Research on 3D Human Body Deformation Based on BiharmonicWeights and Skeleton Skin

To cite this article: Li Yao et al 2018 J. Phys.: Conf. Ser. 1098 012025

You may also like

- ON THE CHARACTER OF THE CONTINUITY, ON THE BOUNDARY OF A NONSmooth REGION, OF A GENERALIZED SOLUTION OF THE DIRICHLET PROBLEM FOR THE BIHARMONIC EQUATION V A Kondrat'ev, I Kopachek and O A Olenik
- Stability of an inverse source problem for the damped biharmonic plate equation Peijun Li, Xiaohua Yao and Yue Zhao
- A h-Version of the Least Squares Collocation Method for the Biharmonic Equation in Irregular Domains Vasily Belyaev, Luka Bryndin and Vasily Shapeev
Research on 3D Human Body Deformation Based on Biharmonic Weights and Skeleton Skin

Li Yao¹,*, Yining Guo¹, Xiaodong Peng¹, Hongjie Ni¹, Yan Wan¹ and Cairong Yan¹

¹School of Computer Science and Technology, Donghua University, No. 2999 Renmin North Road, Songjiang District, Shanghai, China

* yaoli@dhu.edu.cn

Abstract: A new 3D human body deformation algorithm based on bounded biharmonic weights and skeleton skinning algorithm is proposed to improve the defects in traditional Laplace algorithm and contour-driven algorithm, such as the detail distortion and the topological structure change in 3D human body deformation. The deformation is a process from local to global. Firstly, the standard human model is bound to the annular skeleton, and then the local mesh deformation is implemented on the standard human body model based on the bounded biharmonic weights, and then we use the 3D human body proportion measured before to adjusts the position of the skeleton point, finally the 3D human mesh model can be quickly edited with the effect of the skeleton skinning algorithm. The experimental shows that the algorithm can not only maintain the topological structure of the local grid effectively, but also achieve faster 3D model mesh editing compared with directly working on all grid vertices.

1. Introduction

With the extensive research of virtual fitting technology, 3D human body deformation technology has also become a hot topic. The virtual fitting technique mainly includes the following three processes: acquiring human body data through a 3D scanner, deforming a standard 3D human body model, and fitting clothing. Among them, the deformation part directly affects the similarity between the standard human model and the actual human in shapes. In the process of deformation, there are two defects may cause the distortion of the grid details. One is the grid vertex data volume is too large to do the calculation. The other one is that we are unable to determine the specific location of the deformation. In recent years, the main algorithms of the 3D human body deformation technology are Laplace deformation algorithm [1] and contour-driven algorithm [2]. The Laplace algorithm may cause a problem that the size of the meshes at boundaries cannot be guaranteed, which leads to distortion easily. Similarly, the contour-driven algorithm will change the topology of meshes during the deformation process.

This paper proposes a 3D human body deformation method based on the combination of biharmonic weights [3] and skeleton skinning [4]. The method is based on a human body model bounded by circular skeletons. And the local deformation based on biharmonic weights which is performed on the differential domain. It means that Laplace energy is directly defined on the surface. Then we use the biharmonic weights to interpolate the variation of vertex Laplace coordinates on the surface. According to the proportion of the human body, the positions of the annular skeletons are moved, and we can achieve automatic human body deformation. This method can not only protect the
details of the mesh, but also quickly obtain a human body model similar to the actual human body.

2. Related work

2.1 Biharmonic theory

2.1.1 Laplace energy. The energy function describes a kind of state of the system. When the energy function reaches a minimum value, the system reaches the most stable state. The biharmonic equation is the solution of the double Laplace energy equation and it is also the minimum value of Laplace energy function [5]. Correspondingly, in the deformation system, the minimum value of the energy function can make the grid surface more stable, so that the details will be restrained.

Laplace energy can be expressed as:

\[ \|Lx\|^2 \]  

(1)

Where \( L \) is Laplace operator, and it is represented as a sparse matrix. According to the definition of differential coordinates, the elements in this matrix are calculated as follows:

\[
L_{ij} = \begin{cases} 
1 & i = j \\
-\frac{1}{d_j} & j \in \{j \mid j \in E\} \\
0 & \text{Otherwise}
\end{cases}
\]  

(2)

Where \( E \) is the set of directed edges of the grid.

The Laplace equation is a second-order partial differential equation. Therefore, the biharmonic equation is a fourth-order partial differential equation. The deformation can be described as a fourth-order linear system which is applied to the human rigid.

2.1.2 Bounded biharmonic weights. The weights of the vertices are represented by the influence of the handle affine transformation on the vertices in the 3D model. \( w_j \) is the weight function related to handle \( H_j \). A weight is assigned to each vertex on the surface. The coordinates after affine transformation are described as:

\[
p = \sum_{j=1}^{m} w_j(p)T_{jp}
\]  

(3)

The weight spreads uniformly around the point. We consider weight function as follows:

\[ \|Lw\|^2 \]  

(4)

The sum of Laplace energy for all control handles is:

\[ \sum_{i=1}^{m} \|Lw_i\|^2 \]  

(5)

So we can get the biharmonic weights:

\[
\arg \min \sum_{i=1}^{m} \|Lw_i\|^2
\]  

(6)

It Satisfies:

\[ w_j \mid H_j = \delta_{jk} \]  

(7)
\[
\sum_{j=1}^{m} w_j(p) = 1, \forall p \in M
\]  
\[
0 \leq \Omega_j(p) \leq 1, \, i = 1, \ldots, m, \forall p \in M
\]

Compared with the Laplace equation, the bounded biharmonic equation can not only specify the mesh position, but also can specify the normal mesh spacing at boundaries [6].

2.2 Skeleton binding
The skeleton binding [7] is performed in the 3D modeling software Maya. As shown in Figure 1, the left figure is a standard human model, and the right is a human model that has already bound bones. In this paper, the ring bones are bounded. We name the bones while they are created, so that the bones can be displaced conveniently.

![Figure 1. Binding ring bones](image)

There is a parent-child relationship between each of the two connected bones of the annular skeleton. Therefore, it is necessary to take into account the relationship between the parent and child nodes so as to move bone points in radial direction. This paper proposed a method that we move the parent nodes first. Before child nodes moving, we need to subtract the displacement of their parent nodes. The current skeleton point will return to its original position and we can work on displacement in correct direction.

3. Algorithm
Biharmonic deformation is based on the Laplace deformation, as well as the differential domain deformation. Compared with the Laplace algorithm, it can retain local details and specify the normal spacing of the mesh at boundaries. As shown in Figure 2. At first, the surface is directly edited by the differential coordinates [8], and then the Laplace vertices are interpolated with the biharmonic weights. Finally we use the least squares method [9] to calculate the coordinates of vertices.

![Figure 2. Method flow](image)
The algorithm flow in this paper is as follows:

Step 1: Transforming the vertex coordinates of the grid in Euclidean space into differential coordinates [10]:

\[
\Delta = L(V) \\
V = \left[v^T_1, v^T_2, ..., v^T_n\right]^T \\
v_i = \left[v^T_{ix}, v^T_{iy}, v^T_{iz}\right]^T \in \mathbb{R}
\]

Where \(V\) is a \(n \times 3\) matrix, each column corresponds to the vector of the vertices \(x, y,\) and \(z;\) \(L\) represents the Laplace operator, which is a sparse matrix; \(\Delta\) represents the differential coordinates. We can see that the Laplace operator acts on the vertices in the Euclidean space to obtain a linear system. It is like saying that the differential coordinates of the points are the solutions of the linear system [11].

Step 2: Moving the deformed handle and perform a local bounded mixed weighted affine transform:

\[
v'_i = \sum_{j=1}^{m} w_j(v_i) T_j
\]

The handles are divided into two kinds: restricted and unrestricted. The deformed handle refers to the part that we have set in advance and participates in affine transformation as a whole. We set \(H_j (j=1, 2, 3, ..., m)\) to be a deformation handle set in advance, \(w_j\) is a weight function related to the deformation handle \(H_j;\) \(T_j\) represents an affine transformation function; \(v'_i\) is a vertex coordinate after affine transformation.

Step 3: Calculating positions of the remaining vertices by least squares based on the new positions of handle vertices.

\[
V = \arg \min \left\| L(V) - \Delta \right\|^2
\]

Where the \(V'\) represents new position vectors.

It can be expressed as:

\[
\min \left\| Ax - b \right\|
\]

For the matrix \(A\) is not a square matrix, this system cannot be directly solved. We need to change the system into:

\[
A^T Ax = A^T b
\]

The final unknown solution is:

\[
(A^T A)^{-1} A^T b
\]

This system is a sparse linear system. \(A^T A\) is positive definite, so it can be decomposed into:

\[
A^T A = R^T R
\]

The equation becomes:

\[
R^T R x = A^T b
\]

Where \(R\) is the upper triangular matrix. Any change of the handle will cause no change except \(b\), so the unknown can be obtained by substitution.

Step 4: The standard human model that binds the annular bones is used to achieve automatic overall deformation based on actual ratio of the body measurements. Equation expressed as:

\[
P'_i = P_i + \text{dir}_\text{normal} \times \text{param}
\]

Where \(P'_i\) represents bone’s coordinate after displacement; \(P_i\) represents the initial coordinate position of the skeleton point, and \(\text{dir}_\text{normal}\) is the direction vector which points from center to the current skeleton point, and \(\text{param}\) indicates the parameters needed to generate the displacement. We uses this formula to make the bones which centered on the same point have corresponding
displacements in their respective displacement directions.

4. Experimental results and analysis
The local deformation in this paper is based on the method of biharmonic weights. As shown in Figure 3, the left figure is the front view of the standard human body, and the right figure is the side view of the standard human body. This paper carries out Laplace and biharmonic weight-based deformation in the same part of the human body.

Figure 3. Standard human body model

We can see that Figure 4 is an abdomen deformation based on Laplace algorithm, and Figure 5 is an abdomen deformation based on biharmonic weights. These red points in figures are the selected handle. It shows that the human body deformation by Laplace algorithm will lead to poor changes in the topology of the mesh, and distort the details of the grid. While the meshes deformation by bounded biharmonic keep a normal spacing at boundaries. The arrangement is orderly, the features of vertices basically retains, and the meshes are smoother.

Figure 4. Abdomen deformation based on Laplace algorithm. (a) Frontal image of the abdomen Laplace deformation, and the red dots are handles. (b) The structure of vertices are irregular after deformation. (c) Side view of human model after deformation.

Figure 5. Abdomen deformation based on biharmonic weights. (a) Frontal image of the abdomen Laplace
deformation, and the red dots are handles. (b) The structure of vertices are irregular after deformation. (c) Side view of human model after deformation.

As shown in Table 1, four different human bodies were selected in this paper and replaced by a, b, c, and d. Their 3D proportions were calculated respectively. The deformation results are shown in Figure 6, Figure 7, Figure 8, and Figure 9 respectively. The figure on the left is the front view of the human body after deformation, and the right is the side view of the human body after deformation.

**Table 1. Human body measurements**

| Human body | Height (cm) | Bust (cm) | Waist (cm) | Hip (cm) | Upper and lower body ratio | Measurement ratio |
|------------|-------------|-----------|------------|----------|----------------------------|-------------------|
| a          | 158         | 90        | 80         | 101      | 5:5                        | 1.1:1:1.2         |
| b          | 180         | 88        | 78         | 98       | 4:6                        | 1.2:1:1.3         |
| c          | 175         | 94        | 90         | 117      | 4:6                        | 1:1:1.3           |
| d          | 163         | 90        | 72         | 96       | 3:7                        | 1.3:1:1.3         |

![Figure 6. Human body a](image)

![Figure 7. Human body b](image)

![Figure 8. Human body c](image)
5. Conclusion

In this paper, we applied biharmonic weights and skeleton skinning algorithm to the rapid deformation of standard human body, and we have realized the fast deformation from local to global successfully. Firstly, we achieve the local deformation with biharmonic weights, and then we use the ratio of the body measured before to perform the corresponding displacement operation on the skeleton points in different directions to complete the rapid deformation operation. The research in this paper provides a good foundation for the subsequent fitting operation of virtual fitting.

References

[1] LÖhner R, Yang C 1996. Improved ALE mesh velocities for moving boundaries. Communications in Numerical Methods in Engineering; 12:599–608.
[2] Kraevoy V, Sheffer A, 2006,12(1).Mean-value geometry encoding[J].International Journal of Shape Modeling:29-46.
[3] Jacobson A, Baran I, Sorkine O, 2011:1-8. Bounded biharmonic weights for real-time deformation[C]/ Acm Siggraph. ACM.
[4] Miller E, Harkins J M, 2013. Musculo-skeleton shape skinning: ACM, US 8358310 B2[P].
[5] Jin B, 2004, 6(3). A meshless method for the Laplace and biharmonic equations subjected to noisy boundary data[J]. Computer Modeling in Engineering & Sciences: 253-261.
[6] Helenbrook B T, 2010. Mesh deformation using the biharmonic operator[J]. International Journal for Numerical Methods in Engineering: 1007-1021.
[7] Yesil M S, Gudukbay U, 2006. Realistic Rendering and Animation of a Multi-Layered Human Body Model[C]/ Conference on Information Visualization. IEEE Computer Society: 785-790.
[8] Haojie Fan, 2013. Bounded Double Harmonic Weights and Their Research and Application in Surface Editing [D]. Zhejiang University.
[9] Olga Sorkine, D,2004. Cohen—Or. Least-squares meshes[J]. SMI’04,191—199.
[10] Hui Zhao, Xianfeng Gu, Na Lei, 2017. Electronic Industry Press: 60—66.
[11] w_Xu, J. Wang, K. Yin, K. Zhou, M. van de Panne, E Chen, B. Guo, 2009. Joint-aware manipulation of deformable models[J]. SIGGRAPH’, 1—9.