Validation of a feature fusion scheme for urban DSM retrieval from high resolution SAR interferogram

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***Abstract*— Three-dimensional reconstruction in urban areas is one of the major issues in remote sensing applications. SAR interferometry (InSAR) has a great potential to provide Digital Surface Models (DSM), but the context of urban areas and high resolution (HR) is difficult (geometrical distortions, surface heterogeneities, speckle, height discontinuities). Previous studies prove both the difficulty and the potential of the method.**

In this paper, we propose a new fusion method to compute DSM from HR InSAR. The merging approach enables to take into account several kinds of information extracted from the original data in order to retrieve jointly a classification and a DSM. The paper will be focused on the analysis of the results in order to understand the limits and potentials of InSAR over urban areas. Before discussing the results, the method will be briefly described.

I. Introduction

Since some years, airborne SAR sensors have acquired high resolution images (i.e. submetric), enabling to enlarge the application fields of radar image processing to urban area monitoring. Moreover several high resolution SAR satellites should be launched during the next few years, increasing considerably the data takes available on towns. Therefore the study of high resolution SAR data prepares the arrival of these data.

In this paper, we address the problem of urban Digital Surface Model (DSM) computation through interferometric SAR images. DSM are required for many applications such as urban planning, soil monitoring, military applications, etc. and SAR interferometry provides an efficient method to compute height in every pixels [1]. It has proven its accuracy for low resolution images on natural surfaces. Since some years, the challenge has been to move to high resolution and non-natural areas.

The context of urban areas and high resolution is very difficult because of geometrical distortions, surface heterogeneities, speckle and height discontinuities. Nevertheless the phase unwrapping problem is not discussed here because ambiguity altitude is high compared to global height variation of the scene. The most difficult problems are object recognition and adaptive noise filtering.

The simple scheme of interferometric phase inversion fails over urban areas. A higher level process is required. In literature, some algorithms have been proposed dealing with different approaches: shape-from-shadow [2], interferogram filtering with horizontal planes [3], stochastic geometry [4] and segmentation based reconstruction [5]. We keep the global idea of [5] but we restrict to only one interferogram per scene, which makes a drastic condition that may be further relaxed by adding other data.

In this paper, we propose a fusion method to compute DSM from high resolution interferometry to retrieve height and class jointly (Section II). Actually class and height are intrinsically linked and give information the one to another. The algorithm is divided into three main steps that are briefly described in the paper: derivation of new inputs giving higher level information of the scene, merging of this information in a Markovian scheme and improvement of the results.

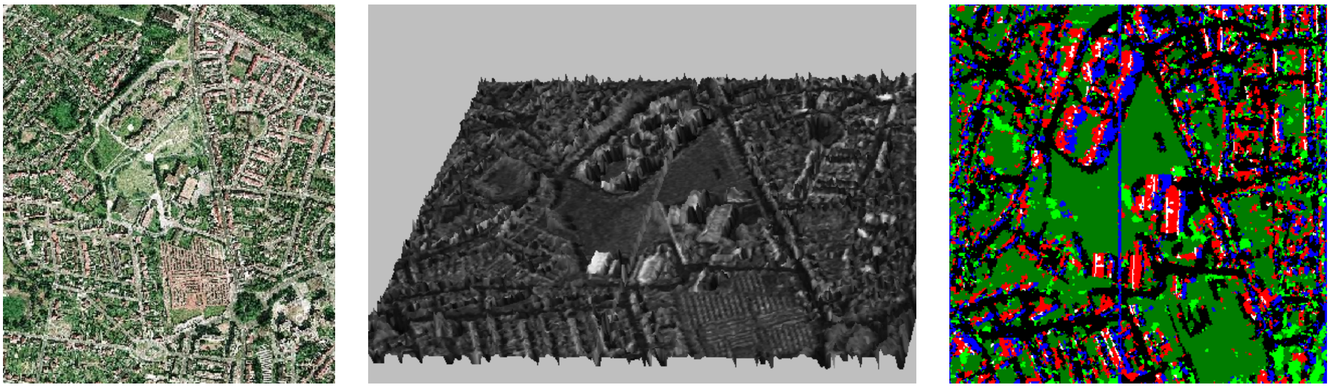
This paper is focused on the analysis of the results in order to understand the limits and potentials of InSAR over urban areas (Section III). We dispose of a real database: X-band SAR data over Dunkerque, France (RAMSES sensor). The processing chain has been conducted on different extracts which represent a large diversity of architecture configurations. A precise knowledge of ground truth enables to check the validity of the classification and the DSM.

II. 3D retrieval method

The theoretical aspects of the method are detailed in [6]; only the global idea of the main steps are explained here. The three steps are: retrieval of higher level inputs from the input data, merging of the new images to compute jointly a classification and a height map and improvement of these two results. The main originality of the method is the joined process of class and height to keep all their inter relations.

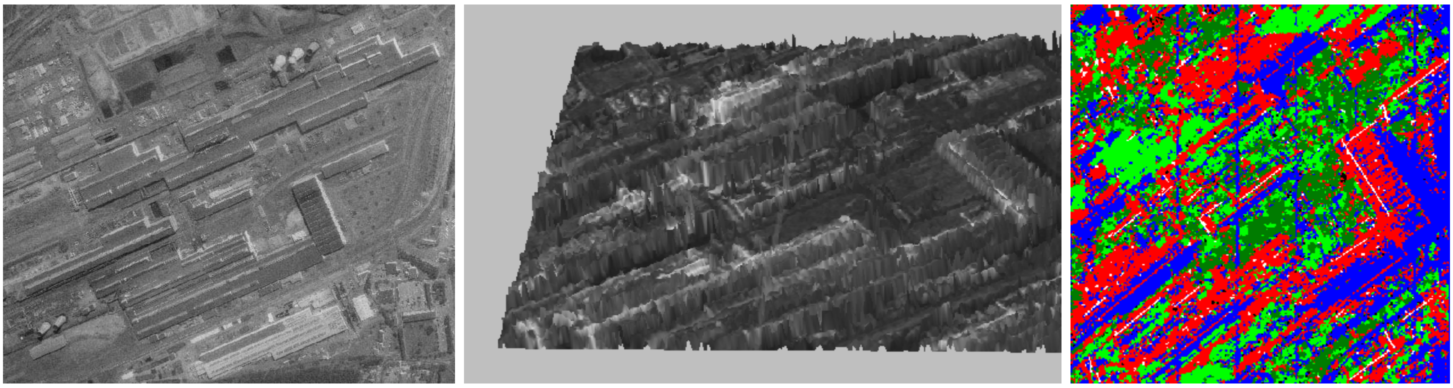
A. Detection step

The initial input data are the amplitude image, the coherence image and the interferogram. These images are processed to get improved or higher level information. The used operators



(a) (b) (c)

Fig. 1. Results of the Bayard district: (a) optical image (IGN), (b) 3D view of the DSM with SAR amplitude image as texture, (c) final classification. (black=streets, dark green=grass, light green=trees, red=buildings, white=corner reflector, blue=shadow)



(a) (b) (c)

Fig. 2. Results of the industrial area : (a) optical image (IGN), (b) 3D view of the DSM with SAR amplitude image as texture, (c) final classification. (black=streets, dark green=grass, light green=trees, red=buildings, white=corner reflector, blue=shadow)

can be divided in three groups:

- classification operator:

a first classification is computed based on amplitude statistics [7] and improved by adding coherence and interferometric information [8];

- filtering operator:

the interferogram is filtered to remove global noise with an edge preserving Markovian filtering [9]; it is a low-level operator giving improved information;

- structure extraction operators:

specific operators have been developed dedicated to the extraction of objects structuring the urban landscape (roads [10], corner reflectors [8], isolated buildings extracted from shadow [11]).

Therefore, from the three initial images, six new inputs are now available. Their content is complementary with possible redundancy. It lets us hope that the redundancy will rather lead to a better identification of the important structures (such as corner reflectors, buildings or shadows).

B. Joined fusion in a Markovian framework

Starting from the six new inputs, our aim is to retrieve a height map and a classification with semantic classes. In some cases, only contextual information allows to retrieve the correct class of a pixel (for instance for close radiometric values in amplitude, unreliable phase, etc.). In this case, it would be necessary to define complex neighbourhoods (i.e. not only restricted to adjacent pixels). Therefore, both for efficiency and computational cost reasons, we propose to deal with regions of the image.

These regions are obtained in the following way: the edges of the new inputs given by the operators, are superimposed, since they are quantified images, either binary or classified, edge detection is obvious. They define a partition of the image; the height and class have to be estimated for each region of this partition.

Then to introduce contextual knowledge at the region scale, a Markovian model is proposed. The neighbourhood of a region is defined by adjacency relationship as in [12]. The associated graph is thus the Region Adjacency Graph (RAG): each node is a region, and two nodes are linked if the corresponding regions are adjacent. The best realization for the joined field (H, L) is searched for.

The observation field is divided into two parts: the filtered field $\bar{H}$ (scalar, corresponding to the filtered interferogram) and the detector and classification values D (vector). Using a Maximum A Posteriori (MAP) criterion, the goal is to find the realization of the joined field (H, L) that maximizes the conditional probability $P(H, L|\bar{H}, D)$. With Bayes equation:

$$P(H, L|\bar{H}, D) = kP(\bar{H}, D|H, L)P(L|H)P(H) \quad (1)$$

with k a constant.

It is possible to prove that the posterior field is Markovian and that the MAP configuration search is equivalent to the minimization of an energy [6]. The energy to be minimized divides into two terms: the likelihood term (related to the observations) and the regularization term (introducing the contextual constraints). Some parts of these terms are defined by the user; this is a semi-automatic process. The optimization is conducted by an ICM algorithm.

C. Improvement step

Even if the classification and the DSM obtained from the merging step are accurate, it remains some errors that can be easily corrected. It is achieved by computing a shadow and layover map from the projection of the estimated DSM. The comparison of this map with the classification underlines wrong building edges (for instance when layover begins in the middle of the roof instead of at the beginning) or forgotten trees (when a grass region induces a shadow). It enables to clarify some confusion in the classification. In parallel, the height of tree regions is corrected: on such part, we do not expect a unique value but several. The values in DSM are replaced by the filtered height values obtained in the first step.

III. Analysis of Results

A. Overview of the results

The reconstruction process has been conducted on a large data take of RAMSES[1] X-band images at high resolution. The images are over Dunkerque, north of France. Two extracts have been chosen to represent all the diversity of urban architecture: one is a residential district (Bayard) and the other one is an industrial area (Fig. 1 and 2). The same parameters have been used to process both areas.

The results present the evolution of the classification and the MNS through the entire process. Visually, the global improvement cannot be denied. Unfortunately a qualitative analysis is hard to drive here as we do not have enough sensor parameters to assure a precise ground projection and to compare widely with ground truth. The precision validation is thus done visually and manually on some buildings.

First of all, the global classification matches well reality. The main confusions occur between the building and tree classes, mostly in the industrial part where no tree are expected. Moreover the spatial resolution is too low to preserve good results on small houses.

B. Analysis on some examples

1) Height accuracy: An IGN[2] BDTopo© which gives building footprint with mean height, is available on Dunkerque. We manually compare the mean height values of roofs in the BDTopo and in the estimated DSM (Fig. 3). The comparison proves that the estimated heights are very close to the real ones. The standard deviation error is approximately equal to 2.5 meters.

The interferogram noise and the ambiguity altitude are such that the height precision is equal to the theoretical standard deviation error. We cannot expect best results on the considered buildings.

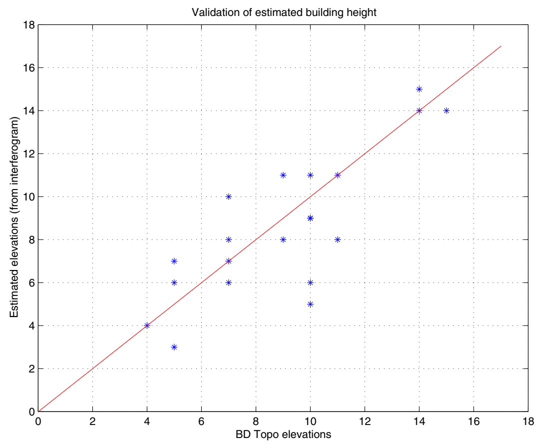


Fig. 3. Comparison of building mean height estimated from interferogram with building mean height of IGN BD Topo© over some buildings of Bayard district.

2) Some precise examples: A close analysis of the DSM proves all the potential of interferometry. Two examples have been picked up to illustrate this paragraph: the first one is a roof of the industrial area (Fig. 4) and the second one is the height estimation over a large building of the Bayard district (Fig. 5).

In the first case, the details of the roof are clearly visible: interferometry enables to have all the roof structure when resolution is high enough.

The second case proves the height accuracy that can be reached when enough samples are available. The central part of this major building of the Bayard district is above ground (first floor altitude). The DSM relays this information.

C. Advantages and limits of interferometry over urban areas

The density of reconstructed pixels is high, despite the layover and shadow problems inherent to SAR images. Compared with radargrammetry, interferometry gives more information over the surfaces, with some details on roof structure. But

[1]French SAR sensor of ONERA

[2]French topographical institute

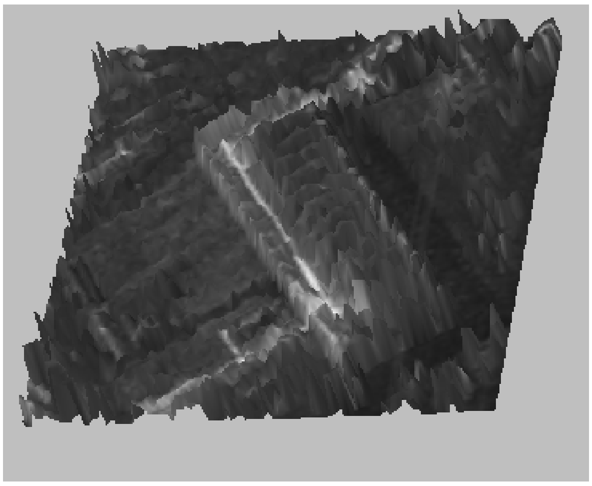
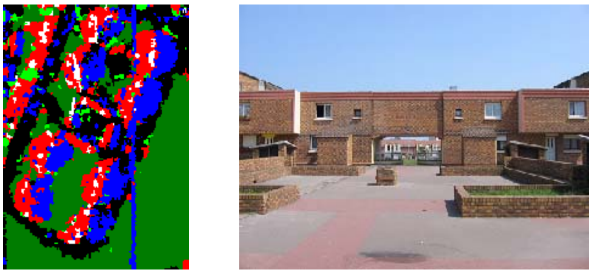


Fig. 4. Roof detail of the reconstructed industrial scene. The different arches of the roof are very well reconstructed from the interferogram.



(a) (b)

Fig. 5. Extract of the Bayard district: classification image (a) and optical image (b) taken from ground. The centre of this building is at the first floor of the surrounding (rectangular building). The reconstructed interferometric estimated height is 2.5 meters which is the expected value.

radargrammetry may bring more accurate results on the reconstructed pixels. The 3D estimation of the industrial scene has been tested also with radargrammetry [13]. The final result has a lower density of 3D points but is more accurate on large rectangular buildings. For instance, see the small buildings of the Bayard district on the top right part of the image : the DSM and the classification are very poor on this part.

The reconstruction is deeply linked with the quality of the initial images; spatial and altimetric resolutions are critical parameters to pretend to high precisions. The height is very accurate where the images are adapted to the building size, otherwise nothing can be deduced.

The complexity of the images prevent from getting a perfect classification. But this classification is deeply needed to well interpret the DSM. These two pieces of information are complementary.

Yet the retrieval of an accurate DSM from an interferogram requires an heavy set of process (semi-automatic only) and reaches limits on very complex architecture (metallic buildings with strong backscattering, complex architecture implying many shadows on roofs, etc.). To go a step further, it is necessary to introduce more information (another interferogram, an optical image or radargrammetry for instance)

IV. Conclusion

A new method of DSM computation from high resolution SAR interferogram has been presented. The paper is focused on the analysis of the results. They prove that interferometry can bring very accurate DSM over urban areas, even if it requires high level process. The tests include only one interferogram per scene, which lets us hope an improvement by fusing several interferograms. In the context of the future satellite high resolution missions, several data will be available on the same area. Thus the following of this work is to introduce more information to improve the results. For instance, one can imagine processing jointly several interferograms with several incidence angles, or an interferogram with radargrammetric images.

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