Computers & Graphics 59 (2016) 107–118

Contents lists available at ScienceDirect

Computers & Graphics

journal homepage: www.elsevier.com/locate/cag

Technical Section

Fast mapping and morphing for genus-zero meshes with cross spherical parameterization ☆

Chao Peng *, Sabin Timalsena

Department of Computer Science, University of Alabama in Huntsville, United States

ARTICLE INFO

Article history:
Received 11 January 2016
Received in revised form
31 May 2016
Accepted 1 June 2016
Available online 17 June 2016

Keywords:
Cross parameterization
Topology merging
Shape blending
Morphing

ABSTRACT

We introduce an efficient approach to establish surface correspondences between genus-zero triangle meshes and animate a morph between them. We employ the concept of mesh simplification and refinement to progressively parameterize meshes using a novel kernel sampling algorithm. Our two-step feature alignment method optimizes the distribution of vertices in a parametric domain. A new mesh is generated after merging mesh topologies, and it represents the shapes of all input meshes and their transitions in-between. Our approach merges topological structures rather than mapping surface properties. Complex meshes with tens of thousands of vertices can be parameterized and merged in a few minutes. The advantages of our approach are demonstrated through 3D morphing applications. Comparing to existing approaches, our solution advances in performance while maintaining high-quality parameterization and morphing.

Published by Elsevier Ltd.

1. Introduction

Merging topological structures of two or more 3D meshes into a single mesh is an important subject of computer graphics. It is also fundamentally important for achieving the effects such as morphing, retopologizing, mesh rigging transfer, etc. The general idea is parameterizing meshes into a suitable common domain. Then, those parametric representations are combined to form a new mesh whose topology fits geometric properties of all input meshes. Given genus-zero meshes, which are homeomorphic, we look for a new mesh representation whose topology supports smooth shape transitions between input meshes, regardless of differences of their original topologies or in correspondence of vertex indices. As introduced in [1,2], the process of finding parametric representations is known as *cross parameterization*.

A sphere is the natural domain for genus-zero meshes. Previous approaches for the construction of spherical parameterizations (e.g., [3–6]) do not achieve efficient performance, and issues like parametric distortion and poor feature alignment still exist: (1) high parametric distortion stretches triangles and causes overfolds on the surface of the parameterization, which prevent from obtaining valid topology merging and (2) user-specified feature constraints displace vertices in non-feature regions and cause triangle degeneration and overfolds.

Contribution. In this paper, we present an efficient approach to merge topological structures of homeomorphic genus-zero meshes with aligned surface correspondences. Our approach advances existing work in performance. Mesh simplification and refinement algorithms are adopted to progressively parameterize meshes using a novel metric that measures the distortion of parameterized triangles. Our parameterization algorithm is efficient and processes tens of thousands of triangles per minute. A novel two-step feature alignment procedure is developed to align user-specified feature constraints. We also develop a remeshing algorithm to generate a new mesh with generated spherical representations of the input meshes. Qualities of parameterization and remeshing are demonstrated through morphing applications. Our approach can produce visually pleasing morphing results for complex meshes that do not have trivial feature correspondences.

The rest of the paper is organized as follows. Section 2 reviews related work and describes parameterization issues. Section 3 gives a system overview. A mesh simplification method is presented in Section 4. Section 5 introduces a parameterization method based on mesh refinement. Section 6 presents a global optimization algorithm to optimize the distribution of vertices in the parametric domain. A feature alignment method is described in Section 7. Section 8 presents remeshing and morphing methods. We show our experimental results in Section 9. Section 10 concludes our work.

☆This article was recommended for publication by K. Hormann.

* Corresponding author. Tel.: +1 2568246433.
E-mail addresses: chao.peng@uah.edu (C. Peng), sabin.timalsena@uah.edu (S. Timalsena).

http://dx.doi.org/10.1016/j.cag.2016.06.001
0097-8493/Published by Elsevier Ltd.

2. Related work

Mesh parameterization is a technique to establish a map that transforms the points of a mesh into a parametric domain. The parametric domain is usually a simple surface, such as a 2D square, a sphere, a torus and a cube. A group of parameterized meshes can be applied with domain-specific operations without regard to their actual 3D shapes. In this section, we discuss previous work related to mesh parameterization.

A planar parameterization method cuts a mesh into flat pieces, just like creating texture mapping for 3D meshes. Sorkine et al. [7] parameterized the surface into a topological disk with strictly bounded distortion. Kraevoy and Sheffer [1] used triangular patch layouts of input meshes with a smoothing mechanism to reduce mapping distortions. Aigerman et al. [8] chose feature correspondent points and geodesic cuts. Their approach allows overlaps in the parametric domain, and bijectivity is recovered using a bijection lifting technique, but recovered mappings may cause artifacts if feature points are poorly chosen. Their follow-up work [9] encoded cut-invariance in the parameterization, but noticeable distortions exist if aligned feature pairs are not structurally similar. Planar parameterizations have been used for texture mapping [10] and generating geometry images [11], but they are not suitable for morphing applications. A 2D parametric domain has boundaries because of cutting. People have to spend many efforts to balance the number of continuous "pieces" and the degree of distortion; and in the 2D parametric domain, interpolation of mesh properties for morphing cannot be done effectively as such properties discontinue at the boundaries.

A spherical parameterization method does not require cutting. We review two categories of the method that projects a mesh to a sphere: *progressive method* and *relaxing method*.

2.1. Progressive method

A mesh is progressively simplified to a base mesh which is trivial for spherical projection. Quicken et al. [12] built a mesh hierarchy using a simplification procedure, and vertices were inserted back iteratively until reaching the full resolution of the mesh. Praun and Hoppe [3] used a progressive mesh. They first mapped the base mesh to a sphere; vertices were then split and projected to an optimal position in the ring of neighbor vertices in the spherical domain. Local angle and area distortions were minimized during vertex splitting and projection. Similarly, Wan et al. [13] developed a hierarchical optimization scheme to minimize both local and global distortion energy.

Progressive methods preserve features, but long and thin triangles may depress the surface of the sphere after the parameterization. In Fig. 1, the depression is very deep because the region has some large triangles with high curvature. When vertices are added back iteratively, the depression in that region will be further narrowed and deepen. Eventually, triangles in the depressed region will lead to flat appearance on the remeshed model.

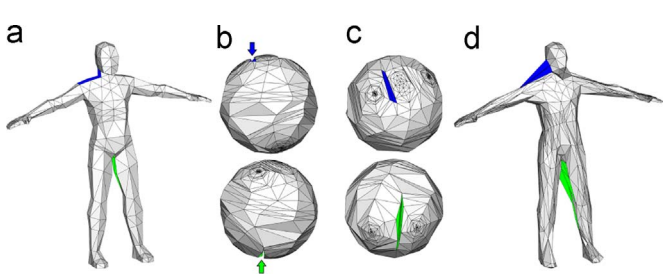

Fig. 1. *Depression issues in spherical representations.* (a) shows the original model with the highlights on low vertex density regions. (b) and (c) show the depressions on the sphere from different view angles. (d) is a remeshed model using (a) and another 3D model. Because of the depressions, the remeshed model has unexpected distortions in colored regions. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

2.2. Relaxing method

A relaxing method updates vertex positions repeatedly based on curvature. Gotsman et al. [4] cut out one triangle to create a boundary. Boundary vertices were projected to a convex boundary, and a barycentric formulation was used to obtain the position of each vertex as a function of its neighbors. Zhang [14] projected a 3D mesh onto a sphere in a brute-force manner, and then relaxed overlapped regions. Mocanu and Zaharia [15] flattened a mesh based on Gaussian curvature. Kazhdan et al. [16] employed a modified mean-curvature flow. Wang et al. [6] minimized ARAP energy, which is an extension of ARAP planar parameterization.

Those relaxing methods adopt global optimization strategies (e.g., minimizing flat energies [17]) and provide smooth transitions across the spherical surface. Edges are weighted with energy values to evaluate vertex distortion. The vertex with the most significant distortion changes its position by minimizing the energy of edges it connects with. This process could repeat until energy reaches zero. However, a desired parameterization result is usually obtained at a non-zero energy. Minimizing energy down to zero degenerates triangles; eventually, the sphere collapses to a point (see Fig. 2). Many relaxing methods, as mentioned by Floater and Hormann [18], have to use a threshold to limit the number of optimizing iterations. Another issue is that, relaxing methods push features into small regions on the sphere, which will be hard to restore after topology merging.

Our curvature reduction criteria for parameterization measures angle and area distortion and triangle aspect ratios. Comparing to previous work, our curvature reduction criterion alleviates the degree of depression that otherwise would occur with progressive methods. Our global optimization algorithm looses dense regions and compact sparse regions on the sphere to avoid triangle degeneration and foldover issues. Our approach is suitable for remeshing and morphing applications.

3. System overview

Fig. 3 illustrates processing stages of our approach:

- Simplification: this stage takes a genus-zero triangle mesh and simplifies it to a tetrahedron by collapsing edges. As a result, a progressive representation [19] is generated, which consists of the tetrahedron and a sequence of vertex split operations (inverse of the edge collapses) that are used to reconstruct the original mesh.
- Parameterization and optimization: With vertex split operations, vertices are inserted back one at a time. A spherical embedding is preserved by minimizing parametric distortion using our local distortion metric. A global distortion minimization is executed intermittently to ensure an appropriate vertex distribution on the sphere. Our parameterization and optimization methods are generic and can be used in conjunction with various parameterization strategies. As a result, we obtain a spherical representation with one-to-one vertex and triangle correspondences to the original mesh.

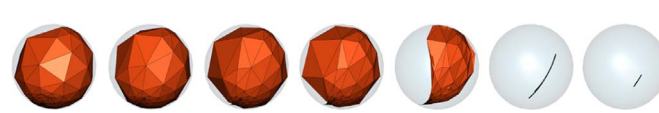

Fig. 2. *Degeneration problem while parameterizing based on relaxation or energy reduction.* As iterations of the minimization proceed, the minimizer fails to produce an acceptable configuration. Eventually the entire mesh will collapse to a point.

Download English Version:

https://daneshyari.com/en/article/441774

Download Persian Version:

https://daneshyari.com/article/441774

Daneshyari.com