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An efficient volumetric method for non-rigid registration☆

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ABSTRACT

We propose a novel and efficient volumetric method for registering 3D shapes with non-rigid deformations. Our method uses a signed distance field to represent the 3D input shapes and registers them by minimizing the difference between their distance fields. With the assumptions that the sampling points in each cell of the object volume follow the same rigid transformation, and the transformations of the sampling cells vary smoothly inside the object volume, a two-step method is used for the non-rigid registration. The first step is the locally rigid registration, which minimizes the difference between the source and target distance fields of the sampling cells. The second step is the globally non-rigid registration, which minimizes the difference between the transformations of adjacent cells. In just a few iterations, our method rapidly converges for the registration. We tested our method on several datasets, and the experimental results demonstrate the robustness and efficiency of our method.

1. Introduction

Non-rigid shape registration is a fundamental problem in geometric modeling and model acquisition. The development of real-time 3D scanners makes non-rigid registration increasingly important. There are various types of non-rigid shapes in our daily life, like the human body, animals, etc.

The goal of non-rigid registration is to find a global deformation for the source shape to match the target shape. Semantic correspondence of two shapes is very difficult to compute if the shapes are non-rigid. A vast amount of work has been devoted to this problem. The general framework has been to preserve the local geometry and regularize the globally non-rigid deformation. Volumetric methods have attracted more and more attention recently due to their improved registration compared to using surface-based methods. However, registration of large deformations remains very challenging for the existing volumetric methods.

In this paper, we propose a fast and robust volumetric method for non-rigid registration, which can regularize the global deformation while preserving the local geometry. We do not require an initial template, or other shape priors, or explicit correspondences. Our approach works well on several datasets, including the synthetic data generated by morphing the source surface, and the mesh pairs from a scanning system. The local geometry is preserved, while a natural global deformation is achieved with our volumetric scheme.

2. Related work

Shape registration is a classic problem in computer graphics and computer vision. A substantial amount of research has been devoted to static shape registration.

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The representative method is Iterative Closest Point (ICP) [1], which uses the closest points as correspondences, and then calculates a rigid transformation by minimizing the distance between the correspondences. Recently, the KinectFusion algorithm [2,3] was proposed, which uses a fusion method to reconstruct a consistent volumetric representation [4] and achieves realtime performance.

Non-rigid registration has become an active area of research due to the development of high-performance 3D scanners. Most of the work focuses on measuring the similarity between shapes and regularizing the global deformation. Ref. [5] introduces a method that looks for the optimal transformation for each corresponding element, and regularizes the globally non-rigid transformation using the dynamic sampling graph [6]. It is used in [7] for capturing a room-sized dynamic scene. Their later work uses a template as a prior to prevent the erroneous topologies, so that the method can handle large deformations [8]. Chang and Zwicker [9] present a registration method for articulated objects using feature points and a reduced deformation model. Ref. [10] introduces an articulated global registration algorithm using the dynamic sample graph to align multiple range scans of an articulated model. Another method uses a subspace deformation model for registration of non-rigid shapes with fixed topology [11]. All of the above methods above perform surface-based registration.

Recently, volumetric methods have been proposed for non-rigid registration [12,13]. Ref. [12] uses a vector field to register local geometry and Incremental Free-Form Deformation (IFFD) to achieve global deformation. Ref. [13] introduces a method that uses a signed distance field [14] for geometry representation, and then uses Free-Form Deformation (FFD) as the deformation model to regularize the globally non-rigid deformation. Our method utilizes a similar scheme, but applies a rigid cell deformation model [15] to achieve a more robust registration.

All these methods treat the deformation model as an important component for non-rigid registration. Deformation models can be roughly classified into surface-based models, and volumetric or space models. Embedded deformation [6] and as-rigid-as-possible surface manipulation [16] are typical surface-based deformation models. Embedded deformation builds a graph on the surface of the shape, and finds the optimal affine transformations by solving a nonlinear minimization problem. The as-rigid-as-possible method solves for a global deformation, while preserving the local rigidity. Surface-based deformation models are efficient and easy to implement. However, the volumetric model is demonstrated to be more robust when applied to large deformations [15,17].

Volumetric deformation models use a volumetric graph, instead of a surface-based graph, to solve the global deformation of the volumetric graph. In the Free-Form Deformation (FFD) [18] method, the shape is embedded in space grids consisting of control points and deformed by moving the control points of the FFD grids. The Volumetric Graph Laplacian method [17] introduces a volumetric graph that consists of boundary edges and interior edges. Then, the shape morphing problem can be solved using a method like Laplacian surface manipulation [19]. To achieve the global deformation, the difference of adjacent space grids is minimized to achieve a global deformation [15,20].

3. Overview

A volumetric scheme is used in our registration of the deformed shapes. The entire pipeline is shown in Fig. 1. With the signed distance field (SDF) representation, as shown in Fig. 1(a), the registration problem of these two shapes becomes the registration of the two signed distance fields. Our system iteratively runs a two-step process to obtain both the *locally rigid registration* and the *globally non-rigid registration*. The first step is performed by minimizing the difference between the source and target signed distance fields for each sampling cell. In the second step, a non-linear deformation model is employed to generate a natural globally non-rigid deformation, given the locally rigid registration results, as Fig. 1(b) shows. The final optimal non-rigid registration, as Fig. 1(c) shows, is achieved after several iterations.

4. Signed distance field representation

In our system, we employ the signed distance function, also called Signed Distance Field (SDF) [14], as the volumetric representation for 3D shapes. For simplicity, we

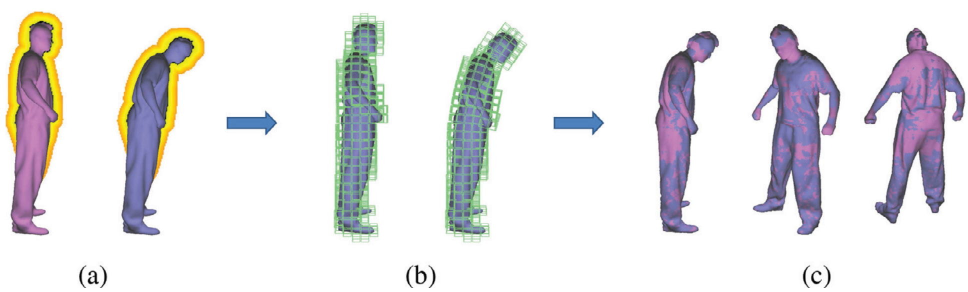

Fig. 1. System overview: (a) signed distance fields of the source and target shapes, (b) locally rigid registration, and (c) globally non-rigid registration.