A REGISTRATION-NOISE DRIVEN TECHNIQUE FOR THE ALIGNMENT OF VHR REMOTE SENSING IMAGES

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1. INTRODUCTION

Image registration is one of the most important steps to implement in applications related to the analysis of multitemporal remote sensing images. Such kind of applications (e.g., change detection, image fusion, etc.) requires aligned images where corresponding pixels are associated with the same position on the ground (i.e. registered images). In the change-detection (CD) process the image registration accuracy directly affects the accuracy of the CD results. The co-registration procedure becomes more critical when very high resolution (VHR) images acquired by the last generation sensors (e.g. Ikonos, QuickBird, EROS, SPOT-5, GeoEye-1, World View-2) are considered. These images can be acquired with different view angles and often show different local geometrical distortions that decrease the effectiveness of standard techniques developed for the registration of medium resolution images. In the literature only few automatic techniques have been proposed for the registration of high and very high resolution remote sensing images, which are focused on specific applications [1][2].

This paper proposes a novel technique for a robust and accurate registration of VHR images, which is especially suitable for change-detection applications. The proposed technique follows the standard scheme of registration process [3]: (i) feature (i.e. control points CPs) extraction; (ii) feature matching and transform model estimation; and (iii) image resampling and transformation. In particular, the presented method automatically extracts the CPs, estimates the disparity map that represents the non-parametric spatial transformation to be applied to the image and finally warps the moving image on the fixed one. The proposed method takes advantages from the technique for the estimation of the distribution of registration noise (RN) presented in [4], which is exploited for automatically extracting and matching the CPs Unlike standard registration methods, the proposed procedure: (i) is effective in obtaining good registration accuracy on the most critical points of the images where misregistration has a high probability to results in the detection of false changes; and (ii) is not affected by the presence of changes between the two images.

2. PROPOSED METHODOLOGY

Let $\mathbf{X}_1$ and $\mathbf{X}_2$ be two multitemporal VHR images acquired over the same geographical area at different times that should be registered. Let $\mathbf{X}_1$ be the fixed image and $\mathbf{X}_2$ the moving one. The objective of a registration technique is to warp the moving image on the fixed one in order to align them. To this purpose, we propose a registration method for VHR images based on the following main steps: (i) automatic extraction of CPs based on the registration noise distribution; (ii) CPs matching and transform model estimation by the generation of a complete disparity map; and (iii) image resampling and transformation.

2.1. Automatic extraction of control points

The control points extraction and matching represents the most novel part of the proposed work. In greater details, we automatically extract as CPs the pixels that have the highest probability to be corrupted by registration noise and thus to result in false alarms in the CD process. It is worth nothing that the term registration noise indicates the effects of a non perfect alignment between the multitemporal images under investigation. The study on the properties of RN on VHR images conducted in [4] resulted in the possibility to detect pixels affected by RN through a multiscale analysis. In particular, in [4] a technique for the adaptive estimation of the conditional density of RN has been defined in a polar domain. For space constraints the formulation will be reported only in the final paper (please refer to [4] for greater details). In this work, we use the estimation of the RN for generating a map M that gives us information about the distribution of RN on the basis of which the CPs are extracted. In particular, to a generic pixel m of this map the value of the probability that m has to be corrupted by RN is assigned. This value is directly derived from the conditional density of RN, projecting it from the polar to the image domain. High value assigned to m corresponds to high probability that the pixel is corrupted by RN. Accordingly this pixel is considered a CP by the proposed technique. Thus, in order to extract all the CPs we apply a threshold T_{RN} to the map M and we consider as CPs for the proposed method all the pixels associated with values higher than T_{RN}. It is worth noting that, as it will be explained in the full paper, this procedure intrinsically excludes from CPs pixels related to real changes, as they corresponds to pixels of M with low values (see [4]). This aspect makes the method robust to changes between images. Once the CPs are extracted, in order to perform the matching between them, we generate the registration noise map R, which is obtained by thresholding M according to T_{RN}. In particular, the map R have pixels with non-zero values only for pixels extracted as CPs; and the value of them corresponds to the probability that they have to be pixels of RN.

3.2. Generation of the disparity map

In order to estimate the displacement for each pixel between the two images, we perform a local analysis using as metric the value of the conditional density of RN. This local analysis is made up of two main steps: (i) evaluation of the displacement for each CP; (ii) interpolation of the displacement values for creating a complete disparity map. In greater details, in order to evaluate the displacement for each CPs, we: (a) generate the registration noise map M for different displacements; and (b) split the RN map and make a quantitative analysis based on the distribution of RN in each split. At first we create a set Ω_d (d=1,…, D) of possible displacements of the original image by taking the moving image and translating/rotating it according to a predefined set of misalignment values. Then for each combination of the original fixed image and one of the D displaced moving images we derive the conditional density of registration noise and generate the registration noise maps M_d. In order to estimate the displacement of each pixel, we perform a local analysis of the D obtained M_d. At first we divide the RN maps into L sub-images of dimension hxh, then for a generic split l subject to a displacement d we evaluate the estimated amount of misregistration AM_d^l in the considered area as:

$$AM_d^l = \sum_{\substack{1\le i\le h \\ 1\le j\le h}} r_d^l(i,j) \tag{1}$$

where $r_d^l(i,j)$ is the pixel with coordinates *(i,j)* in the l-th split of the d-th RN map. It is worth noting that contributions to AM_d^l are given only from pixels of the split l extracted as CPs as they are the only with non–zero value. Finally the displacement value is explicitly derived for all the splits that contain at least one CP (i.e. split with non-zero value of AM_d^l at the initial condition), according to the value of AM_d^l. Each split is associated to the displacement that results in the lowest value of AM_d^l with respect to d. In this manner we estimate the residual misalignment for all the CPs. In order to estimate the misalignment for all the pixels of the image we apply bilinear interpolation to the displacement values already yielded for CPs. Trough this procedure we obtain a complete disparity map that shows for each pixel the estimated displacement vector. This disparity map corresponds to a discrete representation of the image transformation necessary for registering the two original images. It has the advantage of making it possible to apply a non-parametric warping model which is as more general as possible [5].

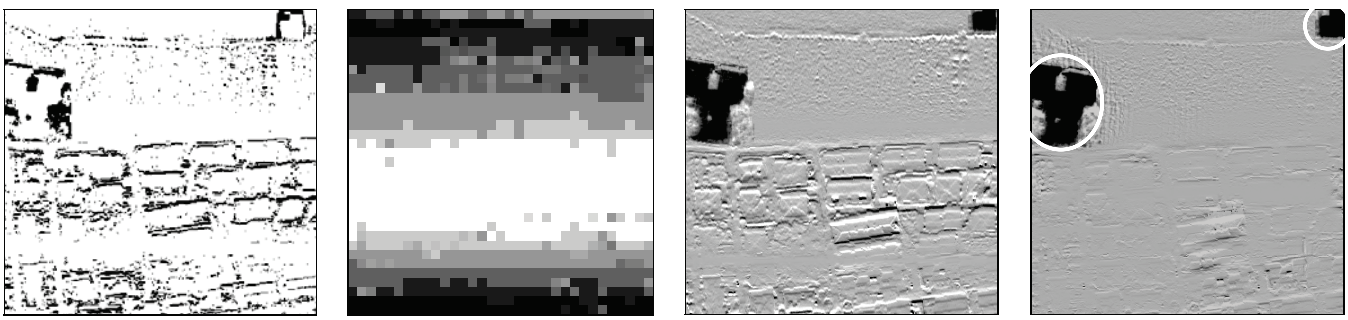
3.3. Image transformation

The last step of the proposed method consists in the mapping of the moving image to the fixed one on the basis of the obtained disparity map. For data with non linear or local geometric distortion (such as VHR images) complex transformation are needed to produce better interpolation results. For this reason, in this work, the warping is performed by applying the thin plate spline (TPS) [6] interpolation function to the retrieved disparity map.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In order to assess the effectiveness of the proposed registration technique several experiments were carried out on both simulated and real data. In particular, VHR multispectral and multitemporal images acquired by the Quickbird sensor on the Trentino area (Italy) in October 2005 and July 2006 were considered. Results obtained on both simulated and real data confirm the validity of the proposed method in identifying effective CPs, in estimating the disparity map and in performing the final co-registration between the considered images. In the following, as an example, some results obtained on a simulated data set made up of an image and a copy of it with simulated changes and a sinusoidal distortion are reported. Fig. 1.a shows the map containing all the extracted CPs. As one can see, they are mainly related to areas that show the effects of misregistration (i.e. border regions of buildings and crop rows). In Fig. 1.b the quantized disparity map is reported; a visual analysis of it confirms the validity of the displacement estimation, as the areas in which the sinusoid has its peak (both negative and positive) correspond to the lowest and higher values of the displacement (black and white regions). Finally Fig. 1.c and d report the difference image evaluated before and after the registration process. As one can observe in some regions (i.e. the regions where the deformation is more consistent) the effects of misregistration are clearly visible in the image before the registration both in urban and rural areas, while in the difference image obtained after applying the proposed registration method the effects are very smoothed. This confirms the ability of the method in performing an effective registration. In addition, changes are correctly reported without distortion (see white circles in Fig. 1.d) and are not considered as CPs, proving the effectiveness of the method also when changes are present between the images.

Further details on the proposed method and results will be reported in the full paper.



(a) (b) (c) (d)

Fig. 1. Regisrtation results obtained on simulated data. (a) Map containing the extracted CPs; (b) quantized disparity map; difference image (c) before and (d) after the registration process.

4. REFERENCES

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