HIGH RESOLUTION GROUND DEFORMATIONS MONITORING
BY COSMO-SKYMED PSP SAR INTERFEROMETRY:
ACCURACY ANALYSIS AND VALIDATION

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ABSTRACT

Synthetic aperture radar (SAR) interferometry is a powerful technology for detection and monitoring of slow terrain movements. Extraction of this information is a complex task. The persistent scatterer pair (PSP) approach was recently proposed to overcome limitations of standard persistent scatter interferometry. The PSP method exploits only the relative properties of neighboring points to avoid the problems caused by atmospheric and orbital artefacts in the signal. In this work, after resuming the main ideas of the PSP method, we describe the validation performed by comparing the PSP measurements obtained from Envisat and high resolution X-band COSMO-SkyMed data over Beijing with precise optical leveling data. The results confirm the validity of the PSP method and demonstrate that very accurate ground deformation measurements can be obtained from COSMO-SkyMed data.

1. INTRODUCTION

Synthetic aperture radar (SAR) interferometry is a powerful technology for measuring ground elevation and deformation due to landslides, subsidence, and volcanic or seismic phenomena. Extraction of this information is a complex task, because the phase of the signal is measured only modulo $2\pi$ and is affected by random noise and systematic disturbances. The permanent scatterer approach brought important advances in the solution of this problem [1].

The persistent scatterer pair (PSP) approach was recently proposed [2] for the identification of persistent scatterers (PS) in series of full resolution SAR images, and the retrieval of the corresponding terrain height and displacement velocity. Differently from standard techniques, the PSP method overcomes problems due to the presence of atmospheric and orbital artifacts in the signal by exploiting only the relative properties of neighboring points, both for identification and analysis of PS.

Moreover, the PSP approach is characterized by the exploitation of redundant information from pairs of points that are not only nearest neighbors, which makes for more reliability and accuracy of the solution. This redundant information is conveniently exploited by a recent method for robust phase unwrapping and finite difference integration [3], [4], which are key processing steps in the reconstruction of ground elevation and displacement from interferometric SAR data.

In this work, after analyzing the qualifying characteristics of the PSP method, we will describe the validation performed by comparing the PSP measurements obtained from Envisat and COSMO-SkyMed SAR images over Beijing with optical leveling data. The results confirm the validity of the PSP approach and demonstrate the dramatic improvement brought in ground displacement measurements by the high resolution X-band COSMO-SkyMed data with respect to low resolution C-band SAR data like the Envisat ones. In particular, not only the density of PS measurements increases, by two orders of magnitudes, but also the accuracy of PS measurements increases by about an order of magnitude. While the higher PS

![Figure 1: PSP mean velocities obtained from Envisat SAR images acquired over Beijing and surroundings, China.](image)
density is very important for monitoring of buildings and infrastructures, the higher accuracy of ground deformation measurements guaranteed by the high resolution X-band COSMO-SkyMed data allows observing smaller ground deformations and with a shorter observation time. In addition, the COSMO-SkyMed constellation can provide an unprecedented frequency of observations, which allows monitoring also faster movements.

In the following sections a summary of the method and of the validation results are given.

2. METHOD

The central idea of the persistent scatterer pair method is to both identify and analyze PS working only with pairs of points (“arcs”). This makes the methods insensitive to spatially correlated signals such as atmospheric or orbital artifacts, differently from standard persistent scatterer interferometry techniques where model-based interpolations of a preliminary set of measurements obtained by radiometric or low resolution analysis are used to try to remove these artifacts. Therefore, the PSP method is more robust to the density of the PS.

In order to promote a pair of points to be a PSP the multi-temporal coherence is a possible test. In general the test can take into account both amplitude and phase information, and measures the similarity of the statistics of the two points. By applying the arc test to a limited set of arcs connecting close (but not only nearest neighboring) points it is possible to identify the PSPs, i.e. arcs connecting pairs of PS. Working with pairs of points instead than with single points can obviously be very expensive computationally. The algorithm is designed in order to analyze the minimum number of arcs necessary to identify all PS.

After identification of all PS, the displacements and the 3D positions of the targets are obtained by integrating the differential estimates obtained corresponding to all the identified pairs (the PSPs). This set of arcs is highly redundant (not pairing only nearest neighboring points), which makes for a more reliable and accurate solution.
In fact, the arc redundancy can be conveniently exploited by a recently proposed method for robust phase unwrapping and finite difference integration [3], [4]. This method includes standard phase unwrapping techniques (e.g., minimum cost flow and least squares phase unwrapping) as special cases, but allows obtaining a robust and accurate solution by working with differences between not only nearest neighboring pixels. (The method also allows to exploit multitemporal, multi-frequency, multi-baseline and in general multi-dimensional information, and to integrate external information as from GPS if available).

3. VALIDATION

The PSP-IFSAR technology has been widely tested and used also for massive productions. We report here the results of a validation performed by comparing the PSP-IFSAR measurements obtained from Himage (stripmap) COSMO-SkyMed and Envisat SAR data with in situ optical leveling data over Beijing, China.

The low resolution (5 x 25 m²) Envisat result covered an area of about 100 x 100 km² including Beijing, China, and surroundings, while the high resolution (3 x 3 m²) COSMO-SkyMed result covered about 7 x 5 km² in a central area of Beijing. For the PSP processing 31 COSMO-SkyMed images acquired between 2008 and 2010, and 49 Envisat images acquired between 2003 and 2010 were used. The temporal span of the comparison analysis was from March 2009 to March 2010. Fig. 1 and Fig. 2 show the ground subsidence mean velocities determined by PSP analysis from Envisat and COSMO-SkyMed data. The area is affected by strong subsidence phenomena. The two sets of PSP-IFSAR ground displacement measurements are in good agreement (see Fig. 2 and Fig. 3).

The two sets of measurements were compared with precise optical leveling data relative to the same period. Two methods were used to analyze the PSP and leveling measurements: (1) point-to-point and (2) contour-level to contour-level comparisons. Fig. 4 and Fig. 5 show the differences between the contour levels obtained by PSP analysis of Envisat data and optical leveling.

The point-to-point validation analysis demonstrated an excellent agreement between the COSMO-SkyMed PSP-IFSAR results and optical leveling.

### Table 1: Comparison of subsidence measurements (March 2009-March 2010) obtained from optical leveling and COSMO-SkyMed PSP-IFSAR analysis over Beijing.

<table>
<thead>
<tr>
<th>Control point</th>
<th>Leveling (mm)</th>
<th>PSP (mm)</th>
<th>PSP-Leveling (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-3</td>
<td>-2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>-5</td>
<td>-3.4</td>
<td>1.6</td>
</tr>
<tr>
<td>3</td>
<td>-1</td>
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<tr>
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<td>5</td>
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<td>1.2</td>
</tr>
<tr>
<td>6</td>
<td>-7</td>
<td>-3.4</td>
<td>3.6</td>
</tr>
</tbody>
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measurements, with an average difference of about 1.2 mm and a standard deviation of about 1.9 mm (see Tab. 1). The average difference between the Envisat PSP-IFSAR measurements and the optical leveling data was about 6.5 mm, with a standard deviation of about 1 cm (see Fig. 8). The Envisat figures confirm the possibility of measuring mean velocities with accuracy of the order of millimeters per year over a time period of several years, as reported in the scientific literature. On the contrary, the performed analysis showed that the same accuracy on the mean velocities can be obtained with COSMO-SkyMed data already in a time span of a single year.

The much better results obtained with COSMO-SkyMed with respect to Envisat data in the performed validation are explained by the higher sensitivity to displacements of the interferometric phase, due to the shorter wavelength (X band vs. C band), and by the low level of noise and disturbances that characterize COSMO-SkyMed data.

Finally, the density of measurements found with COSMO-SkyMed stripmap SAR data in the performed test was of about 30,000 PS per square kilometer (200 times higher than that obtained with Envisat data (see Fig. 2)). Also, a very good (metric precision) reconstruction of the 3D position of the PS was obtained. These characteristics of the PSP COSMO-SkyMed measurements allow distinguishing different possible displacements of different parts of a building (see Fig. 6 and Fig. 7), which is essential for stability monitoring.

4. REFERENCES

