Registration of metric resolution SAR and Optical images in urban areas

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Abstract

Earth observing sensors are of different kinds, providing complementary or different observations. Among the Earth Observation sensors, optical and radar ones deliver images with unlike physical properties. Thus it is interesting to fuse such images in order to benefit from both data. Such a demarch begins with the registration of input images. This paper is dedicated to automatic registration of Synthetic Aperture Radar (SAR) and optical images at metric resolution in urban areas. Our appproach is divided into two main steps. First, a rigid deformation is computed, using the Fourier-Mellin invariant method applied on features extracted in both images. Second, this first transform estimation is refined by a polynomial deformation based on pre-selected pixels grid.

1 Introduction

The increasing of metric resolution satellites launches, like Cosmo-Skymed and Pléiades, raises new problems for image registration. Therefore, new image proocessing tools have to be developped. Indeed, the geometric difference between SAR and optical images increases with the resolution, especially in urban areas, where parallax and shading effects are important on buildings. Moreover, shadows and radiometric differences disturb the registration process. It implies that specific methods are required for registration with multisensor metric images such as SAR and optical ones.

Some previous works proposed methods for automatic SAR/optical registration. Three of them are commonly used, based on features, pixels intensity or the knowledge of the sensors parameters. Ali et al. [1] match homogeneous regions in function of their attributes (perimeter, number of pixels inside the region, center...). Most methods are based on ground control points, which enable to estimate the transformation model, as Wong et al. do [2].

The state of the art on optic and SAR images registration is quite limited when it adresses high resolution. In this case, pixels intensities are often used; Oller et al. [3], as Inglada et al. [4] use a similarity metric and a classification to improve the metric registration. The third registration method is based on sensor parameters. Galland et al. [5] presents a method using a perfect knowledge of these and the influence of a small error on them. According to Gonçalves et al. [6], seven parameters must be known to orient a SPOT image; for SAR images the trajectory with high accuracy and the Doppler frequency for each point are required. In this work, we assume that the parameters are approximately known; the goal is to find an automatic coarse registration method.
It is hard to find a universal method because of the diversity of images to be registred and of the various types of deformations. However, most registration methods can be viewed as the combination of four components [7] [8]:

- the feature space (regions, edges, lines, points...)
- the similarity measure which determines the validity of the registration
- the type of deformation
- the optimizer

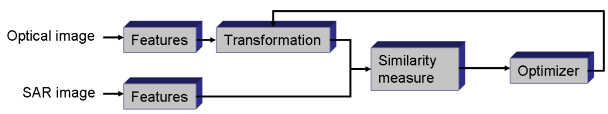
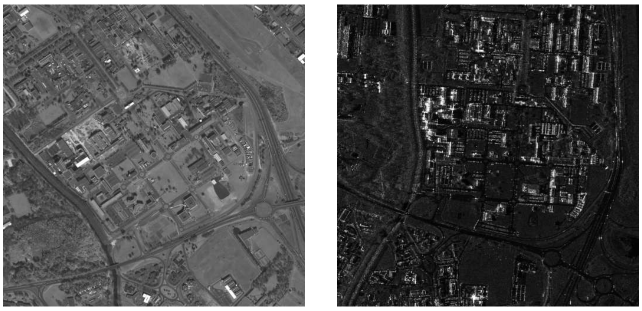


Figure 1: Registration algorithm

Our approach is the following. First, a method for rigid registration is introduced in Section 2, using Fourier-Mellin invariant. Nevertheless, the deformations between optical and SAR images are not only translation, rotation and scale. Section 3 proposes an improvement of the first estimations through the use of a polynomial transformation. Finally, the experimental results on real high resolution images are presented in Section 4.

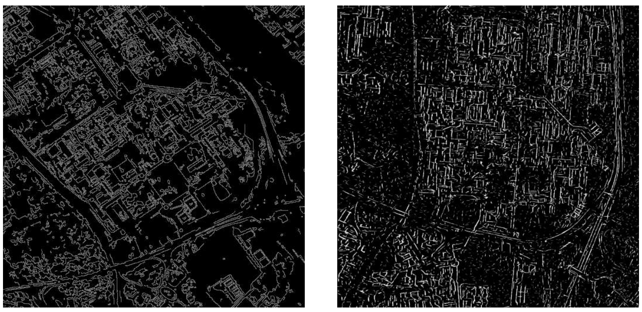
2 Rigid registration

For SAR and optical image registration, the first step is to decide what kinds of features are appropriate. As can be seen in figure 2, due to the radiometric differences, it is not easy to registrate using directly the pixel intensity. We have chosen to extract the edges of the optical images and the lines of the SAR images. First a coarse registration is looked for and the assumption is made that the transformations are rigid; which means only translation, rotation and scaling. The similarity measure used is the correlation. In order to optimize the computation time, we have chosen to work in the frequency domain and to use a multi-scale pyramid.



(a) Optical (b) SAR

Figure 2: The two input images over CNES (Toulouse, France) with metric resolution (a) Quickbird image, (b) Ramses image in X band



(a) (b)

Figure 3: Features images: (a) detected edges of optical image, (b) detected bright lines of SAR image

2.1 Features

The features that are to be matched must be some elements present in both images, that can be points, regions, edges... In this work, the matching is made on lines extracted from each image. For the optical image, the Canny edge detector gives us the contour of roads and buildings. The detector of [9] extracts lines of the SAR images, that often match with buildings edges. These lines-like are the ground-wall double reflexion. Figure 3 shows the extracted features.

2.2 Fourier-Mellin

The registration method uses Fourier-Mellin invariant as described in [10]. It is an extension of the phase correlation technique. This frequency-based approach is used to estimate the translation between two images. Let f_1 and f_2 be two images differing only by a translation, and F_1 and F_2 their corresponding Fourier Transforms:

$$f_2(x,y) = f_1(x - \delta x, y - \delta y)$$

$$F_2(u,v) = e^{-j2\pi(u\delta x + v\delta y)} F_1(u,v)$$

$$\frac{F_1(u,v)F_2^{'*}(u,v)}{|F_1(u,v)F_2^{'}(u,v)|} = e^{j2\pi(u\delta x + v\delta y)}$$

By taking inverse Fourier Transform, an impulse is obtained corresponding to the translation $(\delta x, \delta y)$.
The Fourier-Mellin invariant extends the phase correlation to rotation and scaling, by using a log-polar transform. Let g_1 and g_2 be two images differing by a rotation of θ_0 and a scale of α, and G_1, G_2 be their corresponding Fourier Transforms:

$$g_2(x,y) = g_1(\alpha(x\cos\theta_0 + y\sin\theta_0), \alpha(-x\sin\theta_0 + y\cos\theta_0))$$

According to the Fourier transform properties, a rotation becomes a rotation of the same angle in the frequency domain and a scaling becomes an inverse scaling.

$$G_2(u,v) = \frac{1}{|\alpha|} G_1(\frac{u}{\alpha}\cos\theta_0 + \frac{v}{\alpha}\sin\theta_0, \frac{-u}{\alpha}\sin\theta_0 + \frac{v}{\alpha}\cos\theta_0)$$

By converting in log-polar coordinates, rotation and scaling become translations:

$$G_2(\log\rho, \theta) = \frac{1}{|a|} G_1(\log\rho - \log\alpha, \theta - \theta_0)$$

Yet, this method is highly sensitive to the features that are to be matched. In order to increase robustness, a coarse-to-fine strategy is employed in which we construct a multi-scale pyramid. Three levels of the pyramid are constructed, corresponding to three resolutions.
On the first one, the dark lines of the SAR image are extracted, the research space of the parameters is limited to [-90°;90°] and the scaling between [0.95;1.05]. This suppose to have a knowledge of the approximative resolution and the orientation of the images.

On the other levels, bright lines are extracted. The registration is initialized with the precedent result and the research space is restricted to [-10°;10°] and [0.95;1.05].

2.3 Translation

To find the translation, Fourier-Mellin invariant is not fully satisfactory. Indeed, as explained in 2.1, the features taken are not exactly the same in both images. As the rotation and scaling have been found, it is easier to find the translation using the pixel intensity and the mutual information, described in section 3.2. An exhaustive search on the center of the optical image is made to determine his location on the SAR image. The differences in the coordinates give the parameters of the global translation.

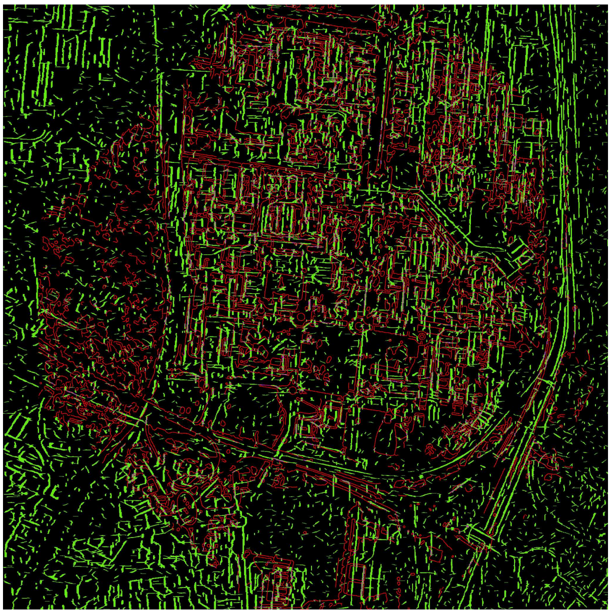


Figure 4: Fourier-Mellin invariant result: green lines correspond to the optical extracted features after registration and red lines to the SAR images.

3 Polynomial registration

In the previous section, an adequate method for rigid registration is used. But in the case of SAR and optical images, this assumption is not fully verified. With metric resolution, there is a parallax effect, that can not be corrected with a rigid transformation only. In order to improve the registration, a polynomial deformation is looked for. To define the coefficients of the deformation, the associated points in both images are searched.

3.1 Points extraction

Control Points are extracted from the optical image, using the Harris corner detector [11]. This is a popular point detector that measures the local changes of the signal in different directions. Interesting points are extracted like corners or intersections. Among all the points, just few of them are holded. In each section of a grid of size 5x5, a point is selected, then those in the border are rejected. Finally, a set of interesting points dispersed among the image are found.

3.2 Matching

Once the points are selected in the optical image, their location is looked for in the SAR image. For this purpose, a similarity measure is needed. Among all the criteria that can be used for multisensor image registration [4] [12], the mutual information (MI) is selected.
The MI is a measure of statistical dependency between two data sets. For two random variables X and Y, it is given by :

$$\begin{aligned} MI(X,Y) &= H(Y) - H(Y|X) \\ &= H(X) + H(Y) - H(X,Y) \end{aligned}$$

where $H(X) = -E_X(\log(P(X)))$ represents the entropy of the variable X, $P(X)$ is the probability distribution of X and E_X the expectation. This registration method is based on the maximization of MI and works directly with image intensities.
The MI is applied on the full intensity of optical image and on the SAR image quantified in ten levels. Because a rigid transformation has already been applied, we assume that for each point, his corresponding point in the SAR image is around the same place. An exhaustive search, on a neighborhood of 60 pixels, around the optical point location is done to find it.

3.3 Transform model

A final registration is performed by estimating the best deformation fitting the couples of points. The model used is a second order polynomial transformation. In a preliminary step, the couples of points are filtered with respect to their similarity value. The final model is then estimated via a least square method. Figure 5 shows the registration results.

4 Experimental Results

The proposed matching algorithm has been tested on different images of size 2048x2048. First it is necessary to initialize the images with the same resolution, as we suppose them approximately known. That means, to resample the SAR image in ground range and to the same resolution than the optical one.
A multi-scale pyramid is created for both images. The Fourier-Mellin invariant is applied to find the best rotation

and scale, on the first level. Then the next level is initialized with the precedent result. The translation is found on full resolution via MI on the center of the image.
Figure 4 shows the results. To improve the clarity, the registrated features are displayed. The matching seems to fit, on some sections there are still some local distorsions. This is due to our assumption of a rigid deformation between the images.
In the second part the polynomial transformation has been applied. 25 points with Harris detector have been extracted. After filtering, only around ten are kept. For each of them, the MI is applied on a window of 400x400 centered on it. The corresponding point on the SAR image is searched around 60 pixels. Actually, results show a local translation lower than 30 pixels. The final registration is shown in figure 5. The local distorsions seen previously have been corrected as can be seen in figure 6.

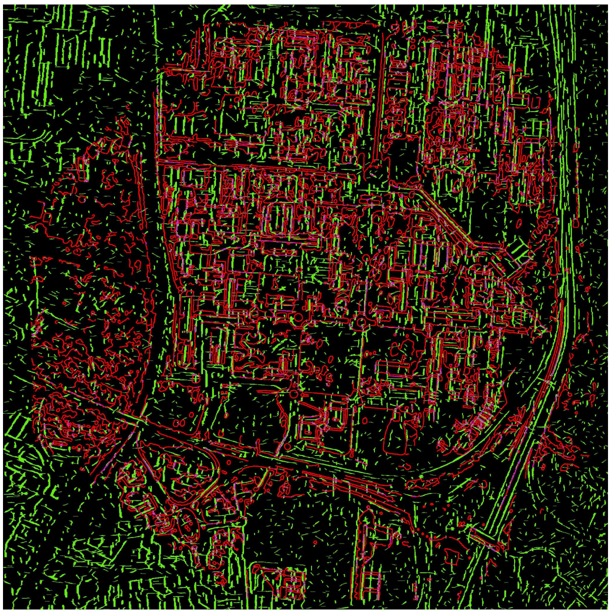
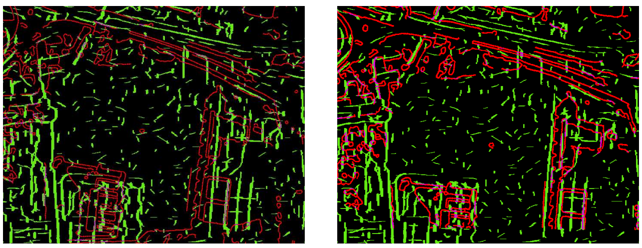


Figure 5: Polynomial registration result: red lines correspond to the optical extracted features and green lines to the SAR images



(a) (b)

Figure 6: extract of previous figures (a) coarse registration, (b) after polynomial registration

With the set of images we disposed, we do not have any truth references to evaluate our registration. Ground control points have been taken manually and an error of 30 pixels has been found after the rigid registration. This result was improved to 11 pixels with the polynomial registration.

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