ISPRS Journal of Photogrammetry and Remote Sensing 117 (2016) 108–114

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

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

Improved Persistent Scatterer analysis using Amplitude Dispersion Index optimization of dual polarimetry data

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ARTICLE INFO

Article history:
Received 29 August 2015
Received in revised form 2 March 2016
Accepted 4 March 2016
Available online 19 April 2016

Keywords:
Polarimetric optimization
Persistent Scatterer candidate
PSInSAR
Amplitude Dispersion Index (ADI)

ABSTRACT

Time-series analysis of Synthetic Aperture Radar (SAR) data using the two techniques of Small BAseline Subset (SBAS) and Persistent Scatterer Interferometric SAR (PSInSAR) extends the capability of conventional interferometry technique for deformation monitoring and mitigating many of its limitations. Using dual/quad polarized data provides us with an additional source of information to improve further the capability of InSAR time-series analysis. In this paper we use dual-polarized data and combine the Amplitude Dispersion Index (ADI) optimization of pixels with phase stability criterion for PSInSAR analysis. ADI optimization is performed by using Simulated Annealing algorithm to increase the number of Persistent Scatterer Candidate (PSC). The phase stability of PSCs is then measured using their temporal coherence to select the final sets of pixels for deformation analysis. We evaluate the method for a dataset comprising of 17 dual polarization SAR data (HH/VV) acquired by TerraSAR-X data from July 2013 to January 2014 over a subsidence area in Iran and compare the effectiveness of the method for both agricultural and urban regions. The results reveal that using optimum scattering mechanism decreases the ADI values in urban and non-urban regions. As compared to single-pol data the use of optimized polarization increases initially the number of PSCs by about three times and improves the final PS density by about 50%, in particular in regions with high rate of deformation which suffer from losing phase stability over the time. The classification of PS pixels based on their optimum scattering mechanism revealed that the dominant scattering mechanism of the PS pixels in the urban area is double-bounce while for the non-urban regions (ground surfaces and farmlands) it is mostly single-bounce mechanism.

1. Introduction

Time-series analysis of SAR data using Differential Interferometric SAR (DInSAR) technique is a powerful geodetic method to map surface deformations with high spatial resolution (1–10 m) over large areas (swath width range of 5–400 km) (Massonnet et al., 1993; Carnec et al., 1996; Amelung et al., 1999; Lu et al., 2005; Li et al., 2008; Fornaro et al., 2009; Eineder et al., 2009; Motagh et al., 2010). Due to the presence of spatiotemporal decorrelations in the interferograms, it is not possible to use all pixels from the study area during InSAR processing (Zebker and Villasenor, 1992). In order to analyse the changes in the pattern of surface deformation in time and space, time-series analysis of Synthetic Aperture Radar, i.e., Small Baseline Subsets (SBAS) and Persistent Scatterer Interferometric SAR (PSInSAR) need to be applied. These approaches help us extend capabilities of InSAR technique by identifying and processing pixels for which the effect of the decorrelations are negligible (Ferretti et al., 2001; Mora et al., 2002; Hooper et al., 2007). These advanced techniques are being developed continuously to make them more efficient in dealing with different kinds of limitations and error sources in InSAR time-series processing (Sowter et al., 2013; Vajedian et al., 2015).

PSInSAR technique is an advanced InSAR method that analyses the phase stability of pixels in a stack of inteferograms and choose those pixels that remain stable over the whole period of SAR data acquisition. Such pixels are named as Permanent/Persistent Scatterers (PS) in the literature (Ferretti et al., 2001; Hooper et al., 2007). The first criterion to select stable pixels for PSInSAR analysis was based on the use of Amplitude Dispersion Index (ADI) on a stack of single-master interferograms (Ferretti et al., 2001; Hooper et al., 2007). The ADI considers pixels with lower values of variations in amplitude of SAR images as candidates for PS analysis, the so-called Persistent Scatterer Candidate (PSC). Therefore,

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http://dx.doi.org/10.1016/j.isprsjprs.2016.03.018

high mean coherence or low ADI values correspond to better quality of the phase.

With the recent development in SAR sensors such as ALOS, RadarSat-2, TerraSAR-X, it is possible now to acquire long time-series of SAR Data in multiple polarizations. Navarro-Sanchez et al., 2010, used standard ADI criterion (Ferretti et al., 2001) for the PS and tried to find a relationship between polarimetric SAR data and optimum scattering mechanism of pixels. Results showed that using multi-polarization data in PSInSAR method instead of single-pol data improves the capability of the technique and leads to detection of more PS pixels in deformation maps. The main goal of polarimetric optimization is searching the polarimetric space for the best scattering mechanism or optimum polarimetric channel that minimizes the decorrelations for each pixel. After projecting polarimetric data onto the optimum polarimetric channel a complex scattering coefficient is achieved, which is similar to conventional SAR data and therefore PSInSAR technique can be used for this reformed data set (Navarro-Sanchez et al., 2014). Analyzing the scattering mechanisms and the separation between urban and non-urban areas helps us to make a better sense of the improvement in these regions (Navarro-Sanchez and Lopez-Sanchez, 2012).

In this paper, we implemented the same concept used by (Navarro-Sanchez et al., 2010) for the Stanford Method for Persistent Scatterers (StaMPS) analysis presented in (Hooper et al., 2007), with the aim to improve its performance in detecting both PSC and PS pixels. In StaMPS approach, the candidate pixels are initially selected based on ADI with higher threshold value rather than standard PS technique of (Ferretti et al., 2001). Afterwards, the candidate pixels are tested for phase stability using a measure called temporal coherency. The improvement in this research is based on minimizing ADI criterion, by means of Simulated annealing method, for selecting PSC pixels in dual polarimetry X-band SAR data. The SAR scenes are then reproduced in optimized scattering mechanism before applying StaMPS method for PS analysis. The final deformation of the optimized pixels are compared with external GPS observations and against the deformation provided by HH and VV channel. Eventually, we distinguish physical characteristics of PS pixels and classify them based on their optimum scattering mechanisms. We test our method for a dataset of 17 dual polarization X-band SAR data (HH/VV) acquired by TerraSAR-X satellite between July 2013 and January 2014 over Tehran plain, Iran (Fig. 1). Tehran region is affected by high rate of subsidence due to over-extraction of ground water resources. The subsidence area in Tehran has affected both agricultural and urban regions (Motagh et al., 2008), which helps us assess the performance of our technique for different land uses. We will show that using PSInSAR in optimized polarization finds more number of PSC (Persistent Scatterer Candidates) and PS (Persistent Scatterer) pixels than conventional single-polarization PSInSAR method using HH or VV channel.

This paper is organized as follows. Section 2 briefly describes phase stability criteria used for PSC/PS selection. Application of polarimetric data in PSInSAR is described in Section 3, followed by formulating the Amplitude Dispersion Index optimization in Section 4. Section 5 devotes to our experimental study, and finally, conclusions are summarized in Section 6.

2. Phase stability criteria

By using PSInSAR technique it is possible to avoid many of the limitations of conventional DInSAR as it focuses on only analyzing certain pixels which behave like point scatters and remain correlated in time. A pixel is defined as PS, if the phase of the pixel is dominated by a stable scatterer. Ferretti et al., 2001 presented an index called Amplitude Dispersion Index (D_A) that can be employed as an estimation for the phase stability in scatterers with high values of SNR when the number of images is large (>30). In this method a low value of ADI, e.g. 0.4, is selected for the threshold and pixels with ADI value less than the threshold are candidate for PS. ADI is defined as:

$$D_A = \frac{\sigma_a}{\bar{a}} = \frac{\sqrt{\frac{\sum_{i=1}^{N}\left(|s_i| - \overline{|s|}\right)^2}{N}}}{\frac{1}{N}\sum_{i=1}^{N}|s_i|} \quad (1)$$

where σ_a stands for the standard deviation of amplitude, s is a complex value of a SLC pixel, $|s_i|$ is the amplitude of the pixel in the ith image, $\bar{a} = \overline{|s|}$ is the mean amplitude and N is the number of images.

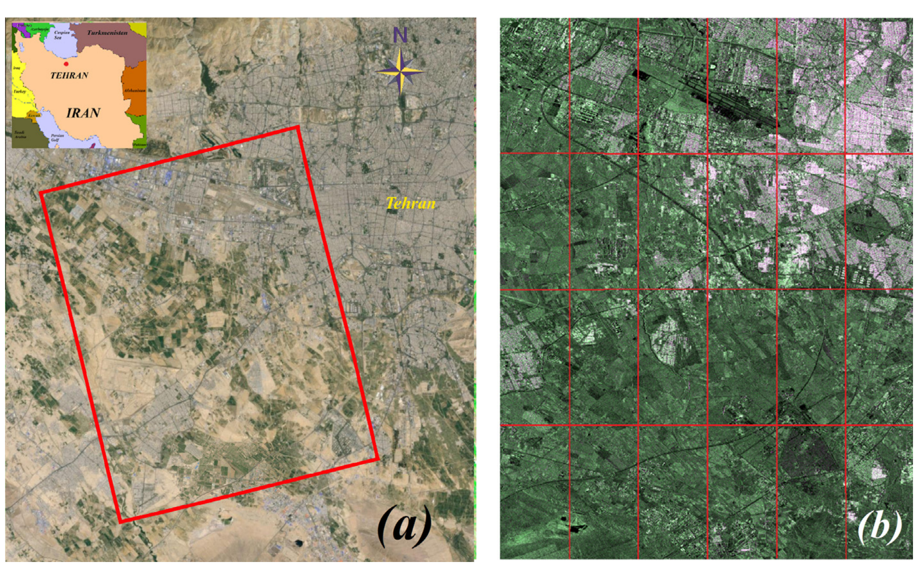

Fig. 1. (a) Landsat image of the study area in Tehran, Iran. The red rectangle shows the outline of the cropped TSX images used in this study. The inset in the upper left shows the location of Tehran in Iran. (b) RGB composite of the red rectangle in (a) made by mean amplitude image of dual-pol TSX data; red and blue channel correspond to amplitude of HH, and green channel to amplitude of VV. The grid lines marked by red indicate the patches that were used in the analysis (see Section 5). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)