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Structure matching driven by joint-saliency-structure adaptive kernel regression

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ABSTRACT

Matching outlier structures with missing correspondences and/or local large deformations is very difficult in image registration. In this paper, we define structure matching as an iterative local adaptive kernel regression which locally reconstructs moving image's dense deformation fields from the discrete displacement fields computed by multi-resolution block matching. First, a new joint saliency map (JSM) is proposed to match a structure-tensor-based local saliency distribution for each overlapping pixel pair and highlight the corresponding saliency structures (called joint saliency structures, JSSs) between the images. To explore the consistency of normal JSSs and their deformations around the outliers, we use JSM to guide the dense deformation reconstruction by emphasizing the JSSs' discrete displacement vectors in kernel regression. The JSS adaptive kernel regression adapts anisotropic kernel's shape and orientation to reference image's structure and weights more contribution from JSS's displacement vectors for the iterative regression, whereby moving image's local deformations can be compliant with reference image's corresponding normal structures. The experimental results demonstrate that the proposed method achieves almost the best performance in structure matching of all challenging image pairs with outlier structures compared with other state-of-the-art intensity-based nonrigid registration algorithms.

1. Introduction

With various imaging sensors offering big image data, matching local structures within the image data has attracted more attention at motion tracking, visual data recognition, change detection, image segmentation, surface reconstruction in the computer vision, pattern recognition and remote sensing for the last decade. In the computer vision community, the structure matching is also knows as nonrigid image registration [1] or the optical flow problem [2]. The objective of structure matching is to determine the local transformations that align every structures (or features) in moving (or source) image with the corresponding structures in the reference (or template) image. However, owing to the image content changes over a period of time and the different physical mechanisms of multimodal imaging sensors, some local structures presented in one image appear partially or even disappear completely in another image. Such local structures with missing correspondences are closely intertwined with the structures' local large deformations in the structure matching. The missing correspondences and local large deformations of structures are called outliers in this paper. At present, it is still a challenging task for matching these outlier structures with missing correspondences and/or the local large deformations.

Over the last several decades, many relevant works were proposed to match the local structures (or features points) of the two images by minimizing the feature-based [3–9] or intensity-based differences between the two images. Feature-based approaches are local model based methods because they always use local feature detectors and descriptors (such as SIFT [2], attribute vector [9]) to select some corresponding features in the images, and then directly match the local features by finding a geometrical transformation from these feature correspondences. To tackle the outlier problem, the popular robust point matching (RPM) [3] work proposed fuzzy softassign strategy for correspondence matrix within iterative deterministic annealing to guarantee one-to-one correspondence. Recent work enforced sparsity prior in the correspondence matrix [4] or incorporated the inverse consistency constraints into the cost function of RPM [5]. Alternatively, the coherence point drift (CPD) work [6] considered the feature point matching as a probability

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density estimation problem with Gaussian mixture model representing the feature points. The recent graph-based CPD work [7] explored graph centralities to bring topological information during the correspondence computation. Furthermore, feature-dependant finite mixture model was proposed in [8]. Though these algorithms are robust to the missing correspondences, due to the smooth transformation computation being very sensitive to the ambiguity in finding local feature correspondences, the joint estimation of correspondence and smooth transformation is still difficult to the outlier issues that have both missing correspondences and local large deformations.

By directly using the complete image data to recover dense correspondences at pixel-level precision, most intensity-based nonrigid registration approaches are regarded as global model based methods that are often formulated as global energy minimization problems with the energy being composed of an regularization term and a similarity term [10–14]. The relative weight of similarity term and regularization term can cause the well-known trade-off between the registration accuracy and the smoothness of the deformation field [12]. In the presence of outliers, the accurate and plausible local structure matching does not exist using whole-intensity driven transformation model. The relative spatial regularization can either cause non-smooth and implausible distortion in these outlier regions or introduce over-smooth and inaccurate mapping artifacts between the whole images. This outlier problem can be partly solved by implementing expectation and maximization algorithm to estimate the missing or partial data [10,11], using a locally varying weight between regularization and image similarity [13–18], creating artificial correspondences [19–24] and cost-function masking [25–27], or developing SIFT flow for large displacement [2]. Most of these approaches are largely dependent on outlier region segmentation without giving full consideration to both the missing correspondences and local large deformations.

At present, there is no doubt that methods and algorithms from intelligent computing and machine learning are very demanded to tackle this challenging outlier problem in structure matching. In these research fields, outliers mean the extreme observations substantially different from all other ones in the real data. In structure matching, the missing correspondences and local large deformations introduce the extreme local geometric and intensity differences between the two images to be registered. The desired structure matching methods should be able to match moving image's local structures to the corresponding reference image's structures from these various local differences. Therefore, the classical local (nonparametric) kernel regression (or local approximation) that is adept at handling the locally varying differences is necessary to account for these outliers, and it provides the rationale behind this work. By successfully handling the locally varying differences in pattern recognition and machine learning, local kernel regression [28,29] is regarded as an ideal local regression model to effectively reconstruct the desired local signal while suppressing the outlier and noise effects. The normalized convolution used by Suarez et al. [30] and the fuzzy kernel regression proposed in [31] are two typical applications of local kernel regression which estimate each pixel's dense deformation from weighted contributions of its surrounding displacement fields in a moving isotropic window/kernel. Besides, the bilateral kernel that is closely related to the locally adaptive regression kernel [34] is explored in recent two independent works [32,33] to replace local Gaussian smoothing of deformation field, whereby it can effectively exclude information from structures having different intensities and deformation filed pattern for discontinuity-preserved deformation reconstruction. However, the deformation reconstruction in these works did not consider the outlier problems with both missing correspondences and local large deformations. Therefore, if the outlier structures are presented in the two images, the moving local (an)isotropic kernel function adopted in these methods [30,31,32,33] cannot be adjusted to emphasize more reliable deformation vectors from the corresponding saliency structures (called joint saliency structures, JSSs) in the two images to remove (or reduce) the outlier effects in the deformation reconstruction.

To localize the JSSs in the two images for their being emphatically grouped in mutual information (MI) based similarity measure computation, the joint saliency map (JSM) was originally proposed in our previous work [35] to reflect the global-to-local saliency structure correspondence in registration procedure, which has been proved to greatly improve the accuracy and robustness of rigid image registration with outliers. The JSM combined with keypoint clustering further obtained useful cluster-to-cluster correspondence to guide the control-point correspondence from the outlier features in the nonrigid image registration [36]. After our works, the similar mutual-saliency map [9] integrated with attribute matching was proposed to successfully remove missing correspondences in feature-based nonrigid image registration. However, matching structures with missing correspondences and local large deformations can easily introduce unrealistic distortions towards object boundaries in local subregions, which will present further complications during registration procedure by decreasing the reliability of available information. Without taking these factors into account, a structure matching approach might violate the continuity and the smoothness of structures (and their deformations) across subregions. Unfortunately, these previous JSM ideas have a clear limitation such that they cannot identify the saliency edge structures of the images to guide the continuous and smooth deformation reconstruction across object boundaries for realistic structure matching.

To solve the outlier problem with both missing correspondences and local large deformations, the proposed approach[2] is the first one to explicitly adopt JSS adaptive kernel regression in weighting more reliable contributions from JSS's deformation vectors at deformation reconstruction for local structure matching. This paper has the following contributions: (1) by computing the center-surround dissimilarity between neighboring local structure tensors to estimate the saliency map indicating the local saliency edge structure distribution of image, we propose new JSM based on the matching degree between the two structure-tensor-based saliency maps at every overlapping pixel pair in the two images. This JSM perfectly reflects the anisotropic JSS information, especially the joint saliency edge structures, in the two images for the ease of subsequent JSS adaptive kernel regression; (2) we propose a new JSS adaptive kernel regression for dense deformation reconstruction to explore the consistency of normal structures and their local smooth deformations surrounding the outlier structures for the problem of missing correspondences and local large deformations. Specifically, with a moving anisotropic window being oriented to be consistent with underlying JSS's structures and deformations, the output dense deformation vectors are locally estimated within an anisotropic moving window based on the specific weights of the discrete displacement vectors, which are iteratively computed from multi-resolution block matching [30,37]. In the presence of outliers, the weights of the surrounding displacement fields around the outliers are as small as possible to reduce the outlier effect on giving a distorted regression of regional dense deformations, while the JSSs and their underlying displacement fields are emphasized with their weights being kept as high as possible to ensure the accuracy of deformation reconstruction. Furthermore, the kernel function adapts its shape and orientation to reference image's local

[2] http://www.escience.cn/people/bjqin/research.html