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A highly accurate dense approach for homography estimation using modified differential evolution

Lai Kang [a,*], Lingda Wu [a,b], Yingmei Wei [a], Bing Yang [a], Hanchen Song [a]

[a] College of Information System and Management, National University of Defense Technology, Changsha 410073, China
[b] The National Laboratory of Electronic Information Equipment System, The Academy of Equipment Command and Technology, Beijing 101416, China

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ABSTRACT

The homography corresponds to a 3×3 matrix which transfers image points between two images of a planar scene or two images captured by cameras under purely rotational motion. Homography estimation is crucial to many computer vision tasks involving multi-view geometry. Unlike most existing algorithms using sparse information extracted from images, this paper proposes a dense homography estimation method taking into account both the color and gradient information of the whole image. In particular, homography estimation is recast as a two-objective optimization problem, which is solved within a global optimization procedure guided by sparse control points (SCPs) based on modified differential evolution (DE). In order to improve the computational efficiency, two strategies namely pre-evaluation and coarse-to-fine (C2F) search are integrated into the proposed framework. The experimental results on synthetically rendered images and real images demonstrate that the new method can consistently improve the accuracy of homography estimation compared with two most successful feature based algorithms, and the incorporated acceleration strategies are able to speed up the minimization procedure by about 15 times. The applicability of our proposed method is further demonstrated in two real-world applications, namely occlusion removal and image mosaicing.

1. Introduction

In computer vision, the term homography is used to describe the relationship between two images of a 3D plane or two images captured from the same location (Hartley and Zisserman, 2004). Specifically, the homography matrix is a reversible 3×3 matrix, which maps image points on one image plane to the other one. One reason that homography estimation has drawn great attention from researchers is that the homography is ubiquitous in practice and it is useful for numerous applications such as camera calibration (Zhang, 2000), metric rectification (Liebowitz and Zisserman, 1998), 3D reconstruction (Kanatani and Niitsuma, 2010), image mosaicing (Szeliski and Shum, 1997), and tracking applications (Carloni et al., 2004). For example, given an image of a scene with projective distortion, metric rectification can be used to get the fronto-parallel view of it, which leads to a number of practical and smart applications involving projector display (Raskar and Beardsley, 2001; Sukthankar et al., 2001; Brown et al., 2005). As for planar target tracking, since the homography between two images can be used to infer the transformation between planes, the target can thus be followed even when it is partially or fully occluded (Agarwal et al., 2005).

As a crucial stage in numerous real-world applications involving multi-view geometry, homography estimation has been widely studied for decades in computer vision community (Hartley and Zisserman, 2004). Most existing algorithms exploit sparse information such as points, lines, conics and curves in the image to calculate homography (Agarwal et al., 2005). While this type of methods is well-established and efficient (Claybrough and Defay, 2012; Marquez-Neila et al., 2013; Seo et al., 2013), it is insufficient for images of a scene with textureless surface, in which case dense approach exploiting the information of the whole image is desired. In this paper, homography estimation is recast as an optimization problem, which is solved by a minimization framework based on modified differential evolution (DE) (Price et al., 2005) with new acceleration strategies. The new method is able to account for both the color and gradient information in the whole image, thus generates homography estimate with higher accuracy.

The rest of this paper is organized as follows. In Section 2, we give a brief review of previous work on existing algorithms for estimating homography. Section 3 presents the preliminaries and notations used in this paper. In Section 4, the two key components of our proposed approach including problem formulation and minimization procedure are presented in detail. In Section 5, the

* Corresponding author. Tel.: +86 731 84576270.
E-mail address: lkang.vr@gmail.com (L. Kang).

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performance of our method is evaluated qualitatively and quantitatively using synthetically rendered images. Two real-world applications (occlusion removal and image mosaicing) are also presented to verify the applicability of our method. Finally, the conclusion as well as future work is presented in Section 6.

2. Related work

In the literature, researchers have proposed numerous techniques for homography estimation, which can be roughly classified into two categories: feature based methods and featureless methods. A brief review is given in the following.

The most widely used and successful feature based method for homography estimation is the direct linear transformation (DLT) algorithm which requires only four point correspondences and minimizes the algebraic error (Hartley and Zisserman, 2004). In practice, tentative point correspondences are usually contaminated with outliers, and a robust homography estimate is required (Moisan et al., 2012). The accuracy of the homography estimated by DLT algorithm can be further improved by minimizing geometric error using the iterative gold-standard (GS) method iteratively (Hartley and Zisserman, 2004), which generates an optimal estimation in the sense of minimizing the reprojection errors. Recently, research (Niitsuma et al., 2010) shows that high accuracy in homography estimation can also be achieved by algorithms without iterations, especially when image data are corrupted by large amount of noise. In addition to point features, line features have also been exploited for the computation of homography (Murino et al., 2002). Although feature based homography estimation methods are well studied, the accuracy of the estimated homography not only depends on the feature detectors (Moller and Posch, 2009) but also on the spatial distribution of sparse features (Bostanci et al., 2012). Moreover, feature based method may not be applicable when such sparse features are not available in some cases (e.g., textureless man-made objects).

Unlike feature based methods, featureless homography estimation methods aim to get a global estimate based on information of the whole image. Cordes et al. (2011) propose to use differential evolution (DE), which is a simple yet powerful evolutionary numerical optimizer (Price et al., 2005), to minimize a new featureless cost function for homography estimation. The authors demonstrate experimentally that the dense approach is able to improve the accuracy of homography estimation and allows to construct more reliable feature evaluation benchmarks. There are two limitations of the above work: the gradient information of image is not considered in the problem formulation, thus it is not robust to illumination change; the use of the original DE framework leads to low computational efficiency. Guerreiro and Aguiar (2006) propose a hybrid method for homography estimation, which splits one image into four blocks and finds their correspondences in the other image using standard correlation techniques, from which a homography estimate is obtained. The first image is then transformed according to the estimated homography and the whole procedure is repeated until the transformed image coincides with the second one. The above method combines the feature based simplicity and the featureless robustness. Unfortunately, no quantitative evaluation and comparison of accuracy are given in Guerreiro and Aguiar (2006).

This paper is mostly related to the work presented in Cordes et al. (2011) and makes improvements on its robustness and efficiency. We propose to solve the homography estimation problem by minimizing a two-objective function within a modified DE framework with integrated acceleration strategies. In fact, evolutionary algorithms (EAs) have been successfully applied to a variety of applications in image processing (Shimodaira, 2000), in which global optimization is usually demanded. In particular, Falco et al. (2007) present an approach for satellite image registration by distributed differential evolution, and Cuevas et al. (2013) propose a new algorithm based on differential evolution to reduce the number of search locations in the block-matching (BM) process for motion estimation. Recent studies also demonstrate the applicability of DE to computer vision tasks such as camera calibration and metric 3D reconstruction (de la Fraga and Silva, 2008; delaFraga and Schütze, 2009; Kang et al., 2012, 2013).

3. Preliminaries and notations

For the sake of completeness, this section presents the required theoretical background and the notations used in this paper. More details on multi-view geometry and differential evolution can be found in Hartley and Zisserman (2004) and Price et al. (2005), respectively.

3.1. Homography

Let $\mathbf{x}$ and $\mathbf{x}'$ be the projection of a 3D scene point $\mathbf{X}$ onto two images. Throughout this paper, both $\mathbf{x}$ ($\mathbf{x}'$) and $\mathbf{X}$ are represented by homogeneous coordinates (Hartley and Zisserman, 2004). Without loss of generality, the first camera is aligned to the world coordinate, i.e., the rotation matrix and the translation vector of

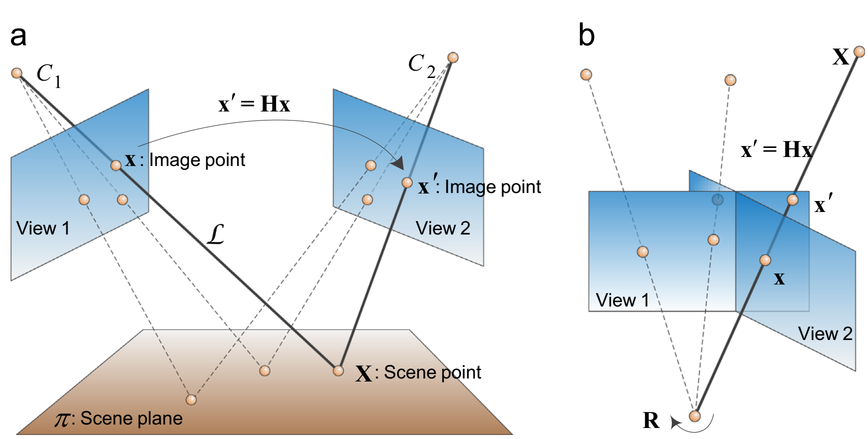

Fig. 1. Illustration of homography induced by (a) planar scene and (b) by purely rotational motion around camera optical center. In both cases, the two image points $\mathbf{x}$ and $\mathbf{x}'$ of a 3D scene point $\mathbf{X}$ are related by the homography $\mathbf{H}$.