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Spectral pose transfer

Mengxiao Yin [a,b], Guiqing Li [a,*], Huina Lu [a], Yaobin Ouyang [a], Zhibang Zhang [a], Chuhua Xian [a]

[a] School of Computer Science and Engineering, South China University of Technology, Guangzhou, China
[b] School of Computer, Electronics and Information, Guangxi University, Nanning, China

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ABSTRACT

In spectral decomposition of a 3D mesh model, it is well known that eigenvectors with respect to small eigenvalues determine its main pose while eigenvectors associated with large eigenvalues encode its surface details. Based on this property, given two meshes with different connectivities, one can use coupled quasi-harmonic technique to transfer the pose of one mesh onto the other by exchanging the low-frequency coefficients in their spectral representations. However, directly synthesizing the new low frequencies with old high frequencies usually exhibits two vital artifacts: one is detail shearing and shape collapsing, and the other is medium-scale pose missing. This paper reformulates the pose transfer as a deformation problem with low-frequency coefficients as handles. It finally leads to a non-linear optimization with the coefficients as data constraint and Laplacian coordinates as regularity term for preserving details. Meanwhile, a hierarchical pose transfer framework is introduced to capture the medium-frequency poses. To reduce the computation complexity and enhance the stability we further solve the problem in a subspace defined by mean-value coordinates.

1. Introduction

3D mesh editing has been exhaustedly investigated in digital geometry processing (Gain and Bechmann, 2008; Xu and Zhou, 2009). Example-based mesh modeling is a commonly used strategy in this field. Deformation transfer, as an example-based deformation method, is an analogue in which two poses of a reference model are given and therefore the underlying motion of the two poses of the model can be extracted as a geometric transformation which can drive a source model deforming in the same manner (Baran et al., 2009; Sumner and Popović, 2004). In this case, the source model is usually required to have a similar pose with the first pose of the reference one.

However, sometimes we may encounter a more succinct problem: given two mesh models, named reference and source models respectively for example, which have different poses and usually possess different connectivities, how can we make the source one deform to a pose similar to that of the reference model? This problem is referred to as a pose transfer in the literature (Kovnatsky et al., 2013; Lévy, 2006). Since neither deforming course of the reference model nor pose registration between source and reference meshes is required, pose transfer can greatly expand the scope of application of example-based mesh manipulation compared to deformation transfer. From the viewpoint of human, it is not difficult to

* Corresponding author.
E-mail addresses: 42045234@qq.com (M. Yin), ligq@scut.edu.cn (G. Li), luhuina2009@163.com (H. Lu), 549088764@qq.com (Y. Ouyang), cheungbon@163.com (Z. Zhang), chhxian@scut.edu.cn (C. Xian).

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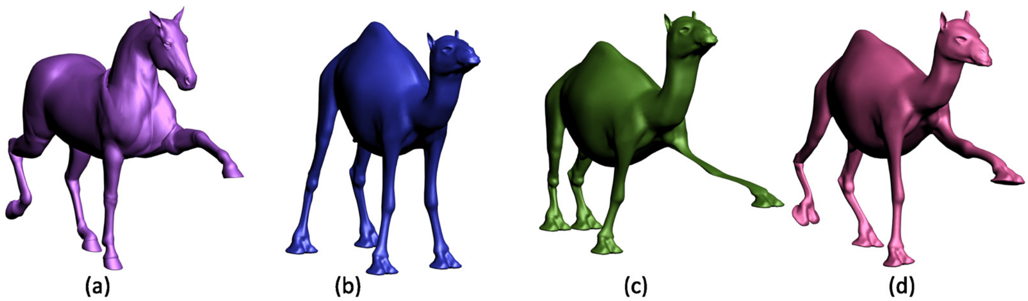

Fig. 1. Naively transferring low-frequency coefficients fails to correctly capture the reference pose and source details: (a) and (b) are respectively reference and source meshes; (c) result by copying coefficients with bases optimization (Kovnatsky et al., 2013); (d) our pose transfer.

imitate all kinds of poses of other people or even creatures even if we do not know how they move to such pose. It is a challenge to automatically conduct a natural pose transfer in mesh editing, however, due to the difficulty in describing a pose. To our knowledge, no deformation process has been proposed to sophisticatedly tackle this issue.

Fortunately, the spectral analysis technique over a 3D mesh exposes that the low-frequency components of the Laplace matrix of a mesh usually encode its pose information. Once the mesh is decomposed as the linear combination of eigenvectors of the matrix, altering the coefficients of the low-frequency components can change the pose of the model (Dey et al., 2012). The coupled quasi-harmonic base technique described in Kovnatsky et al. (2013) first sheds light on transferring poses between two mesh models with different connectivities by replacing the low-frequency components of a mesh with that of the other one. However, as it is impossible to completely decouple pose and shape of a model, this method not only fails to reproduce the reference pose in all scales but also loses geometric details of the target model in general. We present an example to show this in Fig. 1 in which the first two images (Fig. 1(a)–(b)) are respectively reference and source poses. The approach by Kovnatsky et al. (2013) exhibits serious artifacts of distortion and details missing as shown in Fig. 1(c). Fig. 1(d) depicts our result which is better than Fig. 1(c) both in keeping details and in capturing multi-level poses.

Spectral analysis based on Laplace operator has achieved great success as a digital geometry processing tool in 3D modeling applications such as compression (Karni and Gotsman, 2000), quadrangulation (Huang et al., 2008), deformation (Dey et al., 2012; Rong et al., 2008), and shape analysis (Song et al., 2014) to name a few, due to its harmonic and multi-scale properties. One can find more applications in excellent surveys (Lévy and Zhang, 2010; Zhang et al., 2007). We investigate pose transfer in this paper by unifying the advantage of the frequency components of Laplace matrix in coding the rough pose, and the ability of Laplace coordinates in representing details into a framework. Specifically, we extract the low-frequency components of the reference model to drive the source model deforming based on the coupled quasi-harmonic bases and prevent details missing by preserving Laplacian coordinates of the source model up to a rotation during deformation. In addition, we organize the reference pose into a simple hierarchical structure and apply the same pose transfer strategy to learn medium-scale poses. Our main contributions are listed as follows:

- We establish a new Laplace editing framework which regards the frequency components as handles to address the pose transfer issue. It results in a non-linear optimization.
- Observing that solution of the above optimization leads to a dense linear system, we integrate the cage-based subspace technique into the framework. It is not only able to cut down the solution space greatly but also guarantee the stability of the solutions by reducing deforming degree of freedoms.
- Revealing the multi-scale property of the pose of a 3D model, we devise a simple hierarchical strategy to transfer the different-scale poses of the reference model onto the source one progressively.

2. Related work

Considering that 3D pose transfer can be regarded as a special mesh deformation/editing operation, we first recall some classical deformation methods in the beginning of this section. Immediately following, we mention some mesh manipulating methods based on subspace solution. Deformation transfer is semantically most close to pose transfer among all kinds of 3D mesh manipulations. Functional maps are the foundation of the proposed method. We also make a brief survey on these two fields. Finally, we sketch some key ingredients upon which our framework is built.

Mesh deformation Given new positions or transformations of a subset of vertices on a 3D mesh as constraints, the metaphor of deformation (Gain and Bechmann, 2008) is to create a deformed mesh which not only satisfies the constraints but also preserves some plausible geometric or kinetic characteristics. Here, we only cite several simple examples: the Laplacian mesh editing preserves geometric details in terms of Laplacian coordinates (Lipman et al., 2004; Sorkine et al., 2004; Zhang et al., 2011; Zhou et al., 2005); the ARAP deformation enforces the motion of each triangle of the mesh approximating rigidity so as to retain the triangle shape best (Igarashi et al., 2008; Sorkine and Alexa, 2007; Sumner et al., 2007); the example-driven deformation by Fröhlich and Botsch minimizes the change of edge length, dihedral angle and mesh volume during deformation (Fröhlich and Botsch, 2011).