

A THREE DIMENSIONAL DOMINANT SCATTERER MAP EXTENDS THE DEM INFORMATION IN URBAN AREAS

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ABSTRACT:

The generation of digital elevation models (DEMs) by space-born InSAR is a well-established remote sensing technique. Several application projects as for instance the shuttle radar topography mission (SRTM) have proven the outstanding capability to map the Earth's surface globally with great accuracy and constant resolution applying this technique. The short mission time of only eleven days guaranteed the homogenous quality of the generated DEM. The typical InSAR-DEM provides a snapshot of the terrain elevation at the time of acquisition including the vegetation cover. A limitation is that the Earth's cover is mapped only down to a mean radar penetration depth. Polarimetry can be applied to separate volume scattering from the double bounce effect on the ground in forested areas. But in urban areas this scattering model can not be applied.

This is in contrast to the great interest in urban areas caused by the high population density and change. Nowadays, the permanent scatterer interferometry which has been invented at POLIMI is working operational and can provide supplementing information. It allows a monitoring of urban areas over time spans of more than ten years. E.g. the subsidence in such spots can be detected and monitored with millimetre accuracy. The separation of the orbit, atmosphere and topography phase effects form the basis for the extreme accuracy regarding the displacement measurement. Furthermore, the PS estimation results in a high precision DEM update at the PS position.

The structure of the cities and the radar observation geometry are the reason that this simple elevation concept needs to be extended. It is very likely that more than one dominant scatterer is inside a resolution cell. Tomography can resolve this ambiguity and provides the reflectivity along cross slant range height. Consequently, a real but irregular sampled 3D map of the persistent radar scatterers can be generated which describes the city better. The dominant radar scatterers are related to buildings and other man made features. This is the reason the exact three-dimensional locations of the scatterers provide a lot of useful information on the area and the shape of the city and allowing various applications. Such a 3D map can be a better DEM input for each PS processing that allows an effective PS detection and optimal parameter estimation.

A new parametric method for the detection and relative estimation of the two dominant scatterers configuration inside of a resolution cell has been developed. The developed method is more robust because it uses amplitude data only and complements the full tomography which includes the phase information. The city of Munich is one of DLR's testsite for the PS processing and the developed tomography algorithms. Examples for the generated data set and applications will be shown. The permanent scatterers are assessed in situ and the 3D position of the scatterers is checked and compared to the estimates.

1. INTRODUCTION

The permanent scatterer (PS) technique invented at POLIMI (Ferretti et al., 1999) has meanwhile developed into an operational method to detect displacements on the Earth's surface with millimetre accuracy. But the improvement of the PS estimation algorithm is still subject of the actual work. The research aims therefore into the following two main directions:

- improvement of the displacement estimation accuracy and
- enhancement of the spatial resolution of the estimates.

Each of the two approaches can take advantage of the improvement of the other one. E.g. an increased spatial resolution allows to better model the underlying geo-physical displacement effect. This a-priori information can be added into the displacement estimation procedure and results dependently on the information quality in a more accurate and robust estimation.

The following sections present a parametric method for the detection and relative estimation of typical scatterer configurations inside a resolution cell. This newly developed method contributes independently to the two research approaches above. I.e. the PS-density increases due to the

advanced scatterer detection and in parallel the displacement estimation can be performed optimal according to the number of scatterers inside of a resolution cell. The outputs of the algorithm are

- the number of dominant scatterers inside the resolution cell (one or two scatterers) and
- a relative location to each other in cross slant range height.

The absolute 3D location of the detected distinct scatterers can be derived by a geocoding like post-processing utilising a DEM. For this reason, the DEM resolution and accuracy needs to be in the order of half a meter. Such a 3D scatterer map can replace the traditional DEM in the PSI-processing for ERS like sensors with a slant range resolution cell of about 10 x 4 meters.

2. PROBLEM DESCRIPTION

Detected permanent scatterers are usually considered single dominant scatterers only. This assumption is often valid but in urban areas the buildings have different heights and strong radar reflectors can be mounted at the front of buildings. Figure 1 visualizes that it is therefore very likely to have more than a

single PS inside a resolution cell and Figure 2 presents an example for three scatterers in the resolution cell. Such complicated scatterer configurations cause a simple PS detection and PS estimation to fail. It has been found that about 15 percent of the PSs in a test site are composed of more than a single scatterer (Adam et al., 2005). In order to use all available data and to switch to the appropriate frequency estimator which is used for the displacement and height update estimation these complicated scatterer configurations need to be detected. Only tomography resolves distinct scatterers in the cross slant range height (Homer et al., 1996; Fornaro et al., 2003). Unfortunately it is not applicable because it uses the baseline dependent range distance phase and requires therefore the correction of the atmospheric phase screen (APS) and displacement phase beforehand. The developed algorithm allows to cope with the typical resolution cell configurations and detects resolution cells which are composed of one or two scatterers.

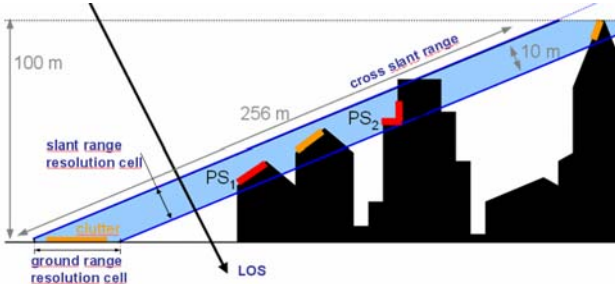


Figure 1: Buildings rise up to 100 m in a typical city resulting in a resolution cell with about 260 m length in cross slant range.



Figure 2: The 3D resolution cell is the volume inside the blue lines which run along cross slant range height. The red rectangle on ground is about 4 m x 30 m for the ERS sensor.

3. PROBLEM SOLUTION

The implemented algorithm uses the scene's amplitude only. Therefore, it can be applied already directly after the coregistration and radar return calibration of all scenes. The

processing takes place point-wise on a pre-selected set of PS candidates. The technique uses the baseline dependency of the radar return similar to the tomography. The power i_k of the radar data is modelled for the two practically most important scatterer configurations. A realistic single scatterer i.e. a panel made of metal with an extension Δ and an orientation φ can be described by

$$i_k = a^2 \cdot \left(\frac{\sin(B_k \cdot \Delta + \varphi)}{B_k \cdot \Delta + \varphi} \right)^2 \quad (1)$$

B_k corresponds to the height-to-phase conversion factor

$$B_k = \frac{4 \cdot \pi \cdot b_k}{\lambda \cdot R_0 \cdot \sin \theta_0} \quad (2)$$

b_k is the effective baseline of the k-th scene, R_0 is the slant range distance, λ is the radar wavelength and θ_0 corresponds to the look angle.

The alternative model describing two dominant point scatterers inside a resolution cell is

$$i_k = a_0^2 + a_1^2 + 2 \cdot a_0 \cdot a_1 \cdot \cos(B_k \cdot \Delta h + \varphi) \quad (3)$$

It results from the intensity of the sum of two complex sinusoids and describes a fading. It models the reflectivities a_0 and a_1 of the two scatterers, their distance Δh to each other in height and the orientation φ . Obviously, the absolute height of the two scatterers can not be estimated.

Because the intensity return measurement of a single scene can be incorrect caused by a misregistration, clutter, calibration inaccuracies or extraordinary weather conditions during the acquisition a robust non-linear model-fit has been developed. The Least Median Squares (LMS) is used in order to be robust equivalent to the well-known Median. Consequently, outliers are ignored and do not bias the estimation. The implemented LMS algorithm provides the parameters which correspond to the fit with the smallest band around it, typically including 70% up to 90% of the data. The amount of included measurements can be tuned with respect to the number of expected outliers. Even 40% outliers would be uncritical because four parameters need to be estimated only. In case 100 acquisitions are available the four parameters are determined from 60 measurements without inference of the incorrect ones.

Because the two scatterers model is described by four parameters compared to three parameters only in the realistic single scatterer case, it can be expected that the more complicated model always better describes the data. This kind of model selection problem is solved by the Bayesian theory. The decision for or against a model is based on the posterior

ratio (Sivia, 1996). It is composed of two factors. The first one includes the goodness-of-fit and the second factor weights this main factor regarding the respective model parameters ranges and the uncertainty permitted by the data for each of the unknown parameters. It is called the Ockham factor.

The amplitude-based parametric estimation of the two scatterers configuration provides a resolution better than a standard spectral estimation which includes the phase information. Two scatterers closely located up to one metre can be separated in fortunate cases. In case the scatterers are more than four meters apart the technique guarantees the detection of the two scatterers. The upper limit in the scatterer's distance is about 30 meters. The only price for the high resolution is the restricted parameter set provided by the models. But exactly this reduced number of parameters allows the robustness and the practical implementation of the algorithm.

4. THE MUNICH TESTSITE

The city of Munich is one of DLR's testsite for the PS processing and the developed tomography algorithms. Due to the close location the permanent scatterers are inspected and the 3D position of the scatterers is checked and compared to the estimates. The processed data stack is composed of nearly 90 ERS acquisitions and covers the time range from year 1992 to 2000. The testsite area is about 20 Km x 20 Km in extend and is characterized by a PS density of about 280 PS per Km². Figure 3 visualizes the PSI displacement estimation and shows that this region is not affected by significant displacements.

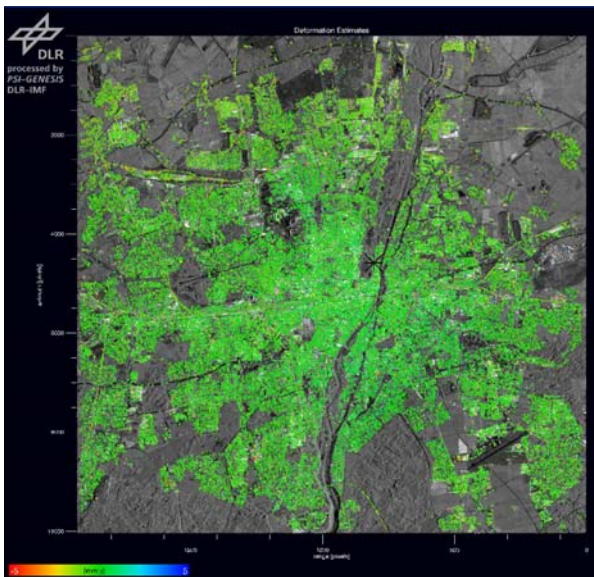


Figure 3: LOS displacement estimation from the PSI processing of the Munich testsite. The colour bar range corresponds to +/-5 mm per year displacement and the green colour indicates no displacement.

Only few permanent scatterers show non-linear motion. Exemplarily, Figure 4 reports the time series and the respective aerial and radar images of two scatterers with a periodic (one year) relative displacement of about 11 mm are shown in Figure 5 and Figure 6.

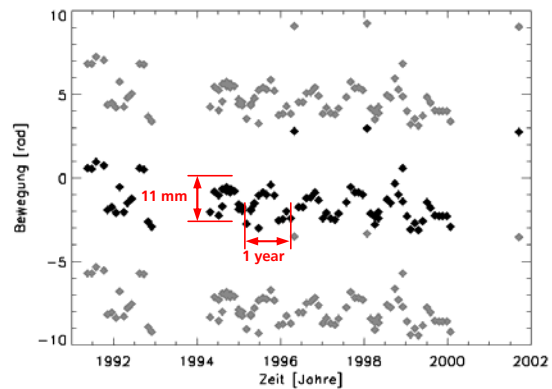


Figure 4: Measured time series of a non-linear displacement between two scatterers.



Figure 5: Aerial photo of the respective scatterers to Figure 4.

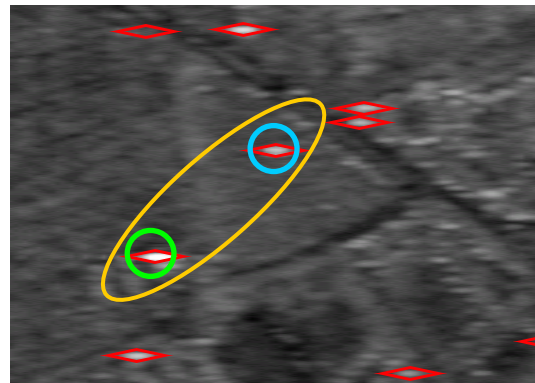


Figure 6: Radar intensity image of the respective scatterers to Figure 4.

About 15 percent of the detected PSs are found to be composed of two dominant scatterers inside the resolution cell applying the new parametric method. This number confirms the detected percentage on the PSIC4 testsite (Adam et al., 2005). Some of the detected PSs have been checked in situ and using aerial photos. One of the assessed scatterer configurations is reported exemplarily. Figure 7 and Figure 8 compare the parameter fits for the two resolution cell configuration models. The sinc-fit corresponds to a single realistic scatterer and the cos-fit to the two scatterers configuration.

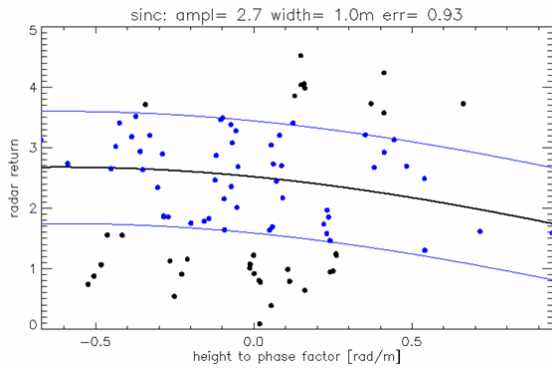


Figure 7: Sinc-fit of the parametric estimation example. It corresponds to a realistic single scatterer.

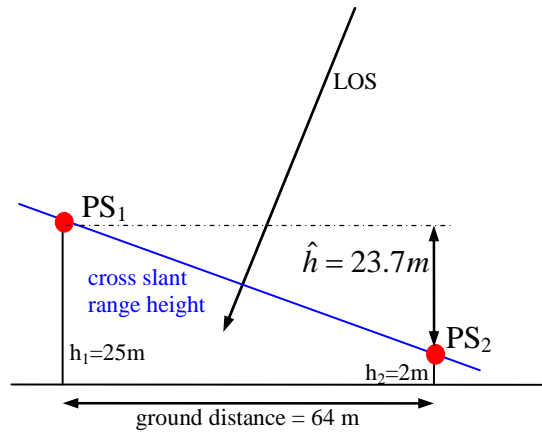


Figure 10 Side view of the observed scatterer configuration from Figure 9. The estimated height difference of about 24 m agrees with the in situ facts.

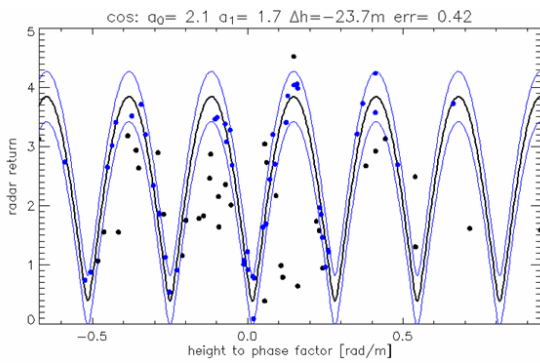


Figure 8: Cos-fit of the parametric estimation example. It corresponds to two scatterers inside a resolution cell. The estimated relative height is 23.7 m. Compared to Figure 7, the two scatterer model better describes the data.

Obviously, the two scatterers model better describes the data. Consequently, it can be assumed that this resolution cell is composed of two dominant scatterers. The estimated relative height difference between the two scatterers is 23.7 m. This geometric configuration has been confirmed by the aerial photo and the in situ scatterer positions which are shown in Figure 9 and Figure 10 in a top and side view.

From the local heights of the scatters a height difference of 23 m is expected. Figure 11 and Figure 12 present actual photos of the observed scatterers. The other assessed PSs confirm the two scatterer detection as well. Often one scatterer is located on top of a building and the other on the ground.

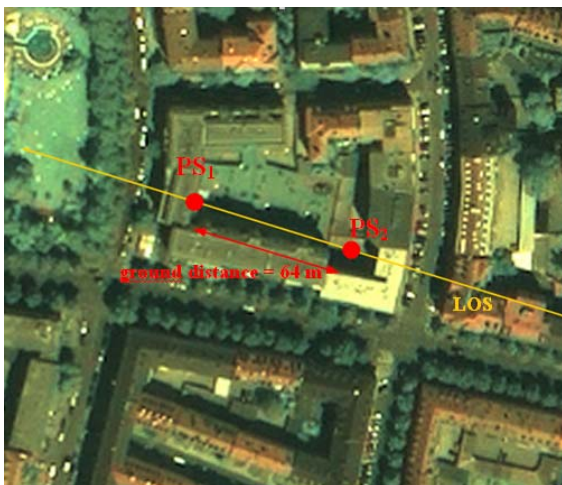


Figure 9 Aerial photo of the detected resolution cell with two scatterers from according to Figure 8 providing a top view of the two scatters inside the resolution cell.



Figure 11: Photo of the first of the two scatterers which are located in one and the same resolution cell. This building is the PS1 and has a height of about 25 m. Figure 12 describes the second scatterer.



Figure 12: Photo of the second of the two scatterers which are located in one and the same resolution cell. The roof made of metal is the PS2 and has a height of about 2 m. Both scatterers are separated by about 64 m in ground distance causing both to appear in one and the same resolution cell. The developed parametric algorithm is able to detect this sort of resolution cell and to estimate the height separation of about 24 m between the two scatterers.

5. CONCLUSIONS

A new parametric method for the detection and estimation of two scatterers inside a resolution cell has been presented. The method uses the amplitude data only and has therefore many advantages compared to the conventional tomography. The described technique is practically applicable for all operational PSI-systems. It needs to be implemented because 15 percent of the overall detected permanent scatterers can take advantage from this information. A simple estimation on these points will result in erroneous subsidence and height update estimates.

The technique has been validated on the Munich test site. Detected permanent scatterers composed of two scatterers inside the resolution cell have been visited in situ and the observation geometry has been checked. A very good agreement of the in situ facts to the estimated geometry has been found.

A 3D-scatterer map can be generated by an extended geolocation using a high resolution DEM. The extended geolocation transforms the relative scatterer location estimates into absolute positions of the scatterers. This irregular sampled 3D scatterer map is a new data set and can replace the conventional DEM. It is the more adequate input for the PSI processing because it allows an effective PS detection and optimal parameter estimation.

The described scatterer map is still very simple and is only valid for the processed track, look angle and polarization. But the principle can easily be extended using advanced techniques (Perissin et al., 2005) to estimate the radiation pattern of the scatterers and the scattering effects. This approach results in a 3D-reflectivity map which can be filled up and used by different sensors. The German sensor TerraSAR-X is best suited to generate such a data set because it provides acquisitions with a wide range of look angles (20 - 55 deg) in different polarizations with a resolution up to 1 x 1 meter in slant range.

6. REFERENCES

- Adam N., R. Bamler, M. Eineder, B. Kampes, 2005. "Parametric Estimation and Model Selection Based on Amplitude-Only Data in PS Interferometry". Proceedings of FRINGE 2005, Frascati, Italy, online
- Ferretti A., C. Prati, F. Rocca, 1999. "Permanent Scatterers in SAR Interferometry". IGARSS Proceeding 1999, Hamburg, Germany, pp. 1528-1530.
- Fornaro G., F. Serafino, F. Soldovieri, 2003. "Three Dimensional Focusing With Multipass SAR Data", TGARS, Vol. 41, pp. 507-517.
- Homer J., I. D Longstaff, and G. Callaghan, 1996. "High resolution 3-D SAR via multi-baseline interferometry", in Proc. IGARSS'96, Lincoln, pp. 796-798.
- Perissin D., A. Ferretti, C. Prati, 2005. "Spaceborn SAR Anatomy of a city". Proceedings of FRINGE 2005, Frascati, Italy, online.
- Sivia D. S., 1996. "Data Analysis: A Bayesian Tutorial", Clarendon (Oxford Univ. Press), Oxford.