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Efficient feature-based image registration by mapping sparsified surfaces☆

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ABSTRACT

With the advancement in the digital camera technology, the use of high resolution images and videos has been widespread in the modern society. In particular, image and video frame registration is frequently applied in computer graphics and film production. However, conventional registration approaches usually require long computational time for high resolution images and video frames. This hinders the application of the registration approaches in the modern industries. In this work, we first propose a new image representation method to accelerate the registration process by triangulating the images effectively. For each high resolution image or video frame, we compute an optimal coarse triangulation which captures the important features of the image. Then, we apply a surface registration algorithm to obtain a registration map which is used to compute the registration of the high resolution image. Experimental results suggest that our overall algorithm is efficient and capable to achieve a high compression rate while the accuracy of the registration is well retained when compared with the conventional grid-based approach. Also, the computational time of the registration is significantly reduced using our triangulation-based approach.

1. Introduction

In recent decades, the rapid development of the digital camera hardware has revolutionized human lives. On one hand, even mid-level mobile devices can easily produce high resolution images and videos. Besides the physical elements, the widespread use of the images and videos also reflects the importance of developing software technology for them. On the other hand, numerous registration techniques for images and video frames have been developed for a long time. The existing registration techniques work well on problems with a moderate size. However, when it comes to the current high quality images and videos, most of the current registration techniques suffer from extremely long computations. This limitation in software seriously impedes fully utilizing the state-of-the-art camera hardware.

One possible way to accelerate the computation of the registration is to introduce a much coarser grid on the images or video frames. Then, the registration can be done on the coarse grid instead of the high resolution images or video frames. Finally, the fine details can be added back to the coarse registration. It is noteworthy that the quality of the coarse grid strongly affects the quality of the final registration result. If the coarse grid cannot capture the important features of the images or video frames, the final registration result is likely to be unsatisfactory. In particular, for the conventional rectangular coarse grids, since the partitions are restricted in the vertical and horizontal directions, important features such as slant edges and irregular shapes cannot be effectively recorded. By contrast, triangulations allow more freedom in the partition directions as well as the partition sizes. Therefore, it is more desirable to make use of triangulations in simplifying the registration problems.

In this work, we propose a two-stage algorithm for effective registration of specially large images. In stage 1, a content-aware image representation algorithm to *TR*iangulate *IM*ages, abbreviated as *TRIM*, is developed to simplify high quality images and video frames. Specifically, for each high quality image or video frame, we compute a coarse triangulation representation of it. The aim is to create a high quality triangulation on the set of the content-aware sample points using the Delaunay triangulation. The computation involves a series of steps including subsampling, unsharp masking, segmentation and sparse feature extraction for locating sample points on important features. Then in stage 2, using coarse triangular representation of the images, the registration is computed by a landmark-based quasi-conformal registration algorithm [17] for computing the coarse registration. The fine detail of the image or video frame in high resolution is computed with the aid of a mapping interpolation. Our proposed

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framework may be either used as a standalone fast registration algorithm or also served as a highly efficient and accurate initialization for other registration approaches.

The rest of this paper is organized as follows. In Section 2, we review the literature on image and triangular mesh registration. Our proposed method is explained in details in Section 3. In Section 4, we demonstrate the effectiveness of our approach with numerous real images. The paper is concluded in Section 5.

2. Previous works

In this section, we describe the previous works closely related to our work.

Image registration have been widely studied by different research groups. Surveys on the existing image registration approaches can be found in [39,6,16,38]. In particular, one common approach for guaranteeing the accuracy of the registration is to make use of landmark constraints. Bookstein [1–3] proposed the unidirectional landmark thin-plate spline (UL-TPS) image registration. In [13], Johnson and Christensen presented a landmark-based consistent thin-plate spline (CL-TPS) image registration algorithm. In [14], Joshi et al. proposed the Large Deformation Diffeomorphic Metric Mapping (LDDMM) for registering images with a large deformation. In [10,11], Glaunès et al. computed large deformation diffeomorphisms of images with prescribed displacements of landmarks.

A few works on image triangulations have been reported. In [8], Gee et al. introduced a probabilistic approach to the brain image matching problem and described the finite element implementation. In [15], Kaufmann et al. introduced a framework for image warping using the finite element method. The triangulations are created using the Delaunay triangulation method [31] on a point set distributed according to variance in saliency. In [18,19], Lehner et al. proposed a data-dependent triangulation scheme for image and video compression. Recently, Yun [35] designed a triangulation image generator called DMesh based on the Delaunay triangulation method [31].

In our work, we handle image registration problems with the aid of triangulations. Numerous algorithms have been proposed for the registration of triangular meshes. In particular, the landmark-driven approaches use prescribed landmark constraints to ensure the accuracy of mesh registration. In [34,22,33], Wang et al. proposed a combined energy for computing a landmark constrained optimized conformal mapping of triangular meshes. In [23], Lui et al. used vector fields to represent surface maps and computed landmark-based close-to-conformal mappings. Shi et al. [32] proposed a hyperbolic harmonic registration algorithm with curvature-based landmark matching on triangular meshes of brains. In recent years, quasi-conformal mappings have been widely used for feature-endowed registration [36,37,24,26]. Choi et al. [5] proposed the FLASH algorithm for landmark aligned harmonic mappings by improving the algorithm in [34,22] with the aid of quasi-conformal theories. In [17], Lam and Lui reported the quasi-conformal landmark registration (QCLR) algorithm for triangular meshes.

Contributions. Our proposed approach for fast registration of high resolution images or video frames is advantageous in the following aspects:

(1) The triangulation algorithm is fully automatic. The important features of the input image are well recorded in the resulting coarse triangulation.
(2) The algorithm is fast and robust. The coarse triangulation of a typical high resolution image can be computed within seconds.
(3) The registration algorithm for the triangulated surfaces by a Beltrami framework incorporates both the edge and landmark constraints to deliver a better quality map as fine details are restored. By contrast, for regular grid-based approaches, the same landmark correspondences can only be achieved on the high resolution image representation.
(4) Using our approach, the problem scale of the image and video frame registration is significantly reduced. Our method can alternatively serve as a fast and accurate initialization for the state-of-the-art image registration algorithms.

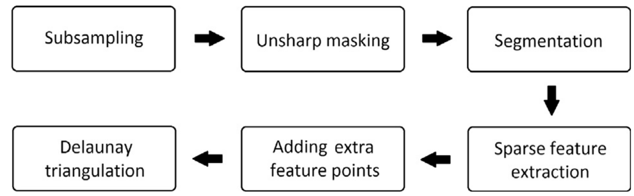

Fig. 1. The pipeline of our proposed TRIM algorithm for accelerating image registration via coarse triangulation.

3. Proposed method

In this section, we describe our proposed approach for efficient image registration in details.

3.1. Stage 1 – Construction of coarse triangulation on images

Given two high resolution images I_1 and I_2, our goal is to compute a fast and accurate mapping $f: I_1 \rightarrow I_2$. Note that directly working on the high resolution images can be inefficient. To accelerate the computation, the first step is to construct a coarse triangular representation of the image I_1. In the following, we propose an efficient image triangulation scheme called *TRIM*. The pipeline of our proposed framework is described in Fig. 1.

Our triangulation scheme is content-aware. Specifically, special objects and edges in the images are effectively captured by a segmentation step, and a suitable coarse triangulation is constructed with the preservation of these features. Our proposed *TRIM* method consists of 6 steps in total.

3.1.1. Subsampling the input image without affecting the triangulation quality

Denote the input image by I. To save the computational time for triangulating the input image I, one simple remedy is to reduce the problem size by performing certain subsampling on I. For ordinary images, subsampling unavoidably creates adverse effects on the image quality. Nevertheless, it does not affect the quality of the coarse triangulation we aim to construct on images.

In our triangulation scheme, we construct triangulations based on the straight edges and special features on the images. Note that straight edges are preserved in all subsamplings of the images because of the linearity. More specifically, if we do subsampling on a straight line, the subsampled points remain to be collinear. Hence, our edge-based triangulation is not affected by the mentioned adverse effects. In other words, we can subsample high resolution images to a suitable size for enhancing the efficiency of the remaining steps for the construction of the triangulations. We denote the subsampled image by $\widetilde{I}$. In practice, for images larger than 1000×1000, we subsample the image so that it is smaller than 1000×1000.

3.1.2. Performing unsharp masking on the subsampled image

After obtaining the subsampled image $\widetilde{I}$, we perform an unsharp masking on $\widetilde{I}$ in order to preserve the edge information in the final triangulation. More specifically, we first transform the data format of the subsampled image $\widetilde{I}$ to the CIELAB standard. Then, we apply the unsharp masking method in [27] on the intensity channel of the CIELAB representation of $\widetilde{I}$. The unsharp masking procedure is briefly described as follows.

By an abuse of notation, we denote $\widetilde{I}(x, y)$ and $\bar{I}(x, y)$ the