereophotogrammetry was developed by Hoevernaren (2015) to determine if it can produce accurate and reproducible images of the hand that can be used for soft tissue analysis [9].

Meanwhile, Leap Motion (LM) uses a pre-loaded realistic generic hand representation to perform tasks and do not take into account the different sizes and appearance of the hands [10]. The Leap motion sensor tracks hand movement at up to 200 frames and can identify the hand’s bone sizes and positions, span, and other hand geometry values. The LM software passes this information to the rigged skeleton of the generic hand representation and animates the 3D hand model directly through motion capture. However the sensor only has a field of view (FOV) of 150 degrees wide and 120 degrees deep, which limits the movement of the user [11].

There are three main concerns in rendering the hand model: producing a photo-realistic 3D model, optimizing the 3D model’s polygon count for fast rendering, and adapting a flexible model to create a person-specific hand. Appearance-wise, an object’s 3D model requires thousands of polygons (high-poly) to closely simulate its real-life counterpart. However, as the number of polygons increases, it is computationally more expensive building the model making real-time rendering slow and jittery. One possible solution is to use less number of polygons (low-poly) and use different 3D model mapping techniques to replicate the small details that may be missing due to the optimization from high-poly to low-poly. Although human hands are anatomically similar, its surface anatomy is person-specific. The model must also be easily adjustable to account for the variability in human hands.

III. HAND GEOMETRY AND APPEARANCE

Every human hand is unique with thirty (30) global features of hand geometry defined based on the structure...
of the fingers and the palm. The features include the length and widths of the fingers, thickness of the palm, maximum spread of the fingers, and others [12]. Human hands have enough anatomical features but are not considered unique for complete personal identification. However, a combination with its surface anatomy (such as palm, and finger creases) and other features makes it unique and usable for biometrics [13]. Hand geometry is not very distinctive among people on a personal level. Since we are constantly using our hands to perform tasks, we are intimately familiar with ours which is significant when creating a hand interface to the virtual world. Manipulating a hand of different size and shape can influence the accuracy of interaction and the immersion in virtual environment.

Human hand is a complex anatomical structure composed of bones, muscles, tendons, and skin, each of which has a complex relationship with each other that significantly affects its kinematics and appearance [4]. The bones of the hand are grouped into three areas: digital, carpal, and wrist. The digital bones of the four fingers consist of distal (DP), middle (MP), and proximal phalanges (PP), while the thumb consist of distal and proximal phalanges, and the palm region consist of metacarpals (MC) [5]. The carpal bones are a set of eight small bones and the wrist are the radius and ulna. For the hand creases, there are three (3) palmar skin regions, and three (3) transverse digital creases. These creases are related to the underlying bones that serve as reference in identifying specific hand structures during surgery [4].

IV. PARAMETRIC 3D HAND MODEL

The shape of the hand is largely based on the dimensions of the fingers, and the palm. The most basic geometric model of the finger is a cylinder, while the palm is an ellipsoid. Based on this idea, we initially create a hand given arbitrary dimensions of fingers and palm. The basic geometry of the hand (bone length and width, palm size, etc.) was obtained using the Leap Motion sensor.

The 3D model has two sets of parameters: hand geometry and number of mesh points per bone. The piecewise model is subdivided based on the bones of the hand. Each hand structure has a corresponding 3D shape: truncated ellipsoid for distal phalanges and palm, truncated elliptic cone for the rest of the bones (see Figure 3), and ellipsoid for the palm.

The truncated elliptical cone (see Figure 4) has five parameters: base semi-axes (a, b), length (l), and height (h). Using similar triangles, the parameter l for the truncated elliptical cone with the semi-axes of the bone (b₁) and the next connected bone (b₂), and height (h₁) is given by:

\[
\frac{l_1}{l - h_1} = \frac{b_1}{b_2}
\]

\[
l_1 = \frac{b_1 h_1}{b_1 - b_2}
\]
cone length (Eq. 1) are as follows:

\[ x = a \frac{l - h}{l} \cos v \]  
\[ y = b \frac{l - h}{l} \sin v \]  
\[ z = u \]  
\[ v \in [0, \ 2\pi] \]  
\[ u \in [0, h] \]  

The ellipsoid (see Figure 4) has three parameters, its semi-axes \((a, b, c)\). Given the length \((c)\) and width of the distal phalanx \((a)\), and an approximated bone thickness \((b)\), the parametric equations are:

\[ x = a \cos u \sin v \]  
\[ y = b \sin u \sin v \]  
\[ z = c \cos v \]  
\[ v \in [0, \ 2\pi] \]  
\[ u \in [0, \ \pi] \]  

Every finger mesh was transformed given a set of angles of spread of the fingers. An ellipsoid was used to form the palm. Figure 5(a) shows the mesh for each finger and palm created using hand dimensions as parameters. After which, the piecewise meshes in the palm region (which consist of truncated elliptic cones and ellipsoid) were combined using 3D Delaunay triangulation creating a single closed mesh (for palm mesh, see Figure 5(b)).

V. RESULTS AND DISCUSSION

The hand generated using this procedure as shown in Figure 6(a) has 4439 vertex points. The general shape of the hand is programatically re-created using the parametric 3D hand model. Texture and skin deformation are not covered in this paper but we present a method that helps reduce the effort in creating the basic shape of an individualized 3D hand by using mathematical representations in the form of parameterized geometric shapes. The hand can be constructed by adjusting several parameters:

- hand dimensions (can be obtained from the Leap Motion sensor)
- number of vertices for each finger bone and palm
- angles of spread of finger (can be calculated from Leap Motion sensor data)

Based on traditional graphics pipeline, a high-poly model creates a more realistic model since it can simulate the object closer to its counterpart by including the minute details in mesh generation. Leap motion’s generic hand representation, which closely resembles a realistic hand, has approximately 10,000 vertices [10]. The number of vertices of the parametric 3D hand model can easily be adjusted to create a high-poly version similar to that of the Leap motion’s generic hand as shown in Figure 6(b) which has 10,428 vertices.

The hand mesh generation does not require the use of 3D modeling softwares (such as Maya) which reduces the loading time and footprints of applications, and the amount of work for graphics artists in creating individualized hand models.
As a preliminary work, the general hand shape is constructed. The resulting 3D model has yet to resemble a realistic human hand. Several areas of improvement which can be included to further improve the parametric 3D hand model:

- Inclusion of palm and joint creases,
- Mathematical modelling of skin deformation, and
- Modelling of skin color

VI. CONCLUSION AND FUTURE WORK

The parametric 3D hand model uses piecewise geometric shapes, such as truncated elliptic cones and ellipsoids, to programatically re-create the hand. Hand dimensions from Leap Motion, and an arbitrary number of vertices serve as model parameters. As a result, a hand is re-created without using traditional graphics pipeline. Since this is a preliminary work, the initial 3D model has yet to resemble the shape of a real hand. Details such as creases, nails, skin deformation, and skin color which significantly affect the realistic appearance of the model are not yet incorporated. For future work, we plan to include mathematical models for the hand crease, skin deformation, and skin color to further improve the parametric 3D hand model.

ACKNOWLEDGMENT

This work is funded by the Human Hands as Input Device for an Immersive Virtual Reality Experience (VREx) Project of the Department of Science and Technology (DOST) and Philippine Council for Industry, Energy, Emerging Technology Research and Technology (PCIEERD).

REFERENCES