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Joint planar parameterization of segmented parts and cage deformation for dense correspondence

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ABSTRACT

In this paper, we present a robust and efficient approach for computing a dense registration between two surface meshes. The proposed approach exploits a user-provided sparse set of landmarks, positioned at semantic locations, along with closed paths connecting sequences of landmarks. The approach segments the mesh and then flattens the segmented parts using angle-based flattening and low distortion boundary constraints. It adjusts the segmented parts with a cage deformation to align the interior landmarks. As a last step, our approach extracts the dense registration from the flattened and deformed segmented parts. The approach is capable of handling a wide range of surfaces, and is not limited to genus-zero surfaces. It handles small features, such as fingers and facial attributes, as well as non-isometric pairs and pairs in different poses. The results show that the proposed approach is superior to current state-of-the-art methods.

1. Introduction

A dense, non-rigid registration of two meshes consists of a mapping between the two surfaces. Non-rigid registration is a fundamental problem with applications in attribute transfer [1,2], morphing [3], shape database analysis [4], and even deep learning on geometries [5]. The goal of the registration is to align the corresponding features of the meshes as closely as possible, while at the same time minimizing the geometric distortion of the mapping between the two surfaces. Current state-of-the-art methods are able to handle a wide range of surfaces, but impose genus-based limitations. Often, handling small features and non-isometric surfaces in different poses continues to be a challenge.

Among dense registration methods, we identify two ways to handle the problem of finding a mapping. The first type of methods consists in finding the dense registration by spectral analysis or by automatically detecting the sparse correspondences [6–9]. This type of methods is fully automatic, but does not allow control over the final mapping, which can sometimes exhibit mismatches at certain semantic areas. The second type of methods relies on the user to define sparse correspondences, and thus control the final mapping to some extent [1,10,11]. The approach presented here adopts this latter type, with the user retaining control over the final mapping. Further, reuse of a selected source mesh mapped with different targets can significantly reduce the user input, while sufficient control is retained. Shapes can be categorized according to their morphological classes; for each class, a source mesh is chosen, on which landmarks are created only once. The presented approach generates a mapping with low semantic and isometric distortion errors. It works by segmenting the two meshes into multiple parts to perform a part-wise matching. User-specified landmarks and closed paths drive the segmentation process. The pairs of segmented parts are then flattened, and their boundaries are aligned. Aligning only the boundaries of the patches does not guarantee the alignment of the interior landmarks. To address this problem, we apply a cage deformation step, which is a novel approach to aligning interior landmarks. The final step consists in constructing the mapping from the flattened and aligned parts. Our robust dense registration approach makes four novel contributions. Firstly, we demonstrate a process for constructing small patches based on closed paths. Secondly, we propose a dual-flattening approach using the mesh with the least distortion to align mesh boundaries. Thirdly, we present a novel cage deformation method that aligns interior mesh features, also ensuring no fold-overs are introduced in the flattened meshes. Finally, we propose a quantitative evaluation measure using isopoints to compare different dense

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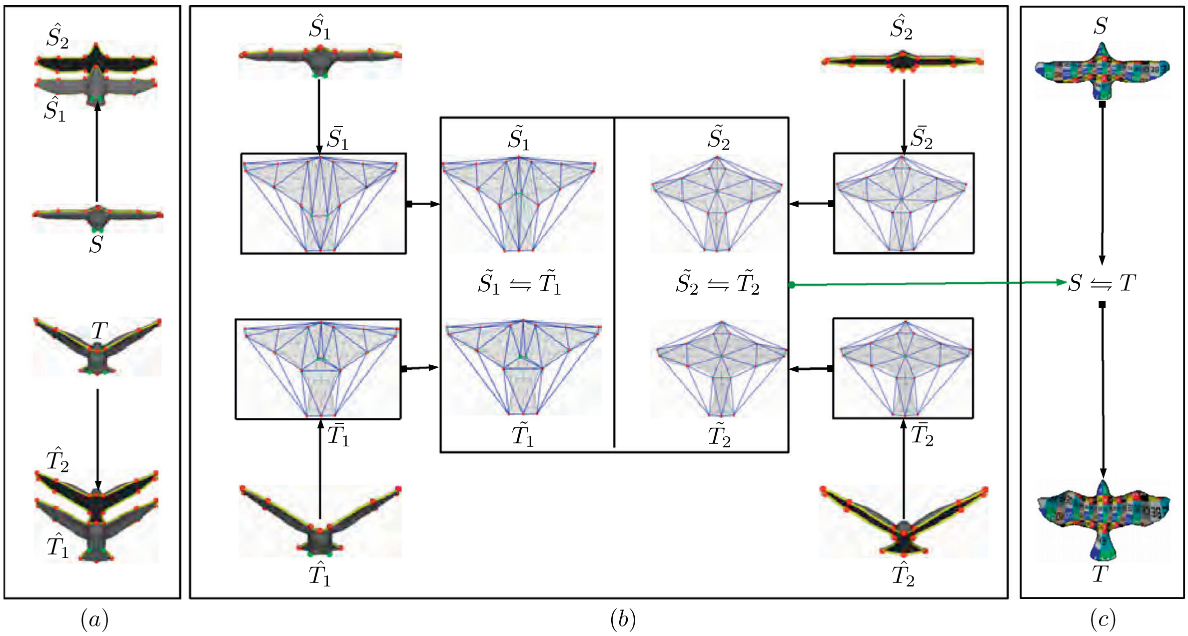

Fig. 1. Overview of the approach: (a) The source and target meshes and their respective segmented parts ($\hat{S}_1, \hat{S}_2, \hat{T}_1, \hat{T}_2$). (b) Planar parameterization applied on the source (top) and target (bottom). The pairs $\tilde{S}_1, \tilde{T}_1$ and $\tilde{S}_2, \tilde{T}_2$ are aligned with their boundaries. Internal landmarks of the target (colored in green) are aligned to the source internal landmarks using our deformation based on cages (blue lines), resulting in new pairs of fully aligned mesh pairs $\tilde{S}_1, \tilde{T}_1$ and $\tilde{S}_2, \tilde{T}_2$. The mappings are extracted between each pairs and transferred to the original source and target. (c) Visualization of the resulting mapping between the source and target. Kindly revert the current black and white mask to the original texture grid. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

registrations. It should be noted that in our paper, we refer to a non-rigid dense registration as a *surface mapping* or simply as a *mapping*.

2. Previous work

Surface mapping methods, also referred to in the literature as correspondence or registration methods, relate semantically similar surface components to one another. We are interested in mapping methods that can handle a wide range of surfaces. Accordingly, we favor methods that are not limited to genus-zero surfaces, or that can handle surfaces with small features, such as fingers and facial attributes. We are also interested in methods that do not impose too many constraints on the surfaces. In that regard, we want to handle non-isometric surface pairs, pairs with different genera, and pairs set in different poses. In this section, we present the mapping methods most relevant to the proposed approach. We classify them in terms of the space within which they establish the mapping: 3D Euclidean, Möbius, functional, spherical, and planar. The reader is referred to the survey of van Kaick et al. [12] for a more exhaustive list of geometric correspondence methods.

2.1. Deformation in 3D Euclidean space

Non-rigid registration methods deform the given surfaces until they match [4,13,14]; however, most such methods are limited to near-isometric objects. Generally, few methods try to extend the range of objects to handle non-isometric pairs. Sumner et al. [10] propose an iterated closest point method with regularization based on input landmarks to deform one surface into another, and allowing the extraction of mapping through the deformed surface. Zell and Botsch [11] combine the concepts of deformation-based registration and transformation of surfaces into smoother shapes. While their method works relatively well for character heads, it has a strong tendency to collapse protruding extremities, such as legs and arms, which causes artifacts in the resulting mapping. Methods that deform surfaces in 3D Euclidean space are prone to fail if the surfaces have different poses; accordingly, their resulting mapping depends greatly on how well the surfaces are initially aligned. Moreover, most of these methods only handle near-isometric objects or small non-isometric deformations [13], which in turn highly restricts their application domain.

2.2. Möbius and functional spaces

Möbius methods [7,15] rely on the hypothesis that isometries are a subspace of conformal maps, which could be explored based on Möbius transformations. These methods are limited to isometric and near-isometric surfaces. Kim et al. [8] present Blended Intrinsic Maps (BIM) to handle non-isometric surfaces by using weighted combinations of low-dimensional intrinsic maps to generate a blended map. The BIM method provides an efficient search procedure to find smooth maps between surfaces in a fully automatic fashion. The method handles surfaces with different poses, but it fails for examples containing small features such as facial details and fingers.

The functional space of the Laplace–Beltrami decomposition is also used to express mappings based on real valued functions instead of the regular point-to-point maps [16,17]. This provides a flexible representation of the maps between the shapes, but as with the Möbius methods, it struggles in handling mappings between non-isometric surface pairs.

2.3. Spherical parameterization

Reliance on parameterization works by the transformation of the surfaces into a space where detecting a correspondence is facilitated. The spherical domain allows a seamless and continuous parameterization of genus-zero surfaces [18,19]. Athanasiadis et al. [20] drive a geometrically-constrained optimization technique to map 3D genus-zero surfaces on a sphere. Then, they apply a feature-based method to morph between surfaces with structural