Persistent Scatterer localization and prediction technique

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Abstract:

Synthetic aperture radar (SAR) Persistent Scatterer Interferometry (PS-InSAR) is an extension of the Differential Interferometry (D-InSAR). Using a large data stack consisting of a time-series of SAR images of the same area, stable reflectors which persist over a long period of time, the so-called Persistent Scatterers (PS), are determined and the phase shifts of these PS over time are measured. In this way, temporal decorrelation caused by unstable targets can be avoided. The disturbances by the atmosphere are eliminated by assuming the atmospheric effects are uncorrelated in time but correlated in space. Using PS-InSAR, small movements in the line-of-sight of the sensor of each PS can be measured. PS-InSAR is a precise measurement technique and can measure deformations in the scale of millimetres per year. Using high-resolution SAR satellite systems, e.g. TerraSAR-X, a higher density of PS per square kilometre can be found, compared to PS-InSAR based on mid-resolution systems like ERS. In high-resolution SAR, each location of a PS can be determined more precisely and the higher spatial resolution allows the clear distinction of each PS. This allows us to differentiate between PS measured on building façades and PS on the ground. Based on 3D city models, the PS of each building can be determined. Knowing the location of each PS and adding topological information allows for a more precise and meaningful PS-InSAR analysis.

Keywords: SAR, PS-InSAR, simulation, data fusion

1. INTRODUCTION

The new high-resolution SAR systems already provide tremendous improvements for the generation of digital elevation models (DEM) from interferometric SAR (InSAR) and stereo radargrammetry. Subsidence measurements in urban areas using Persistent Scatterer Interferometry (PS-InSAR) [1],[2] benefit from the increased spatial resolution which allows the measurement of several persistent scatterers (PS) per building [3].

Using ERS data around 100-500 PS/km^2 can be found, whereas more than 30,000 PS/km^2 are found using TerraSAR-X [4]. This high density allows for a more precise PS-InSAR analysis, but also leads to more problems and questions. The spatial and logical relationship between the various PS becomes more relevant. The movement of PS residing on the same building is correlated and this information can be used to improve the PS-InSAR analysis.

Two important questions for the interpretation of the PS-InSAR results are:

- Where is the location of the PS on the building/ground?
- What is causing the PS?

Using 3D city models, the location of PS on a building model can be identified. In combination with façade textures, either acquired using terrestrial photogrammetry or by oblique aerial images, the cause of the PS can be identified, improving the scientific understanding and the PS-InSAR analysis.

In this paper we propose an approach for the combined analysis of PS points with 3D city models and oblique aerial images. In the next section PS-InSAR with high-resolution TerraSAR-X data stacks will be briefly described. In the third section, the approach of using oblique aerial images for the identification of PS on building façades will be demonstrated. Finally, conclusions are drawn.

2. HIGH-RESOLUTION PS-INSAR USING TERRASAR-X DATA STACKS

InSAR technique is based on the measurement of phase difference between complex radar signals, i.e. the range differences between sensor and target. Using the range difference and the orbital parameters of the sensor, the elevation of the illuminated surface can be derived. If the phase caused by terrain elevation can be removed from an interferogram, the targets movements in the line-of-sight direction can be obtained [5]. The main limitations of InSAR applications are the geometrical and temporal decorrelations. Even though the coherence of two radar signals is high enough, the atmospheric phase screen differences between SAR images still reduce the achievable accuracy. PS-InSAR overcomes these restrictions of conventional InSAR technique. PS-InSAR identifies certain natural point-like stable reflectors, i.e. persistent scatterer (PS), from long temporal series of interferometric SAR images. The coherence of these PS is good enough to obtain digital surface models (DSM) in sub-meter accuracy and millimetric terrain motion [6],[7].

An exemplary result of a PS analysis carried out with a data stack of ERS-1 and ERS-2 images showing the city of Stassfurt in the eastern part of Germany is shown in Figure 1.

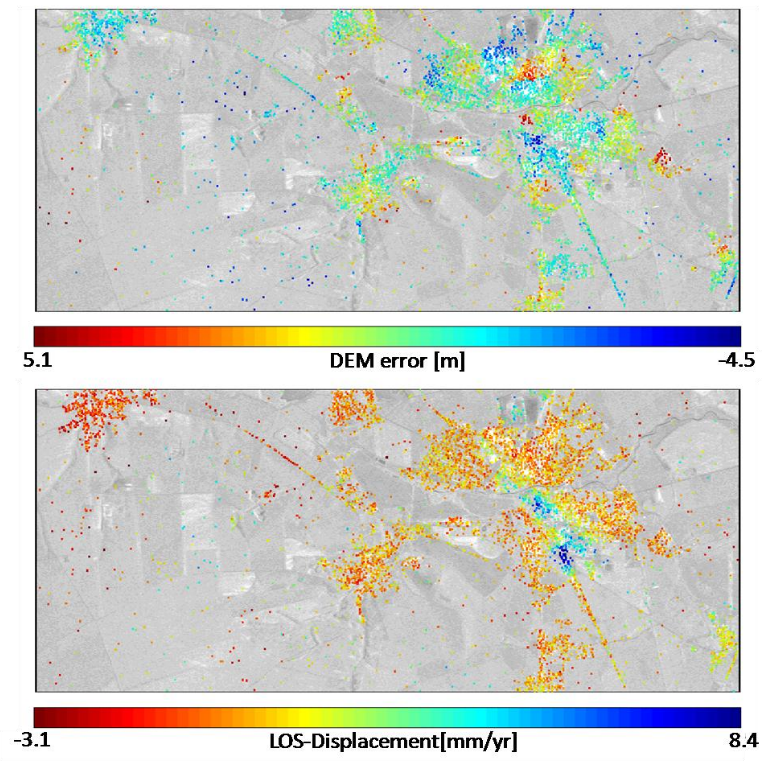

Figure 1: The results of a PS analysis using a stack of 43 ERS-1 and ERS-2 SAR images are displayed. The upper image shows the estimated PS height corrections, while the lower image depicts the estimated rates of deformation in the sensor's line of sight.

The estimated deformation trend in the lower image of Figure 1 clearly shows ground subsidence in the centre of the city. This result is in good agreement with reference data, i.e. a mined subsurface space is directly underneath the area of subsidence. The estimated DEM error map shows some interesting results. In Figure 2 the assignment of two groups of PS showing a strongly positive PS height correction are highlighted. These groups of PS can be assigned to particular real world structures, which substantiate the reasonableness of the results.

It is noteworthy, that just a (spatial) low pass component of the height correction is displayed. The high pass component contains a signal due to the deviation of the position of the PS from the pixel centre in range direction in addition to the high pass component of the PS height corrections [8].

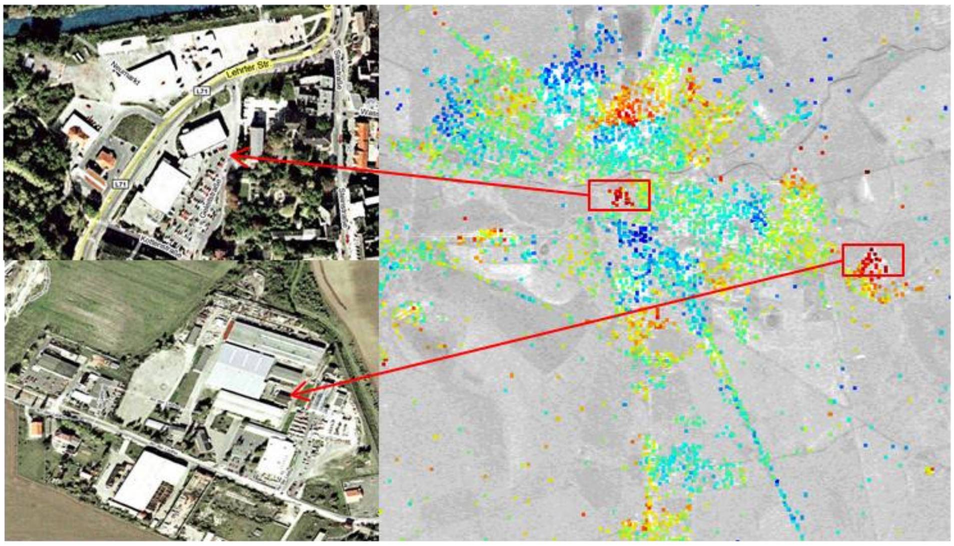

Figure 2: Estimated DEM error with two highlighted regions of maximal PS height corrections that can be associated with particular real world structures.

Using TerraSAR-X, a higher temporal and spatial resolution can be obtained. Within TerraSAR-X data, one PS per 2 m by 2 m can be found. Using ERS it is more likely to have one PS per 50 m by 50 m or 100 m by 100 m. A corner reflector forming a PS in ERS needs to have around 27 cm side length, but a corner reflector for a PS in a TerraSAR-X data stack only needs approximately 6 cm side length [9].

Trihedral corner reflectors with around 6 cm side lengths are common in urban areas, e.g. at building edges, windows, roof edges, balconies. Many PS can be found per building, allowing for the analysis of building deformations. For these analyses it is useful to group the PS in a meaningful way, for example to assume that PS residing on one building are related. This can improve the accuracy of the PS analyses.

Knowledge about the nature of each PS could further increase the PS-InSAR analysis and the interpretation of the measured deformations. For this purpose it is useful to identify the object/building each PS belongs to. Furthermore, the position on the building façade is to be determined. Afterwards, the position is to be identified in photos, either terrestrial photos or oblique aerial images and the location and the cause of the PS are to be identified. This approach is described in the next section.

3. IDENTIFYING PERSISTENT SCATTERERS IN OBLIQUE AERIAL IMAGES

SAR is a sensor system with an oblique viewing geometry [10]. While analyzing mid-resolution SAR systems with spatial resolutions of 10–25 meter this fact is less obvious. Working with high-resolution images, a true 3D analysis of the data is needed in order to fully understand the backscattering behaviour.

SAR systems and photogrammetric systems operate in different parts of the electromagnetic spectrum. The different systems offer a wide variety of spatial, temporal, and spectral resolutions. VIR images contain information about the multispectral reflectivity of a target, whereas SAR images contain information about the physical properties of the target, e.g. surface roughness and di-electricity.

The geometry of optical sensor systems differs strongly from SAR. For simplicity, we ignore push broom sensors, physical optics and lens issues. In this simplified case we can model a frame camera using the pinhole model. Hence, if a building is imaged in oblique view, its roof is at least partly mapped behind its footprint. Smaller objects or the ground behind the building are occluded.

The differences are shown in Figure 3 and Figure 4. In the SAR case, the roof point *C* is mapped in near range of the building in *C'*, between the points *A'* and *B'*, as shown in Figure 3. In Figure 4, showing the geometry of a frame camera, the roof is mapped behind the ground point *A* and the points are mapped to *A'*, *B'*, and *C'* in the right order.

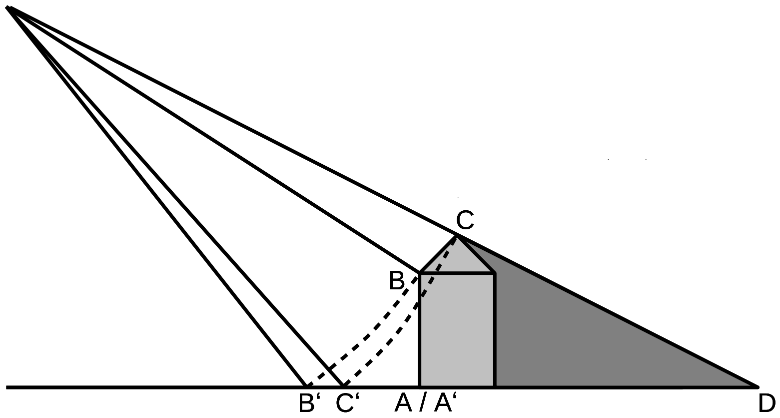

Figure 3: SAR geometry in range direction

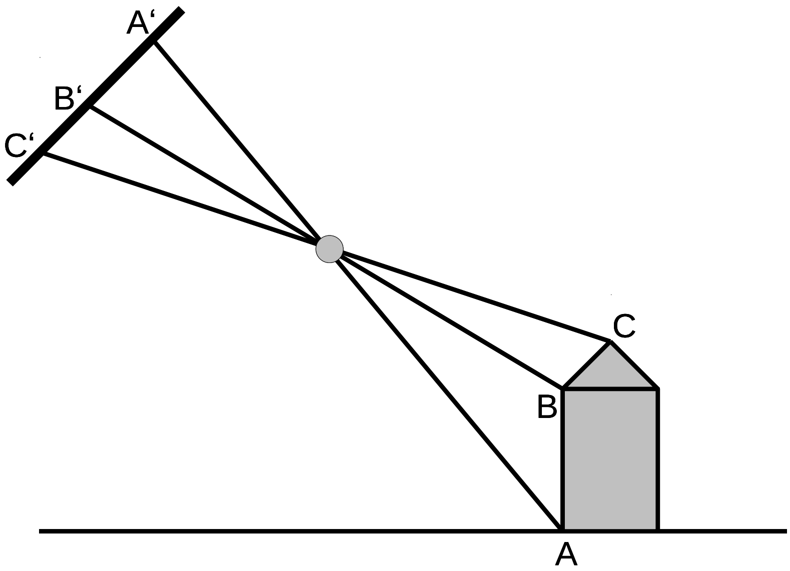

Figure 4: Geometry of a frame camera

PS can be identified in an oblique aerial image by using the geometrical properties of the SAR and the optical images. The PS position in the oblique aerial image can be identified based on the position of the PS in the SAR image. But, due to the different imaging geometries of the systems, it is possible, that the results are ambiguous. It is therefore advisable to base the positioning of the PS on 3D city or 3D world models, if they are available

In a first step, the identified PS are mapped to the 3D model using the known imaging geometry of the SAR image. Due to layover effects the position of a PS in 3D space is ambiguous. This fact can be seen in Figure 3, where point *B'* or *C'* in the radar image are a mixture of backscattering from the façade and the ground in front of the building.

However a decision about the position can be made based on the PS height information obtained during the processing of the interferometric data stack. The number of possible PS positions is governed by the complexity of the façade, the shape of the roof, and the resolution of the SAR images given the acquisition geometry. Assuming a very simple building model, i.e. plane walls and a flat roof, the distinction to be made is whether the PS resides of the ground, at the wall, or on the roof. This situation is depicted in Figure 5. A PS is mapped to the 3D model resulting in the three possible real world locations *A*, *B* and *C*. The decision about the PS position based on its height might be made if the difference in height dh_1 and dh_2 is at least bigger than the accuracy of the height estimate.

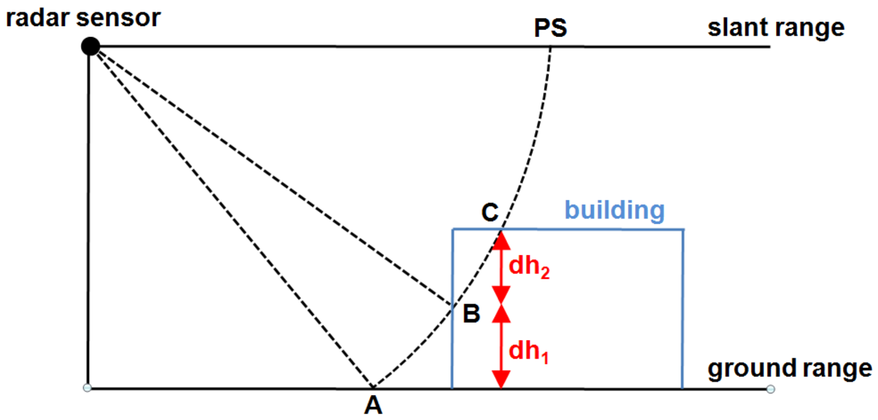

Figure 5: Schematic situation, when a PS is mapped to a 3D model. In this case the simplest possible building with plane walls and a flat roof is assumed for simplicity. The PS might be placed at the positions *A*, *B*, and *C*. If the height differences dh_1 and dh_2 are big enough it is possible to make a decision about the PS 3D location.

Figure 6: Data for a scene located in the city of Hannover (Germany). Image a) depicts a TerraSAR-X image acquired with an incidence angle of approximately 44°. Image b) shows the same scene in an oblique optical image gathered from a similar perspective. c) and d) illustrate typical facade structures of the buildings within the scene. e) is a view to an already textured 3D model of a similar area in Hannover.

In the second step the 3D model is textured using one or more oblique optical images. The façade textures are provided by linking the 3D object coordinates of the building models to the corresponding coordinates of the aerial image. The transformation from world coordinates to image coordinates can be calculated, as long as the exterior orientation and the camera parameters are available [11].

In Figure 6 the various data sources needed for the proposed processing are shown. It is obvious from the façade structures in parts c) and d), that the schematic in Figure 5 is not realistic. Balconies for instance might lead to an increased number of possible PS positions with a lower height difference. In this case the PS height estimation has to be more accurate, in order to decide for a 3D position with a certain confidence.

It is now conceivable to add a subsequent step comparing the PS positions with interest points identified in the optical image in order to remove erroneous assignments of PS to the façade. The extraction of the interest points in the optical image may at first be done with standard point detectors like the Foerstner operator [12] or by manually labelling regions in the optical image as being likely to result in PS in the radar data.

4. CONCLUSION

High-resolution PS-InSAR with TerraSAR-X data stacks offers unprecedented high-resolution and high-precision deformation measurements. This allows the identification of several PS points per building and even per building façade. Based on the precise position information and a 3D building model, the position can be identified in terrestrial photos or in oblique aerial photos. Based on this identification, more information about the PS can be obtained from the photo and the PS-InSAR analysis can be improved.

Using first results from high-resolution PS-InSAR analysis of Shanghai [13], we plan to demonstrate the approach using different test areas in Shanghai. We hope to improve the scientific understanding of PS-InSAR and the analysis result. We furthermore plan to classify and categorize the PS based on the classification of the optical images and their position in space. This will be used to improve the PS-InSAR accuracy and the interpretability of the PS-InSAR results.

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