Using dual quaternions for Control Cluster Method

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Abstract

Realistic character mesh deformation has been one of the key issues in different applications of 3D computer graphics as video games or crowd simulation. Geometric techniques such as skinning are considered an intuitive way to achieve visually plausible animation of the human-like characters despite of having certain shortcomings. Control cluster method is an alternative to tackle those drawbacks of the traditional techniques. In this paper a modification of control cluster method using dual quaternions and Bezier patch meshes is presented. Control cluster method tends to split all the vertices of the polygonal model mesh into two groups: cluster and free vertices. Free vertices position is calculated based on cluster vertices position in a non-linear fashion. Dual quaternion skinning application to cluster vertices calculation is discussed.

Keywords: *Skinning, Control Cluster, Non-linear Deformation, Polygonal Mesh Deformation.*

1. INTRODUCTION

Realistic mesh deformation has been one of the key issues in different applications of 3D computer graphics as video games or crowd simulation [1 - 3].

This research focuses on non-linear geometric approach to deformation because most of the geometric algorithms proposed demonstrate shortcomings connected with their linear approach.

Previously an approach based on a control clusters technique for correcting 2D models skinning deformation was described by us in [4]. Then a generalized and more versatile approach to deforming 3D polygonal models – Control Cluster Method (CCM) was proposed in [5]. The generalized approach could be implemented in a wide variety of applications including physical processes simulation, such as ecological processes (e.g., computational domain flooding and dewatering as a result of wind upsurge-downsurge; fire spreading; prevalence of air and water pollution). It makes use of control clusters to facilitate the work of the animator in creating realistic animation of the character without involving much user-input data. The method proposed provides intuitive control and it is easy to use because it allows the user to influence only a small group of vertices leaving the non-linear deformation of the rest of the vertices to the algorithm.

In this paper a modification of control cluster method using dual quaternions and Bezier patch meshes is presented. Control cluster method tends to split all the vertices of the polygonal model mesh into two groups: cluster and free vertices. Free vertices position is calculated in a non-linear fashion based on cluster vertices position. Using dual quaternion skinning as a way to deform cluster vertices is discussed.

2. RELATED WORK

A lot of research on 3D object deformation from different perspectives has been done, but we focus on recent development applicable to skeletal animation.

Linear Blend Skinning (LBS) is considered the most widely used technique for real-time animation in spite of its well-known shortcomings [6] thanks to its versatility, efficiency and straightforward GPU implementation [7].

Recent skinning techniques can be divided into geometric and example-based techniques. Geometric techniques use the single input mesh, as for the example-based ones, they require using sample meshes to correct or train the weights of the model mesh.

Dual-quaternion skinning is a relatively recent geometric skeletal animation technique [8], describing both rotations and translations using quaternions. Having no shortcomings of LBS, dual-quaternion skinning demonstrates some new limitations connected with too much volume (see Fig. 1).

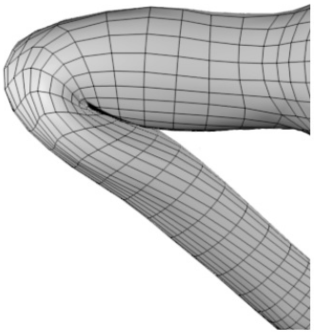

Fig. 1. Bending the arm model with Dual Quaternion Skinning (courtesy of [9])

To avoid notorious artifacts Pose Space Deformation proposed in [10] takes advantage of using sample shapes of the model, the technique requiring much input from the user [11].

It was also proposed in [12] to pre-compute optimized skinning weights for linear and dual-quaternion skinning at joints to approximate the skin transformations produced by nonlinear variational deformation methods.

Research [9] exploits the advanced compositions mechanisms of volumetric implicit representations for correcting the results of geometric skinning techniques.

Some other techniques proposed such as [13] modify the basic LBS formulation by generalizing the weight functions to matrix-valued or vector-valued forms.

3. CONTROL CLUSTER METHOD

3.1 Approach description

The key idea of Control Cluster Method consists in all the vertices of the model being split into two types: cluster vertices and so-called free vertices. The position of the cluster vertices is to be set using some input data. The key areas of the mesh defined by cluster vertices form the shape of the model, thus cluster vertices control the deformation of the model. The position of free vertices is calculated automatically by a non-linear algorithm.

3.2 Cluster vertices transformation

Cluster vertices can be transformed in a great variety of ways, either by direct mesh editing or by applying some deformers including lattices, cage or skeleton. Cluster vertices transformation could be also defined by data ranges from some type of measuring equipment, for example water level measuring device or motion capture data.

The key cluster vertices before were deformed with the help of Linear Blend Skinning, so vertex $\vec{v} \in V_p$ is associated with a set of weights $\{ w_i \}, \sum_i w_i = 1$, where w_i denotes the weight of the bone $\vec{b}_i$. Weight w_i defines the extent to which the vertex position is influenced by the bone $\vec{b}_i$. Let $\{B_i\}$ be the skeleton configuration in the bind pose. The skeleton being in an arbitrary pose W_i, the transformed position of vertex v' is calculated according to the formula.

$$\vec{v}' = LBS(\vec{v}) = \sum_i w_i W_i B_i^{-1} \vec{v} \quad (1)$$

But as deformation is inherently spherical we seek non-linear blending of rigid transformations. As for LBS, the component-wise interpolation of matrices results in not preserving the orthogonality of the rotational part of the matrix. Even in the proximity of singular configuration, the matrix being regular involves a non-uniform scaling, which ends in the loss of volume of the deformed character.

3.3 Free vertices transformation

If a vertex does not belong to the cluster, it is considered a free one and its position is recalculated based on its position in the model topology and its nearest cluster vertices position. Free vertices position can be defined in several non-linear ways so that it corresponds to the position of the cluster vertices.

In previous works on Control Cluster Method [4, 5] Catmull-Rom splines [14] or cubic cardinal splines generalizing cubic Catmull-Rom splines were used as a non-linear item of the method. Using interpolation, C^1-continuity and local control, cardinal splines are an acceptable way to solve the task. The spline remaining flexible, smooth natural look of the character is provided by the C^1-continuity of the spline. Direct control over the points of the curve is achieved with the spline interpolating its control points. With local control the spline has every control vertex provide a slight impact on the overall look, so the details of the model remain preserved.

The problem is that using splines requires special topology of the model and is not always suitable. So a more general approach would be a welcome alternative.

3.4 Fields of application

Control cluster method could be used in different spheres of visualization ranging from animation to ecological processes simulation.

The cluster vertices deformation can be set using user-input data, including different deformers such as a skeleton to produce a character animation or some certain pose of the model.

Provided cluster vertices positions are defined by some scientific equipment, a wind upsurge-downsurge flooding and dewatering simulation could be achieved with the help of control cluster method. Among possible spheres of control cluster method application in ecological processes simulation fire spreading and prevalence of air and water pollution can be mentioned.

In this paper application of the method to animation of human-like character models is presented.

4. MODIFICATION OF THE METHOD AND ITS SKINNING APPLICATION

4.1 Limitations of Control Cluster Method skinning

Skinning application of CCM can be used for creating character animation. The existing modification of Control Cluster Method using Linear Blend Skinning and cardinal splines as cluster and free vertices deformers respectively is characterized by some limitations. On one hand, capable of preserving the level of detail, it gives satisfying results without demanding much user input (see Fig. 2); on the other hand, splines cannot meet every possible topology of human-like models. Therefore the new modification is to deal with an arbitrary topology models.

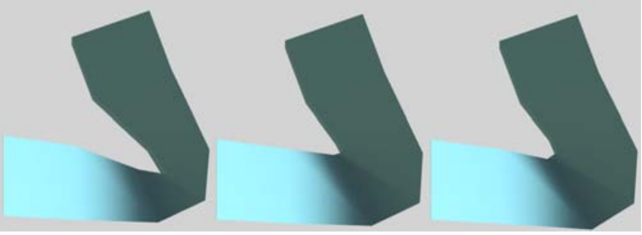

Fig. 2. Side view of the simplified two bone hand model, frames of the child bone rotation animation. From left to right: LBS, PSD, CCM

4.2 Cluster vertices transformation for skinning

Generally speaking, cluster vertices transformations can be defined in different ways that are not strictly set. To demonstrate it we consider three different ways for cluster vertices transformation in creating arm rotation animation: Dual Quaternion Skinning (DQS), Pose Space Deformation (PSD) and procedural dependence.

4.2.1 DQS deformed cluster vertices

The most efficient, versatile and wide-spread way of creating a character animation, Linear Blend Skinning, is challenged by Dual Quaternion Skinning [8] that is available in many of 3D editors of nowadays. The advantages of using DQS include allowing for spherical nature of skeletal deformations, efficiency and simple implementation. Moreover, the technique as well as LBS does not require the modification of existing models. Therefore, base cluster vertices can be deformed with DQS.

The first step is to convert skinning matrices $W_1,...,W_p$ to unit dual quaternions $\widehat{q}_1,...,\widehat{q}_P$. This operations doesn't take much time because the number of the joints ***p*** is usually rather small and the conversion itself needs only one quaternion multiplication. Presented as 2 x 4 matrices, the dual quaternions $\widehat{q}_1,...,\widehat{q}_P$ are sent to GPU.

Then the linear combination is calculated for every vertex *v* according to the following formula:

$$\widehat{\mathbf{b}} = \sum_i w_i \widehat{\mathbf{q}}_{ji} \qquad (2)$$

But to get a unit dual quaternion we need normalization $\hat{\mathbf{b}}' = \frac{\hat{\mathbf{b}}}{\|\hat{\mathbf{b}}\|}$.

Then after the optimization where $\hat{\mathbf{b}} = \hat{\mathbf{b}}_\mathbf{0} + \varepsilon\hat{\mathbf{b}}_\varepsilon$ and w_k, x_k, y_k, z_k denote the components of $\frac{\hat{\mathbf{b}}_k}{\|\hat{\mathbf{b}}_k\|}$,

the resulting unit dual quaternion is converted into matrix *M* as follows:

$$M = \begin{pmatrix} 1-2y_0^2-2z_0^2 & 2x_0y_0-2w_0z_0 & 2x_0z_0+2w_0y_0 & t_0 \\ 2x_0y_0+2w_0z_0 & 1-2x_0^2-2z_0^2 & 2y_0z_0-2w_0x_0 & t_1 \\ 2x_0z_0-2w_0y_0 & 2y_0z_0+2w_0x_0 & 1-2x_0^2-2y_0^2 & t_2, \end{pmatrix} (3)$$

where $t_0 = 2(-w_\varepsilon x_0 + x_\varepsilon w_0 - y_\varepsilon z_0 + z_\varepsilon y_0)$;

$t_1 = 2(-w_\varepsilon y_0 + x_\varepsilon z_0 - y_\varepsilon w_0 + z_\varepsilon x_0)$;

$t_2 = 2(-w_\varepsilon z_0 + x_\varepsilon y_0 - y_\varepsilon x_0 + z_\varepsilon w_0)$;

So $v' = Mv$.

Due to coordinate-invariance the operation produces the shortest path screw motion. And though the motion speed is not constant it is close to constant [8]. Therefore no visible drawback in skinning is present.

4.2.2 PSD deformed cluster vertices

DQS exceeds LBS in many points but it is considered to have too much volume, producing a non-natural smooth outgrowth (see Fig. 1). To correct those undesired artifacts PSD can be used.

It requires using sample pairs <*X, S*>, where *X* is a user-input sample shape of the model corresponding to skeleton configuration *S*. With the flexibility of control cluster method it is possible to avoid defining sample shapes of the whole model. Instead only the problem vertices of the elbow area of the model can be defined as cluster ones and only one sample pair is used for deforming those vertices likewise PSD thus achieving the necessary amount of volume.

So cluster vertices of the elbow problem area undergo additional transformations with the help of the displacements. Let us assume that *v* is a vertex position in the sample pose of cluster vertices in the pose X^i, v^0 is vertex position in the bind pose *B*. Then displacement d_j is calculated to compensate the deformation.

If the current pose is $X = X^i$, the current cluster vertex position $v' = DQS(B_j^{-1}v + d_j)$. For arbitrary pose calculation radial basis functions are used to interpolate between different samples X^i.

4.2.3 Procedurally deformed cluster vertices

Another welcome feature for realistic animation is muscle bulging. Both LBS and DQS lack such a feature. Yet it could be achieved using PSD but it would require for the user to create some sample pairs to imitate realistic muscle bulging. As an alternative way cluster vertices corresponding to biceps area of the upper arm can be deformed procedurally depending on the angle between upper arm and lower arm bones.

4.2.4 Free vertices transformation for skinning

For free vertices transformation Bezier patch meshes are used as they allow working with the models of arbitrary topology.

5. RESULTS

As an example arm model with rigging is used (see Fig. 3). All the vertices are split into 4 groups: 3 cluster groups and free vertices.

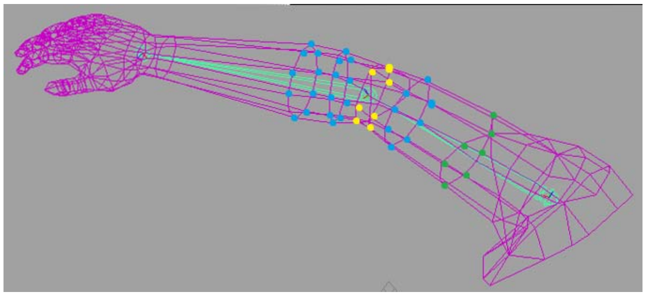

Fig. 3. The model of an arm with a two bone skeleton. Blue – free vertices; yellow – cluster likewise PSD deformed vertices; green – cluster procedurally deformed vertices; not marked – DQS deformed vertices.

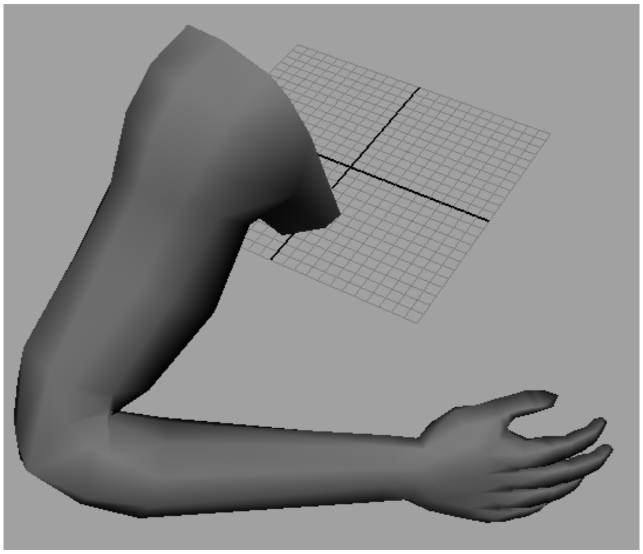

Fig. 4. CCM rotation animation of the model with a slight muscle bulging effect

The base cluster vertices of the model are deformed with help of DQS, they define the overall shape of the model. Cluster vertices of the elbow problem area of the model are transformed using one sample pair for the four cluster vertices, the sample pair being extracted from PSD sample shape of the whole model. To create biceps bulging effect corresponding cluster vertices position is calculated procedurally based on the angle between the two bones. Comparing the three methods (LBS, DQS, PSD and CCM) in a rotation animation it is possible to say that yielding close results neither PSD, nor DQS or CCM demonstrates the volume loss common for LBS. As far as user input data is concerned, PSD requires to create at least one sample pair of the whole model for the animation, while it is enough to store only several vertices sample for CCM. Both LBS and DQS do not require any samples but it is very difficult to adjust the weights properly and moreover one can't achieve all possible shapes adjusting weights. Therefore some sample data seems to be an inevitable part of the user guided animation.

6. CONCLUSION

Control Cluster Method is an approach for geometric non-linear deformation of the model in a labor-saving way. In this paper its modification in application to skinning is described.

The advantage of CCM is that it captures the designed shape, including effects like muscle bulging as well as exampled based methods. The drawback is the necessity of acquiring the example vertices positions. CCM inherits some versatility from geometric methods as examples are needed only for several vertices of the model, the rest of the vertices calculated with the non-linear approach automatically. The proposed algorithm has a limitation. The CCM modification is limited to rigid transformation and therefore no models that have got parts that can scale or shear can be skinned in an adequate way.

Applications of the approach to other fields as physical processes simulation is in the scope of the future research.

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