STATISTICAL EDGE DETECTION IN URBAN AREAS EXPLOITING X-BAND SAR DATA

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ABSTRACT

This paper is focused on the urban edge detection topic, i.e. the identification of building and man made structures edges. An approach able to exploit jointly both the amplitudes and the interferometric phase of two complex SAR images is considered. This work is mainly focused on the application of this technique to real data sets. In particular, first experiments on COSMO-SkyMed data over the area of Naples have been carried out. The obtained results confirm the effectiveness and the accuracy of the approach, making it a useful tool for building edge detection using when very high resolution are available.

Key words: Building Edge Detection, Synthetic Aperture Radar, Markov Random Fields.

1. INTRODUCTION

The aim of building edge detection is to recover the position of building and man made structures within an observed image. Typically, building edge detection has been carried in the optical domain, exploiting the well known gradient based techniques, such as the Sobel filter [1].
With he availability of very high resolution SAR data, many efforts to extend the building edge detection to radar images have been done. The available techniques can be divided in two groups considering which kind of information is exploited: amplitude or phase of SAR data. Most of the amplitude based one implements gradient based techniques after a despeckling filter is applied, in order to take into account the multiplicative nature of the speckle. Also some ratio-based techniques for edge detection exploiting the amplitude have been proposed, resulting to be effective in retrieving the correct shape of the ground structures, but at the cost of high false alarm rate.
The other class of techniques performs the detection considering the strong phase changes in the interferogram, which are related to different heights of the structures. These methods start from the idea of finding building edges from the height information (i.e. the interferometric phase) and are characterized by a low false alarm rate in terms of building edge reconstruction. Often an a priori knowledge of the observed scene is required in order to achieve effective results.
Among the phase based edge detectors, the one proposed by [2] does not need any a priori information about the scene under observation: buildings are well detected but the recovered shapes are not fully consistent with man made structures.

Recently, an extension of [2] has been proposed in [3]. The main idea is to exploit both amplitude and phase of the available SAR data, in order to perform a joint detection. As a matter of fact, it is known that building edges are characterized by discontinuities in both amplitude and phase images (i.e. phase and amplitude discontinuities share the same positions) [4]. It is likely that the edges of one image are also present in the other one. The joint estimation allows to further improve the building edge detection both in terms of false alarm rate and detection probability. In [3], some interesting results have been achieved both on L-band and X-band data sets. In this work, the proposed algorithm was tuned and tested on COSMO-SkyMed X-band data sets. This first and preliminary results on COSMO-SkyMed data show interesting and promising performances using high resolution images.

2. METHODOLOGY

In this section, the main details about the methodology and the theory on which the proposed algorithms is based are provided. For further details and for a full discussion, please refer to the paper [3].

The labels (pixel interferometric phase and the pixel reflectivity) are modeled using Markov Random Fields (MRFs): this implies that the behavior of each pixel is related only to the pixels belonging to its neighborhood $\mathcal{N}$. In particular, we use Local Gaussian MRF (LGMRF), which is a Gaussian MRF with local hyperparameters.

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Figure 1. Surroundings of Naples, COSMO-SkyMed amplitude image (mean of the stack).

According to this model, the energy function is set to be:

$$U(\boldsymbol{\ell}, \boldsymbol{\theta}) = \sum_{p=1}^{N} \sum_{q \in \mathcal{N}_p} \frac{(l_p - l_q)^2}{2\theta_{p,q}^2} \quad (1)$$

where N is the number of pixels across the image, $\mathcal{N}_p$ is the neighborhood of pixel p, l are the labels to be modeled (in our case, phase values or reflectivity values)and θ is the *hyperparameter*, a parameter used to tune the model to achieve the best possible probability density function (pdf) fitting.

One hyperparameter is defined for each couple of pixels, instead of a single hyperparameter for the whole image. The proposed edge detection is based on the estimation of these hyperparameters. Given two neighboring pixels p and q, the local hyperparameter $\theta_{p,q}$ can be seen as an indicator of the spatial correlation of neighboring pixels. For our problem, a high value of $\theta_{p,q}$ corresponds to a transition between different label values (an edge between p and q), while a low value of $\theta_{p,q}$ means no label transition (no edge between p and q). Clearly, $\theta_{p,q}$ is unknown and it is estimated starting from the available data using the Expectation Maximization (EM) algorithm [2] which turns to be efficient in order to provide the estimation of the hyperparameters.

The hyperparameter estimation for the pixel p, using the EM algorithm at the $(k+1)$-th iteration is:

$$\hat{\theta}_p^2(k+1) = E\left(\sum_{q \in \mathcal{N}_p} \frac{(l_p - l_q)^2}{9} | \mathbf{d}, \hat{\theta}_p^2(k) \right) \quad (2)$$

In order to perform the expectation over the labels,

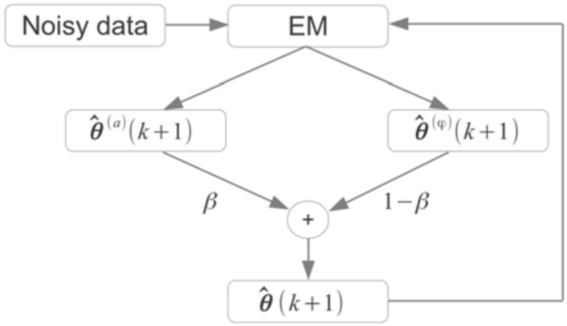

Figure 2. Processing chain for the estimation of the hyperparameter map at the $k-th$ step.

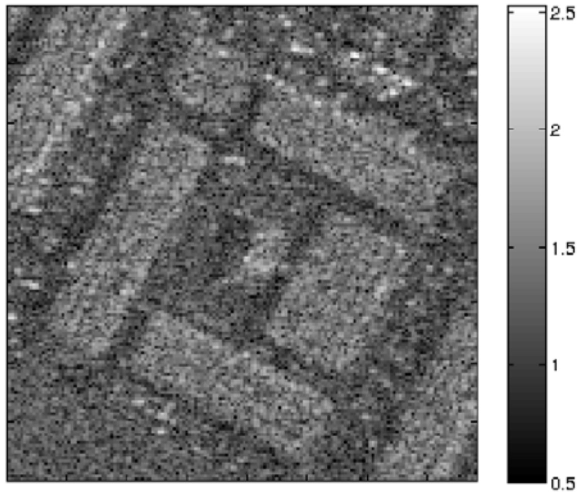

Figure 3. Test area, mean amplitude image of the interferometric pair, logarithmic scale.

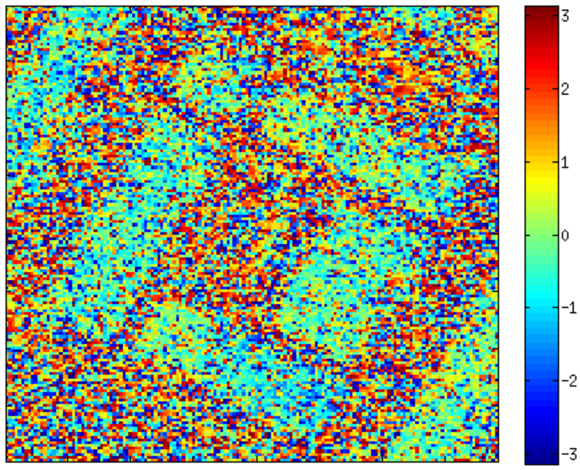

Figure 4. Test area, interferometric phase.

random samples are required. The sampling is performed starting from the *a posteriori* distribution of the labels by using the *Metropolis Algorithm*.

The processing chain for the hyperparameter estimation is presented in figure 2. Two hyperparameter maps, using EM algorithm, are produced, starting from amplitude and phase data: $\hat{\boldsymbol{\theta}}^{(a)}(k+1)$ related to the amplitude and $\hat{\boldsymbol{\theta}}^{(\varphi)}(k+1)$ related to the phase. The global hyperparameter map is synthesized starting from these two via a weighted mean:

$$\hat{\boldsymbol{\theta}}(k+1) = \beta \cdot \hat{\boldsymbol{\theta}}^{(a)}(k+1) + (1-\beta) \cdot \hat{\boldsymbol{\theta}}^{(\varphi)}(k+1) \quad (3)$$

where β is a weighting coefficient.

The two hyperparameter maps are first separately estimated and then mixed in order to preserve a certain degree of freedom during the detection process when working with different data sets (sensors, working frequencies and acquisition parameters).

3. NUMERICAL EXPERIMENTS

In this section, results on real data, obtained with MATLAB®and Fortran coding, are presented. Weighting coefficient β has been manually tuned for the presented results.

A pair of complex images (providing two amplitude images and one interferogram) has been considered. A pre-processing step consisting in coregistration and flat earth removal has been applied to the data. The data set consists of two X-Band SAR images acquired by the COSMO-SkyMed Sensor over the area of Naples. The system parameters are reported in Table 1. We focused on a particular area close to the city of Nola. The whole area is shown in figure 1. In this area, we focused on a particular set of buildings. The mean of the two available amplitude images of the considered buildings is shown in figure 3, while the interferogram is shown in figure 4. It is important to stress that the considered interferometric pair is characterized a combination of spatial and temporal baseline that implies high decorrelation, so it can hardly be considered an ideal data set for the considered algorithm.

Comparing estimated edges of figure 5 with the ground truth of figure 6, it can be seen that all building edged have been detected with the exception of the central small (and taller) building. This is due the small value the wrapped phase (figure 4) assumes in that area, not obtaining a big discontinuity in the phase trend. The extension to the multichannel case is expected to solve this kind of issue: with the exception of the ground, no height is characterized by a value of the interferometric phase close to zero for all the available interferograms.

Table 1. COSMO-SkyMed system parameters for the considered data set.

frequency	9.6 GHz
range resolution	3 m
azimuth resolution	3 m
orthogonal baseline	645 m
temporal baseline	40 days

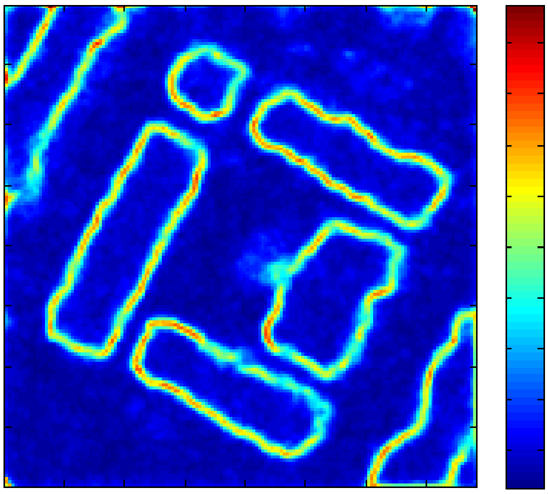

Figure 5. Edge estimation result.

4. CONCLUSION

In this paper the application of the joint amplitude and phase building edge detection to X-band COSMO-SkyMed data has been presented. The algorithm has been tuned to meet the specific characteristics of the considered data. Moreover, thanks to the availability of a couple of images characterized by high spatial and temporal decorrelation, it has been possible to test the method on a non ideal data set. Even in these conditions, the technique has shown to be effective and accurate. The next step will be the extension of the method to a multichannel data set, in order to avoid possible problems due to the wrapping of the phase and to improve the overall accuracy.

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Figure 6. Optic image of the test are (©2011 Google - Map Data ©2011 Digital Globe ©2011 Tele Atlas).

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