Review Article

pISSN 2383-5389 / eISSN 2383-8116

Journal of International Society for Simulation Surgery 2015;2(2):52-57

http://dx.doi.org/10.18204/JISSiS.2015.2.2.052

3D Character Animation: A Brief Review

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Virtual Reality makes a virtual environment more realistic and, furthermore, it provides a variety of experiences which we cannot have in reality. A drastic growth of GPU performance and increase of computing capability make virtual environment more realistic than ever. One important element of constructing virtual environment is to animate 3D characters. Many researchers have been studying 3D characters animating and a myriad of methods have been proposed to make them more realistic. In this paper, we discuss the technologies and characteristics of 3D character animation. We believe that realistic characters in Virtual Reality will be applied to various fields: education, film and game industry, business and, particularly, medical area such as telemedicine, virtual surgery, etc.

Key Words 3D character animation · Blend shape · Skinning.

Received: November 23, 2015 / **Revised:** November 25, 2015 / **Accepted:** November 30, 2015
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Introduction

The Augmented Reality (AR) and Virtual Reality (VR) technologies provide many contents that we can barely experience in reality. Further, the developments in performance of computer and GPU are based on putting virtual environment into our reality efficiently. The core technologies in developing contents of AR and VR are 3D character modeling and 3D character animation. These are used in various areas such as 3D film, game industry, Physics, Medical simulation and Educational contents. In this review, we discuss the method of animating contents in the virtual reality.

There are two topics of 3D character animation, namely, Facial animation and Body animation. Facial animation implies the representation of natural facial expressions. There are two methods of producing this type of animation. One is the Geometry-based approach which is based on control point in 3D character face mesh and the other is Blend shape model-based approach which utilizes 3D facial expression template blending. The tree-structured skeleton is usually used for animating body motion. In addition, to achieve more realistic character movements, not only physics but also non-rigid deformation of skin or clothes are adopted.

In this paper, we discuss Geometry- and Blend shape model-based of facial animation as well as Skeleton- and Physics-based of body animation.

Facial Animation

There are two ways to construct a face model. The first one is based on geometry. In this method, control points are defined in 3D character's face meshes and the face meshes related to moving the control points are deformed. The second method is based on Blend shape. It is a way to represent facial expressions by blending sample shapes. In the following section, we introduce the methods of animating using these face models.

Geometry-based

In many studies employing Geometry-based approach, researchers show how to match the facial feature points from input video or webcam to the control points in face meshes using regression. Then the animation is made by controlling the face meshes which are dependent on the controlling points. Dutreve (1) proposed a method of facial animation. In his work, he extracted the facial feature points from videos and images. By using RBF (Radial Basis Function), regression problem between the feature points from 2D data and 3D feature points can be solved. It implies a map from the feature points of source image to the corresponding feature points in 3D face meshes using RBF. Then, displacement was calculated by GPU based on a linear blend skinning and animation was made by automatic rigging. Rhee (2) extracted feature points from webcam and defined the displacement using RBF regression. The displacement was used in face mesh deformation by GRBF (Geodesic Radial Basis Function). Rhee pointed out that defining geodesic distance using connectivity between face meshes was more efficient than defining Euclidean distance between feature points as RBF's input.

Blend Shape model

"Blend shape" is a kind of sample model to represent facial expressions. It is usally used in film industry for making realistic humanoid characters. It represents facial expressions by blending using many weights of sample models. Blend shape model is defined as the following equation (3).

$$\mathbf{f} = \sum_{k=0}^{n} w_k \mathbf{b}_k.$$

where $\mathbf{f}$ is resulting face, $\mathbf{b}_k$ is individual Blend shape and w_k is blending weight.

Basic template 3D meshes which represent neutral expressions are used for constructing blend shape and they are usually hand-crafted. One of the most famous methods is constructing blend shape's parameters from real human model. This method is well-known to be capable of making more realistic models. For example, Erika (4) applied motion capture data of feature points which work frequently such as eyelid, eye and mouth to 3D Blend shape model (Fig. 1). Deng in (5) used more than 100 feature points to improve the performance of motion capture.

There are several methods for facial animation. The method using blend shape model is calculating weights per selected frames. Key-frame animation and Performance-driven animation are two approaches of this method. In the former approach, key-frames are selected randomly and motions are produced by interpolating blending weights of each Key-frame. Many commercial programs (such as Maya) provide such spline interpolation (6).

The latter approach creates character's motion based on 3D motion capture. Using motion capture is one of the famous schemes in not only facial animation but also body animation. Joshi (7) proposed a way of blending weight α_i to minimize difference between position of face from motion capture ($\boldsymbol{M}_i$) and Blend shape ($\boldsymbol{V}_{ij}$) as following equation

$$\underset{\alpha_1,\cdots,\alpha_n}{\operatorname{argmin}} \sum_{j=1}^{m} \left[\boldsymbol{M}_j - \left(\sum_{i=1}^{n} \alpha_i \boldsymbol{V}_{ij} \right) \right]^2.$$

where M is the number of motion markers and n is the number of Blend shapes. The blend weight α_i should be updated in every frame and in every region. However, there is a limitation on representing various facial expressions because Blend shape model is linear. To solve this linear problem, a number of methods such as expression retargeting are used to make natural movements (8). Although there are many ways to capture motion such as using Kinect, researchers tend to develop their own motion capture technologies recently. Kiran (9) constructed actor's Blend shapes by making meshes which focus on important contour features such as eyelid and mouth from input video. He wanted to get a more detailed movement by focusing on more significant parts of face which involve in frequent movements.

Besides, Expression cloning is also used for facial animation (10). Expression cloning applies real face's motion to target face (blend shape model). It is usually used in putting expressions to CG characters in movie making. For instance, in production of "Avatar", synchronization between Blend shape and actors

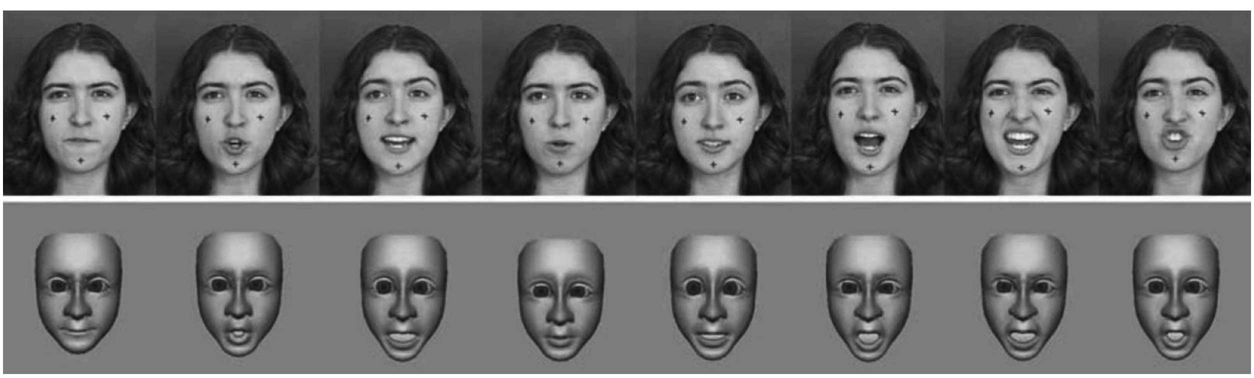

Fig. 1. Constructing blend shapes with motion capture (4).

whose faces are marked is used for putting expressions.

As we mentioned earlier, linear Blend shape model causes a limitation on representing a variety of facial expressions. Nevertheless, Blend shape model makes expressions more various and detailed compared with other linear models such as PCA analysis. Therefore, Blend shape model is used in many areas including facial animation.

Body Animation

In this section, we present a brief review of methods about 3D character body animation in computer graphics area. Generally, 3D character body animation can be understood as surface deformation followed by movements of several control points called bones or joints. While most of facial animation methods depend on blending with pre-defined expression shapes, the body animation techniques are defined as a binding between skeletal primitives (joints or bones) and vertex on mesh surface.

Early in the 21st century, Face Body Animations (FBAs) specification which is 3D character animation coding standard was published by MPEG-4. For body animation, FBAs specifies the Body Definition Parameters (BDPs) and the Body Animation Parameters (BAPs). The BDPs consist of 88 joints and 296 BAPs which are control parameter of animation. Detailed character movements such as hip twisting are defined in BAPs. However, the number of the BAPs-296 is are so too large to be implemented efficiently. For this reason, recent character animation methods do not use the FBAs.

Most methods of 3D character body animation can be categorized into Skeleton-based and Physics-based approach. The former animates the character body with skeleton-surface bindings. On the other hands, the latter facilitates detail part (hair, clothes…) animation by solving the Finite Element Model (FEM) or the Boundary Element Model (BEM).

Skeleton-based approach

This approach animates the character body by characterizing the relation between underlying skeletal structure and motion. These methods are called Skeletal Subspace Deformation (SSD) or Skinning. We refer to this approach as Skinning. The earliest Skinning-related work is the method proposed by Magnenat-Thalmann (13). He proposed a Joint dependent Local Deformation (JLD) operator which is able to generate object grasping animation of hand through the binding between joint and local deformation. Nowadays, this method is referred as Linear Blend Skinning (LBS).

General LBS deforms the character surface using a matrix which represents rigid motion of the bone of the character. Blending this matrix with skinning weight and vertex position yields,

$$\mathbf{v}' = \sum_{i=1}^{n} w_i T_{j_i} \mathbf{v}.$$

Where $\boldsymbol{v}$ is a position of a vertex, $\boldsymbol{v}$' is position of the deformed vertex, T_{ji} is homogeneous transformation and w_i is a weighting parameter of blending. Displaced position $\boldsymbol{v}$' is represented by weighted sum of homogeneous transform matrix of related joint and the position vector of that vertex. Because of its simple notion, LBS has wonderful advantage for implementation and processing speed.

However, this simplicity arises some artifacts. When the object's joint is twisted hard, blended vertex displays unwanted results called candy-wrapper artifact. Another serious artifact called skin collapse is occur when the elbow is bent more than 90 degree with respect to its forearm (Fig. 2). These artifacts are derived from intrinsic problem of blending transformation matrix. Alexa (14) stated that the result of linear blending of rotation is not more than that in SO (3) group. This means that linear blending the rotational part of homogeneous transform matrix is not rotation anymore.

Some researchers proposed methods to solve this problem without changing of LBS's equation (15, 16). Wang (15) proposed Multi Weight Enveloping (MWE) assigns 12 weights to each transform matrix related to vertex deformation. These numbers are derived from the number of motion-related component of homogeneous transform matrix (3×3 rotation, 3×1 translation). This method solved these above artifacts. But 12 weights are too many for animation control. Also implementation becomes complex with this method. Merry (16) pointed out that 12 weights are not necessary for solving LBS's problem. The

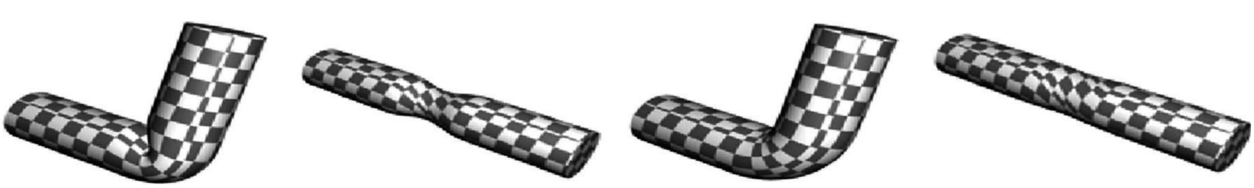

Fig. 2. Skin collapse (Right), Candy wrapper (Left) artifacts and Result of Right (16).

method called Animation Space uses only four parameters. It is a less complex algorithm compared to the MWE.

Another approaches are related to modify the blending methods (17, 18). They uses various technique to solve unnatural deformation of body. Park (17) proposed a complex but more natural deformation method which uses adapted transformation matrix. This matrix consists of rotational transform matrix (3×3) and quadratic deformation matrix (3×3) and its residual (3×3). These are concatenated to generate the final transform matrix (3×9). His work shows a more sophisticated deformation than the general LBS. In another study related to this field, Cordier (18) used Log-matrix blending method. The logarithm function was used for sophisticate blending. Although their implementation is more natural than Park's one. But there is a serious artifact which is related to the characteristic of rotation. Log-matrix blending does not always guarantee the shortest-path between rest pose and deformed pose. This yields a serious artifact as illustrated in (Fig. 3).

To preserve the simplicity and speed of LBS and to solve the artifacts derived from the property of blending rotations, many researchers relied on mathematical tools (19-23). In kinematics the quaternion blending is widely used to blend the rotation matrix without the loss of algebraic property of SO (3) group (20). Ken (21) proposed Spherical Linear Interpolation (SLERP) which perfectly blends rotation using non-linear method. Based on this, Kavan (22) proposed Spherical Blend Skinning (SBS). For computational speed, he used the linear blending of quaternions. He stated that linear blending of quaternion was a better approximation than linear blending of rotations. However, there is another problem with this effort. General quaternion cannot represent the translational part of rigid motion. That's why Kavan (19) augmented his prior work with dual quaternion. Rigid-motion of the character can be understood as a screw motion. This motion can be represented efficiently by dual quaternions. So he linearly blend dual quaternions to get better approximation of correct blending of transformation. This approach called Dual quaternion Linear Blending (DLB) preserves rigid-motion in SE (3). DLB is more powerful yet less complex than other methods. Famous 3D animation movie "Frozen" adopted this method (23).

Other interesting studies related to skinning are automatic skinning weight calculation which is a part of rigging (24, 25). Generally, the skinning weights are determined by artistic labor. On the other hand, automatic assignment can also be done with proximity between bone and surface vertex. Baran (24) pointed that proximity-based weight assignment can be resulted in improper vertex-bone binding. His method considers not only proximity but also smoothness related to the surface. He solved heat diffusion equation for vertex-bone binding. Another approach is Example-based approach (25). A set of examples provided by artists is used for determining skinning weights. This method shows more natural results than the previous one but it requires the artists to do tedious work in making examples. Moreover, unless sufficient examples are provided, the animation would be unnatural.

Besides, there are several approaches such as directly interpolating example meshes or non-rigidly deforming the character using Principal Component Analysis (PCA) (26, 27).

Physics-based approach

Animation details such as skin deformation through muscle contraction or behavior non-rigid unit like clothes are modeled using physical theories. Mathematical models are used for these purposes. Methods for deforming human skin with muscle contractions exploiting such models are FEM and BEM (28, 29). Guo (28) adopted FEM method to generate user specific skin deformation using deformation chunk. Another research related to this is proposed by Tang (29). His method is based on BEM, which demonstrated skin deformation caused by movement of human lower limb.

Non-rigid deforming parts such as hair or clothes is also another interest of this area (30-32). Velocity, bending, stretching of mass-spring systems play a key role in motion of this deformation. Hyun (33) proposed a sweep surface instead of skeleton. The sweep surface can afford to realize anatomical details such as bone-protrusion, muscle bulge, skin folding. The GPU-based collision detection model helps improve performance of this method.

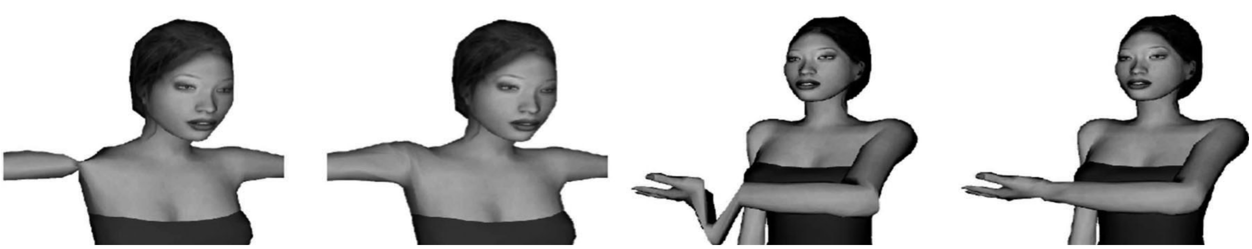

Fig. 3. Comparison between LBS and DLB (Left), Log-matrix and DLB (Right) (19).

Discussion

We categorized the 3D character animation as face and body animation. In many applications, both types of animation require simple and real-time applicable method. But there are some problems related to such efficiency. For blend shape animation, linearly blending of template shapes would fail to realize fine-scale details such as winkle. Recent studies support this hypothesis using Detail-maps for shading (34). For skinning, applying non-rigid deformation to a character is hard. It seems that physics-based approach can solve this problem. Nonetheless, there is no generalized method to animate detail animations. Kavan (19) tried to animate non-rigid deformation by separating animation as non-rigid part and rigid part.

Conclusion

To create a realistic avatar in virtual reality, 3D character animation techniques are very important. We reviewed various researches which aim to animate natural 3D character. For a decade, many industrial manufacturers have been using these methods for 3D films, games and scientific simulations. However, non-rigid deformation of the 3D character is still hard to realize. Much research focuses on non-rigid deformation of object, which deals with local deformations of special part such as clothes. To augment the naturalness of virtual environment, more sophisticated method to generate detail animation without the loss of simplicity and computational speed would be needed. These methods would enable us to apply the virtual environment to remote diagnosis, virtual surgery and so forth.

Acknowledgements

This work was supported by ETRI R&D Program [15ZC1400, The Development of a Realistic Surgery Rehearsal System based on Patient Specific Surgical Planning] funded by the Government of Korea.

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