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As-rigid-as-possible shape deformation and interpolation

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Abstract

We provide a detailed analysis of the 2D deformation algorithm based on non-linear least squares optimization, and prove that different mesh structure is of critical importance to deforming result. Based on triangle mesh, preserving the length of edges during deforming is enough to preserve the local, global and boundary properties of the shape. Sufficient theoretical analysis and experiments proved the advantage of the algorithm: (1) It is more stable. The constraint of edges length is strong enough to preserve the stability of triangle, thus the local and global structure are stable. (2) Due to less constraints, the calculating cost is reduced and the performance is improved. (3) The problem of parameter adjusting is solved in the approach. Further more, the algorithm has the ability to control facial expression and to adjust the area of shape etc.

In addition, a new approach to shape interpolation is presented. The inputs of the shape interpolation algorithm are bitmap represented images without any topology information in both the original and the target shapes. The strategy is to extract the topology of the original shape, and set up the correspondence between the original and the target shapes, which is to find the matching contour vertices between the original and target shapes. And the shape deformation algorithm is applied using the interpolation of the matching vertices as controlling points. The algorithm guarantees as-rigid-as-possible and rotation invariant shape interpolation. The interpolated shapes have the same topology structure with the original and the target shapes. Experiments indicate that the algorithm is stable and well performed.

Keywords: Triangle mesh; Edge length constraint; Global properties; Local properties; Boundary properties; Contour vertices matching

1. Introduction

1.1. Overview

Shape deformation technique is widely used in the field of computer animation, image editing, motion control and other applications. All the algorithms aim to provide simple user interface, most of which need the user to drag the controlling points (or lines, polygon) to finish deformation. And the deforming process should be smooth, the final position of the controlling points should be precise, and it should also run in real time.

Recently, Weng et al. [1] presented a state-of-art 2D shape deformation algorithm using non-linear least squares. It preserves the following constraints during shape deforming: Laplacian coordinates of the boundary vertices; mean coordinates of the inner vertices, the lengths of inner edges and the area of the shape. The problem is formulated into a non-linear least squares problem, and furthermore transformed into a quadratic optimization problem. The algorithm obtained results with visual pleasure, and generated more realistic deformation with elastic objects. But the constraints used in the algorithm were not robust enough to preserve the local properties inside the shape, and this kind of mesh cannot guarantee the stability of inner structure. Therefore, it may cause errors in some cases.

In this paper, a detailed analysis is made on deformation based on different meshing methods. We also prove that different types of meshes are of critical importance to shape

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deformation, and each constraint has different magnitude on different mesh condition. So an improved algorithm is presented in which triangular mesh is introduced. All it needs during shape deforming is to preserve the length of each edge, which is robust enough to keep the local properties, the global area and the contour shape. Thus the redundant constraints are discarded, and the problem is simplified to non-linear least squares without constraints. Ample theoretical analysis and experiments prove that the improved algorithm reached excellent results and speeds up the deforming process as well. Fig. 1 is an example of our algorithm.

Shape interpolation aims to interpolate smoothly between original and the target shapes. It can be divided into two categories: image morphing and shape blending. The former is based on images but shapes, and the interpolating images contain the feature of both the original and target image, which is different from this paper, so we put focus on the second catalog. Shape blending uses the corresponding topology of both the original and the target shapes to compute interpolating shapes. The weakness of this kind of algorithms is that the interpolating images make no sense on topology, though it can interpolate smoothly. Fig. 2 is a demonstration. The kind of as-rigid-as-possible shape blending algorithm makes the interpolated shape the similar topology with the original and the target shapes, but it has to know the corresponding relation between the topology of the original and the target shapes as a prior knowledge. For those bitmap represented shape without any topology information, it was extremely hard to apply this kind of algorithm. The method presented in this paper solves these two problems at the same time, and uses only bitmap represented shapes without any additional information. First the topology structure of the original shape is computed. And it finds the matching vertices of the original contour vertices on the target shape boundary, using rotation invariant Laplacian coordinates. Finally, interpolation of the matching contour vertices are used as the controlling points, and 2D shape deformation is applied to reach shape interpolation. The algorithm guarantees smooth deformation and as-rigid-as-possible result

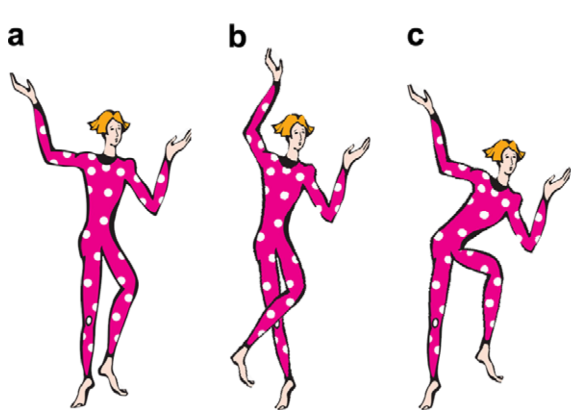

Fig. 1. An example of our deformation algorithm.

without the topology structure information of the original and the target shapes as a prior knowledge. And the interpolated shapes become meaningful and have the same topology with the original and the target shapes. Our algorithm is also rotation invariant which gains advantage comparing with other algorithms, as shown in Fig. 2.

Both shape deformation and interpolation are discussed in this paper. The reason is that they are closely related in algorithm details, and shape interpolation mentioned in Section 3 is based on shape deformation algorithm presented in Section 2. The content of the paper is arranged as follows: previous work will be introduced in Section 1.2; image deformation will be detailed in Section 2; shape interpolation will be described in Section 3; and we will give a conclusion in Section 4.

1.2. Previous works

Shape deformation techniques related to this paper share two features: they are based on mesh and using controlling points. Many researchers presented their resolution to this kind of problem. The most famous might be free form deformation [2,3]. FFD embeds the object into an space, and makes the space to deform in order that the object deforms with it. The space is divided into several regions by the user, and the regions are controlled by the controlling points. Though it is able to operate any type of primitive to gain better result, region dividing is a tough job and user have to operate many controlling points, which is the disadvantage of the algorithm. Beier and Neely [4] developed algorithms based on meshes, which gains advantages in some special application such as facial expression controlling. These methods assign the same cost for each point in the mesh, so it is not suitable to apply on skeleton-based shape. Lewis et al. [5] presented a deformation algorithm based on skeleton. The user controls the deformation of the skeleton, furthermore, the shape deformation result is reached according to the correspondence between the skeleton and the shape. The method gains better result on animal motion, but the initialization of the skeleton is made by the user, and it is a tedious job. Gibson and Mirtich [6] presented a physical based deformation algorithm, which is easy to implement but slow in convergence and it is not stable in some cases. Celniker and Gossard [7] used finite element theory and reached precise result, but it is complex and time consuming, which makes it not suitable on user interaction. James and Pai [8] developed a system running accurately but only fitting for small deformation.

Alexa [9] presented as-rigid-as-possible deformation first. The method applies an rigid transformation on each triangle, and seams them together. Refs. [10,11] used a similar idea. It minimizes the deformation of all the triangles in the mesh to reach as-rigid-as-possible deforming result. Sheffer and Kraevoy [10] is very slow on interaction, so [11] turns the problem into linear, and computes the rotation and scale distinguishingly using least squares, which