



Distinctive Order Based Self-Similarity descriptor for multi-sensor remote sensing image matching



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ABSTRACT

Robust, well-distributed and accurate feature matching in multi-sensor remote sensing image is a difficult task due to significant geometric and illumination differences. In this paper, a robust and effective image matching approach is presented for multi-sensor remote sensing images. The proposed approach consists of three main steps. In the first step, UR-SIFT (Uniform robust scale invariant feature transform) algorithm is applied for uniform and dense local feature extraction. In the second step, a novel descriptor namely *Distinctive Order Based Self Similarity descriptor*, DOBSS descriptor, is computed for each extracted feature. Finally, a cross matching process followed by a consistency check in the projective transformation model is performed for feature correspondence and mismatch elimination. The proposed method was successfully applied for matching various multi-sensor satellite images as: ETM+, SPOT 4, SPOT 5, ASTER, IRS, SPOT 6, QuickBird, GeoEye and Worldview sensors, and the results demonstrate its robustness and capability compared to common image matching techniques such as SIFT, PIIFD, GLOH, LIOP and LSS. © 2015 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

1. Introduction

Image matching is the process of finding corresponding points in two or more images of the same scene and is a crucial process to a wide range of applications such as image registration (Gianinetto, 2012; Parmehr et al., 2014), change detection (Qin and Gruen, 2014; Sadeghi et al., 2013), and to the 3D modeling and mapping sciences (Ahmadi et al., 2010; Ekhtari et al., 2009; Lerma et al., 2013; Mohammadi and Malek, 2014; Soheilian et al., 2013).

Local invariant image features have recently received more attention in the field of photogrammetry and remote sensing. Nowadays, most image matching algorithms are based on the local invariant features because of their robustness to geometric and illumination differences.

The most of local feature matching algorithm consist of three main steps:

- *Feature detection*, which selects salient features in two images (reference image and input image), such as corners, blobs and regions.

- *Feature description*, which generates feature attributes (“descriptors” to characterize and match them) using various image properties such as intensity, color, texture, and edge.
- *Feature matching*, which establishes the correspondence between the features in the two images using particular similarity measures of their descriptors and then use a consistency check process to remove probable mismatches.

The main objective of this article is to develop a local feature matching method for various remote sensing images having different sensors, resolutions, illuminations and acquisition times. In previous researches, many image matching methods based on local features have been proposed in the literature (Barandiaran et al., 2013; Goshtasby, 2012; Gruen, 2012; Tuytelaars and Mikolajczyk, 2008).

The most popular local feature detector and descriptor algorithm is the scale invariant feature transform (SIFT) (Lowe, 2004) that uses the DoG (Difference of Gaussian) scale space function and distribution of gradients for detection and description respectively. Recently SIFT based method has been widely applied in remote sensing image matching and registration (Joglekar et al., 2014; Sedaghat et al., 2011; Yu et al., 2013).

Wang et al. (2012) proposed a robust multisource image automatic registration system (MIARS) based on the SIFT descriptor, which uses image division and histogram equalization as pre-processing steps. Han et al. (2012) proposed an automatic

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registration of high-resolution satellite images using local properties and geometric locations of SIFT control points. Song et al. (2014) proposed a robust estimation algorithm namely HTSC, histogram of TAR (triangle area representation) sample consensus, for remote-sensing image registration based on SIFT algorithm. Gong et al. (2013) proposed a coarse-to-fine scheme for automatic image registration based on SIFT and mutual information. Wu and Goshtasby (2012) proposed a progressive subdivision algorithm for high-resolution image registration using SIFT and Voronoi decomposition. Sun et al. (2014) proposed an efficient SIFT feature extraction and matching implementation for large images in large-scale aerial photogrammetry experiments.

The majority of the previous works use original SIFT algorithm, which often suffers from some problems in the quality, quantity, distribution of extracted features, and descriptor sensitivity against significant intensity differences, particularly in multisource remote sensing imagery (Ghassabi et al., 2013; Sedaghat et al., 2011).

In a previous research, we proposed a fully automated matching algorithm based on improved SIFT algorithm called Uniform robust SIFT (UR-SIFT) (Sedaghat et al., 2011). The main key to this approach is a selection strategy of SIFT features in the full distribution of location and scale where the feature qualities are quarantined based on the stability and distinctiveness constraints. Also in another research we introduced a method for image matching of satellite data based on quadrilateral control networks, which is based on SIFT algorithm and a piecewise model (Sedaghat et al., 2012).

Generally, a good descriptor should have two main properties, including distinctiveness (different features should have different descriptors) and robustness (the descriptor stability to a variety of image geometric and photometric transformations). Local Self-Similarity (LSS) (Shechtman and Irani, 2007) is a local feature descriptor that captures the internal geometric layouts of images based on a Log-Polar location grid. The LSS descriptor has some advanced properties, including invariance to color changes, and is computationally simpler than the SIFT algorithm (Liu and Zeng, 2012). For its stability against complex intensity variations, it has been successfully applied for the registration of thermal and visible videos (Torabi and Bilodeau, 2013).

Recently, Ye and Shan (2014) proposed a coarse-to-fine automatic registration scheme for the registration of multisource remote sensing images with non-linear intensity differences. In their approach, a pre-registration process is first carried out using the Scale Restriction Scale Invariant Feature Transform (SR-SIFT) (Yi et al., 2008) algorithm. Then Harris and Stephens (1988) corner points integrated with LSS descriptor are used to establish an accurate piecewise transformation for fine registration.

Despite the attractive illumination-invariance property of LSS descriptor, its performance in direct remote sensing image matching is relatively low in comparison with other well-known descriptors such as SIFT descriptor. Some improvements have been suggested for the standard LSS, such as Fast Local Self-Similarities (FLSS) (Liu et al., 2012), and Oriented Local Self-Similarities (OLSS) (Liu and Zeng, 2012). Both FLSS and OLSS are an integrated descriptor based on SIFT and LSS. These improvements are based on gradient orientation distribution in SIFT method, which is sensitive to the illumination and radiometric change and does not offer good results in multimodal image matching (Chen et al., 2010).

The main drawback for either LSS or extended LSS is that the descriptor discriminability is relatively low. In fact, the difference between LSS descriptor values for various features are relatively low, and they cannot reliably distinguish and match among different features. Probably, for this reason, Ye and Shan (2014) used a coarse registration process based on SR-SIFT algorithm in their

approach and then applied LSS descriptor for finding tie points in a small search region to decrease the low discriminability effect of LSS descriptors.

In this paper, a new robust feature-based matching method is presented. The main contribution of this paper is an advanced version of the self-similarity descriptor that has high discriminability and can be effectively used for remote sensing image matching. The proposed matching method is based on UR-SIFT feature extraction algorithm and is named *Distinctive Order Based Self Similarity descriptor*, DOBSS descriptor. The integration of the proposed feature descriptor with our previous work (Sedaghat et al., 2011) for uniform and robust sift feature extraction makes an effective method for reliable multi-sensor remote sensing image matching.

2. Methodology of the proposed method

In this section, an effective and robust automatic approach for reliable matching in remote sensing images with significant illumination differences is presented. The proposed method can be divided into three main steps, as illustrated in Fig. 1.

In the first step, a set of uniform and dense local features is extracted in both reference and input images. This process is effectively performed with UR-SIFT algorithm. In the second step, for each extracted feature, a distinctive descriptor is generated for finding feature correspondence. This process is automatically performed by a novel descriptor namely *Distinctive Order Based Self Similarity descriptor*, DOBSS descriptor. This descriptor is inspired from well-known Local Self-Similarity, LSS descriptor, and is based on the correlation surface order based grouping. A novel orientation assignment approach is also presented to achieve orientation invariant feature descriptor computation. Finally, a cross matching process followed by a consistency check in the projective transformation model is performed using Euclidean distance between feature descriptors. The details of the proposed method are presented in the following sections.

2.1. UR-SIFT feature extraction

Various methods for robust local invariant image feature extraction have been proposed (Aanæs et al., 2011; Barandiaran et al., 2013; Tuytelaars and Mikolajczyk, 2008). One of the most effective and prominent methods for this purpose is the extrema of DoG (Difference of Gaussian) function in SIFT algorithm. DoG function is an approximation of LoG (Laplacian of Gaussian), whose feature extraction process is based on scale space theory. While invariant to scale and rotation, and robust to change in illumination and 3D camera viewpoint, the SIFT feature extractor suffers from some problems in the quality, quantity, and distribution of extracted features, particularly in multi-sensor remote sensing images (Sedaghat et al., 2011). The main problems of the original SIFT are as follows:

- (1) *Controllability of the feature number*: The complex nature of multi-sensor remote sensing image causes high sensitivity to the SIFT parameters, particularly contrast threshold, which controls the number of extracted features.
- (2) *Quality and distribution of features*: The original SIFT does not have control on the scale and the spatial distribution of the extracted features.

UR-SIFT algorithm (Sedaghat et al., 2011) is an improved version of the standard SIFT algorithm for effective, robust, reliable, and uniformly distributed blob-like feature extraction in remote sensing images. The main key to this approach is a selection strategy of high quality SIFT features in the full distribution of location

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