ISPRS Journal of Photogrammetry and Remote Sensing 114 (2016) 228–241

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Building detection and building parameter retrieval in InSAR phase images

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ARTICLE INFO

Article history:
Received 11 August 2015
Received in revised form 15 February 2016
Accepted 17 February 2016
Available online 4 March 2016

Keywords:
High-resolution spaceborne interferometry
InSAR phase images
Layover areas
Phase detector
Building detection
Building parameters

ABSTRACT

The high resolution provided by the current satellite SAR missions makes them an attractive solution for the detailed analysis of urban areas. Especially due to their weather and daylight independency, they can be employed when optical sensors come to their limits. Due to the specific oblique side-looking configuration of such SAR sensors, phenomena such as layover, double bounce and shadow appear at building location, which can be better understood with very high resolution (VHR) SAR data. The detection of those areas, as well as the retrieval of building parameters through a detailed analysis of the extracted structures, is a challenging task. Indeed, depending on the acquisition configuration, on building material and surroundings, those patterns are not always consistent in amplitude SAR images. They can be difficult to recognize and distinguish automatically. Considering InSAR phase images instead of amplitude images is very helpful for this task, as InSAR is more depending on the geometry. Therefore, in this paper, we focus on the detection and extraction of building layover in InSAR phase images. Two complementing detectors are proposed, and their results are combined, in order to provide reliable building hypotheses. Based on the extracted segments, further analysis is conducted. Especially, the number of connected facades is analyzed. Characteristically geometrical shapes are finally fitted for each facade to permit the determination of the final building parameters as length, width, and height. Results of this approach are shown for three different datasets, first in terms of correctness and completeness of the extraction, and second in terms of accuracy of the extracted building parameters. For the considered datasets, the completeness and correctness are of about 70% and 90%, respectively. Eliminating clear outliers, the determined parameters present an accuracy up to 4 m (length), 2 m (height) and 3° (orientation). In this article isolated, middle to high rise buildings with flat roof and rectangular shape are considered.

1. Introduction

Current spaceborne SAR missions such as TerraSAR-X, TanDEM-X and COSMO-Skymed permit to achieve a resolution of less than 1 m. Moreover, new modes and new sensors will provide even better resolutions in the very near future. For example, TerraSAR-X benefits from a new Staring Spotlight mode since 2013, allowing to achieve 0.25 m resolution in azimuth and 0.8 m in range (Mittermayer et al., 2014). Furthermore, the TerraSAR-X Next Generation mission should continue to provide and enhance very high resolution modes up to 0.25 m beyond 2025 (Janoth et al., 2014). With such data, urban areas can be analyzed in much more detail. Those areas are characterized by different kinds of objects (e.g. buildings, trees, roads), whose representations in the SAR image show specific image distortions such as layover or shadow, or overlap due to occlusion effects. Very high resolution (VHR) SAR data allow a detailed and local analysis of those effects and of their interaction, which is still not well understood. Besides, a local analysis allows the retrieval of the 3D information of single building, which is particularly interesting to serve city planning projects and disaster monitoring issues.

Among all SAR methods for retrieving relief and 3D information, SAR interferometry (InSAR) is very popular. The utilization of phase differences between two or more images taken in across track configuration allows a very precise height determination.

1.1. State-of-the-art

Two main trends can be observed in the context of building reconstruction by SAR interferometry. The first considers sparse

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http://dx.doi.org/10.1016/j.isprsjprs.2016.02.009
0924-2716/

reconstruction by analyzing a stack of interferograms. A very efficient and popular method therefore is Persistent Scatterer Interferometry (PSI), which consists in extracting stable points in a stack of several interferograms and retrieving their heights based on their phase values. After unwrapping and geocoding, scatter points belonging to multiple 3D structures are retrieved, permitting among others the recognition of building shapes (Gernhardt et al., 2012). Recently, tomographic approaches, using multiple SAR images acquired from slightly different looking angles, permitted to separate multiple scatterers situated in the same resolution cell (e.g. separation from ground and wall scatterers) (Zhu and Bamler, 2010). Fusion of PSI and TomoSAR methods allows to overcome the superposition problem of layover in most urban scenarios (Frey et al., 2014). Although those methods provide a very high geometric accuracy, they only allow a sparse reconstruction of the building facade, so that further processing is needed in order to retrieve all building parameters (Zhu and Shahzad, 2014). Besides, those methods usually require more than two acquisitions in order to detect PS points, which makes them unsuitable when rapid information is on demand.

The second trend concentrates more on the global appearance of buildings in InSAR data, trying to extract specific features that distinguish them from the surroundings. The determination of building parameters from the extracted features is then straightforward. Here, it has to be distinguished between multi-aspect and single-aspect InSAR data. In Bolter and Leberl (2000), four interferograms (from each building side) are acquired and processed. The building footprint is delimited on each side by the shadow, and elevation is retrieved by taking the maximum InSAR height of all four views. Coherence is used in order to distinguish buildings from other high objects. In Sörgel (2013), building primitives as edges and lines are extracted from the amplitude data and building hypotheses are made by fusion with connected component of the elevation data. Using multi-aspect data in order to suppress layover and shadow effects, this approach performs iteratively to retrieve the correct building shape. In Thiele (2014), primitives are extracted from amplitude and interferometric phase data and fused in the same geometry. Based on the created building hypotheses, InSAR phase signatures (layover and shadow) of buildings are simulated and compared to the corresponding real data in order to assess the extracted parameters. Those multi-aspect approaches have the advantage of using information from several sides of a building and allow a better elimination of trees and neighboring effects. However, the recognition of building features in single-aspect data is of paramount importance for each of these approaches. In addition, as for natural disaster management, only single-aspect is preferable, due to time pressure. In Dell'Acqua et al. (2001), the authors propose to detect nearby buildings with different elevation by a joint segmentation and region growing of amplitude and elevation data of a single-aspect image. A preprocessing taking into account the density of edge pixels using the elevation data is exploited in order to separate building candidates from the surrounding. This method performs well for the kind of buildings found in industrial areas, i.e. low rise and long flat roof, but shows limitations if applied on buildings with large layover. In Gamba et al. (2000), a similar segmentation is performed in the elevation data and combined with a plane fitting strategy for the ground and roof. It leads to underestimated building footprints, as layover areas and shadows are not considered. On the contrary, in Tison et al. (2004), the authors consider the shadow areas for detecting buildings. After the segmentation of the shadow areas in the amplitude image, the building footprint is estimated by considering both amplitude and interferometric phases, minimizing an energy function. This method performs well for isolated buildings, as the recognition of the shadow area could suffer from neighbor objects, which produce layover that overlap with the shadow. More recently, Wegner et al. (2009) proposed to extract double-bounce lines by detecting bright lines in the amplitude image and eliminating wrong extractions through analysis of the interferometric heights of the neighbor pixels.

Only very few authors consider layover areas in a single interferometric phase image. In Petit et al. (2000), the authors exploit the spectral shift between the interferometric image pair in order to separate the vertical signal from the horizontal signals. In Ferraioli (2010), edges are detected in the phase image at both layover borders. The method does not utilize the whole layover part, which could become critical if one edge is hidden from the surroundings. In Wegner et al. (2014), the authors propose an improvement of their method presented in Wegner et al. (2009). After the extraction of a double-bounce line in the amplitude image, a line is searched for in the phase image, which is parallel to the double-bounce line towards near range, and shows maximum phase values. A parallelogram is created consequently, connecting horizontally the extracted parallel lines. This method involves the extraction of double-bounce lines in the amplitude image, which are not always recognizable, and cannot rely only on the interferometric phase image. With the start in 2010 of the TanDEM-X mission, and the subsequent creation of the global DEM, new methods for building analysis have been developed, profiting of the single-pass, non time decorrelated, data (Zink et al., 2008). From the already created TanDEM DEM, some rough estimation of local building heights have been undertaken (Marconcini et al., 2014). In Guo and Zhu (2014), the authors propose first a segmentation of building layover candidates based on amplitude and coherence image, before determining their orientation using the fringe frequency of the interferometric phases. Mainly the amplitude image is used for layover detection and shape determination. This has the drawback of being sensitive to changes in building appearance due to incidence angle or material changes. In Rossi et al. (2014), a layover map is created by counting the occurrence of a single SAR pixel in several geocoded cells, using the phase discontinuity between master and slave image. The retrieval of the building parameters from the created map is not obvious though, as many areas overlap. Finally, in Zhang et al. (2015), a top down approach based on a generative building model is employed to reconstruct buildings. This approach fits a building hypothesis to a determined image patch by analyzing statistical properties (intensity, coherence and phase) inside regions of interest (layover, shadow, double-bounce) that are adapted iteratively using Monte-Carlo methods. This approach allows the complete building extraction considering all effects occurring at the building location, but it necessitates an approximate location of the building position.

Our approach proposes a bottom up method in order to detect buildings in whole images without any complementary information. It investigates the potential of using only the phase information for detecting and reconstructing buildings.

1.2. Motivation

This work focuses on the detection of middle to high rise buildings with flat roofs and rectangular shapes, which present a predominant layover area.

Fig. 1 shows different buildings in interferometric data of single-pass TanDEM-X, respectively repeat-pass TerraSAR-X. Considering the similar buildings of Paris, it is obvious that single-pass data suffer less from noise as repeat-pass data, as there is no time decorrelation. But some common characteristics can be observed. The overall building appearance (layover, double-bounce line, roof and shadow) in amplitude and phase SAR data has already been thoroughly explained in Thiele et al. (2007b,a) and is not recalled here. We will simply focus on their appearance