Using a Production System for the Detection of Regular Patterns in Urban High Resolution SAR Datasets

Alexander Schunert and Uwe Soergel
Leibniz Universitaet Hannover, Institute of Photogrammetry and GeoInformation, Hannover, Germany;{schunert,soergel}@ipi.uni-hannover.de

Abstract. The high resolution of modern SAR satellite sensors leads to an enormous PS density resulting in a spatial grid, which is fine enough to sample typical regular urban structures at sub-building level such as windows and balconies. As those structures are often arranged in a grid-like setup, so are the PS sets as well. The resulting patterns contain various information about the geometrical setup of the PS set. For instance, horizontal rows of windows can be used to impose constraint on the estimated PS height. Vertical groups of windows can in turn be used to directly improve the geocoding by enforcing the same planimetric position for the grouped PS. In this work we focus on the identification of horizontal rows of PS. The employed methodology is purely rule based and utilizes simple building models (i.e. the building outline and the maximum height) to facilitate the grouping process. The obtained results indicate a good performance of the methodology for simple cases but quite incomplete outcomes in more complex settings. The application of the identified grouping information for the improvement of the estimated PS height is finally demonstrated by means of the alignment of the geocoded PS.

Keywords. SAR, Persistent Scatterer Interferometry, urban, grouping, TerraSAR-X.

1. Introduction

Persistent Scatterer Interferometry (PSI) is a technique to estimate both surface topography and deformation on a sparse grid of temporally stable radar targets using a stack of complex valued SAR images. Those stable scattering mechanisms referred to as Persistent Scatterers (PS) have to exhibit a phase noise sufficiently low to enable an extraction of the parameters of interest.

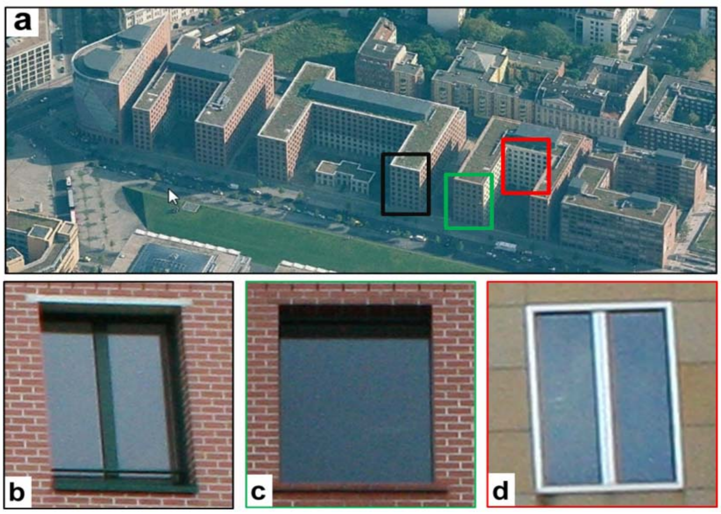

Figure 1: a) Oblique view aerial image of the building under investigation (© Microsoft® Bing™). The boxes mark areas, where the windows types shown in the close-up images b), c), and d) appear; b): Window type divided by a vertical and a horizontal structure. c): Plain window leading to the most point like amplitude patterns. d): Windows without a sill almost coplanar to façade. At those windows no PS could be detected.

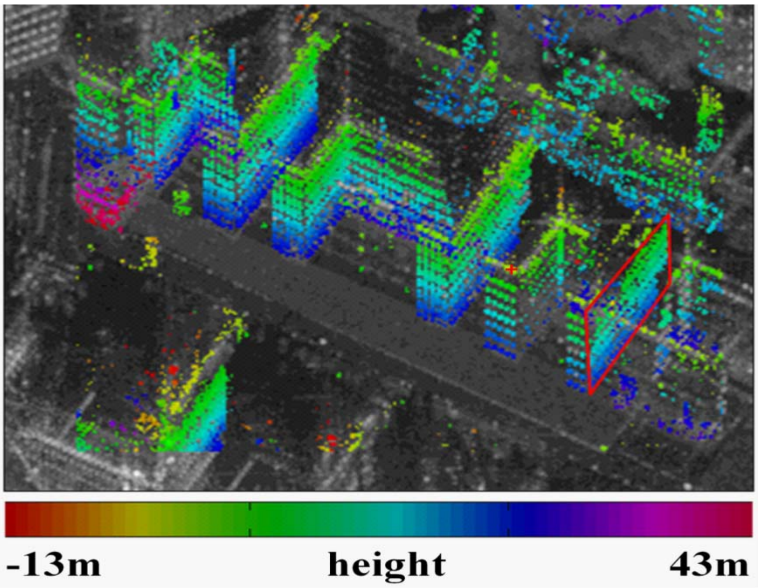

Figure 2: Result of a PS analysis for the considered test area. The color indicates the estimated PS height with respect to a reference point indicated by the red cross. The background image is the mean amplitude image of the used data stack. Points were selected if their temporal coherence is above 0.7.

In the majority of cases PS show high amplitude and are induced by man-made structures rendering PSI especially suitable for urban areas.

The achievable PS density essentially depends on the characteristics of the scene at hand (i.e. the number of stable and sufficiently strong scattering mechanisms) and on the spatial resolution of the SAR sensor. The latter factor is important for two reasons: first, a denser sampling of the scene at hand obviously allows identifying more PS and, secondly, a fairly strong scattering mechanism is more likely to dominate the signal of a smaller resolution cell.

In this work, a stack of 20 high resolution spotlight images acquired by the TerraSAR-X satellite covering the inner city area of Berlin is used. For this kind of data, featuring a resolution around one meter on the ground, enormous densities of up to 100,000 PS per square kilometer have been reported [5]. According to [1], a trihedral structure of 8cm side length may suffice to cause a PS.

Many façades host structures like windows and balconies and are thus often densely populated with PS. Since those structures are often arranged in a grid-like setup, the PS is as well. Information contained in the spatial arrangement of the PS with respect to each other is among others, interesting for two reasons. Firstly, information that some PS share the same height (horizontal groups) or the same planimetric position (vertical groups) can be used to improve their geolocation. Secondly, the grouping result may be used to iteratively improve the PS processing. One could think of a case where all but one PS of an actual group have been found. The reason for the rejection of the missing PS may be a noise level slightly above the chosen threshold. The following grouping step would give the information that a PS is likely to reside at this very position, which could in turn be used to check the phase stability of the corresponding pixel again using a slightly lowered threshold.

After a short description of the used datasets and the test site, the methodologies used for the PS processing and the grouping are outlined. Finally, results of the grouping process and its application for the improvement of the PS height estimates are presented.

2. Data set and test site

We used a stack of 20 high resolution spotlight images of Berlin for our investigation. All studies are focussed on a specific building exhibiting a regular setup. An oblique view aerial image of this building is shown in Figure 1a. The main feature is obviously the matrix like arrangement of the windows, leading to quite regular patterns of bright scatterers in the SAR image, which is displayed in Figure 2.

3. Persistent Scatterer

The PS processing scheme used in this work is mainly based on the ideas presented in [2], [6]. The objective is basically to identify a set of PS in a SAR image time-series taken from the same satellite track and then to estimate the potential motion in line of sight and the 3D position of each PS. In this paper, we focus on the 3D position and have accordingly chosen a test site without any surface deformation. The methodology is a two step procedure. Firstly, the atmosphere is estimated with a sparse network of very stable points. Secondly, after removal of the estimated atmosphere, a parameter estimation is conducted on a pixel by pixel basis using a periodogram approach [2], [3]. As a result, the height and the magnitude of the temporal coherence, which serves as a quality measure, are obtained for each pixel exhibiting a sufficiently high SNR.

4. Grouping of Persistent Scatterers

In this work we focus on the search of horizontal rows of PS using a production system. The employed strategy is purely data driven (i.e. a bottom-up approach) and implemented in a greedy fashion. Although subject to the SAR imaging properties (like layover) the whole grouping process is conducted in the slant range geometry. The alternative would be to search for groups in the geocoded PS set, which would be extremely difficult because of the insufficient positioning accuracy. In order to keep the production system as straightforward as possible, simple building models, comprising outline and maximum height, are used as prior knowledge.

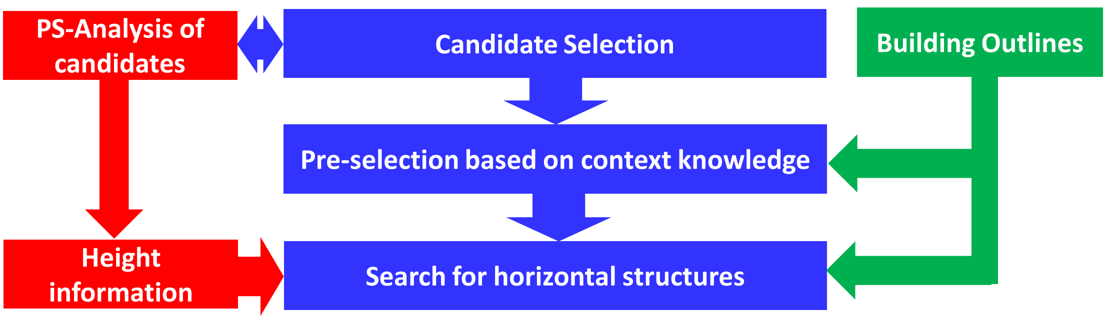

Figure 3: Workflow of the grouping procedure. The core grouping steps are depicted in blue. Red colour refers to the PS processing and green color depicts context information.

The outline determines the direction in which to search for horizontal rows and determines the search area for groups together with the maximum building height. Even though the need for prior knowledge hampers the general applicability of the outlined methodology, it can be quite easily generated from cadastral or even freely available datasets like Google Earth™. It is worth mentioning here, that other approaches may produce similar results without relying on prior knowledge. Another option would be to conduct a grouping in two dimensions (i.e. to search for lattices) as outlined in [7]. However, since the number of possible combinations grows tremendously by going from a one-dimensional problem to a two-dimensional one, an exhaustive search may not be possible leading to poor results. An overview over the grouping procedure is shown in Figure 3. The single steps are outlined in the following.

4.1. Candidate selection:

The first and very crucial step is the selection of candidates. Due to the sinc-shaped target response of SAR, signal coming from strong reflectors tends to propagate into adjacent resolution cells and masks clutter nearby. This can be seen from Figure 2, where clusters of PS rather than single points are visible. To find the actual PS position, the mean amplitude image is oversampled by a factor of 10 and examined for local amplitude maxima. The resulting points are processed as PS (a parameter estimation using the periodogram approach is conducted). All points having a sufficiently high temporal coherence (i.e. a value greater than 0.7) are selected for further investigation.

Finally, only those candidates, which are likely to be located on the façade of interest, are maintained. For that, the prior knowledge introduced above is used. The maximum building height and the outline determine begin and end of the considered area respectively.

Thereafter the set of PS located in one region is examined for regular patterns. An overview over the procedure is given in Figure 5. First of all, one of the PS is selected as starting point (called triggering PS). Subsequently a search area for a successor is defined, which is shown in green in

4.2. Assembly of lines:

The main grouping step is carried out along the direction defined by the building outline. Initially, a preliminary grouping is conducted to find subsets of PS possibly forming horizontal rows. For that, rhomboid shaped search areas are constructed beginning from the outline of the façade under investigation. The geometrical setup can be seen in Figure 4.

For the examined façade, the first region R_0 is constructed directly at the outline. All following regions are obtained by shifting R_0 in negative range direction leading to a gradual scan of the whole façade. The magnitude of the shift is chosen according to the typical floor spacing. The current region under examination in Figure 4 is R_i. The set of PS located within this region is checked for regular patterns, that is, a periodic appearance of PS. In order to not lose or split up any groups, the width of each region denoted with w is chosen to be bigger than the shift (i.e. the distance between two consecutive regions) leading to an overlap labeled with s. This may result in PS appearing in several groups, which has to be handled in a post processing step.

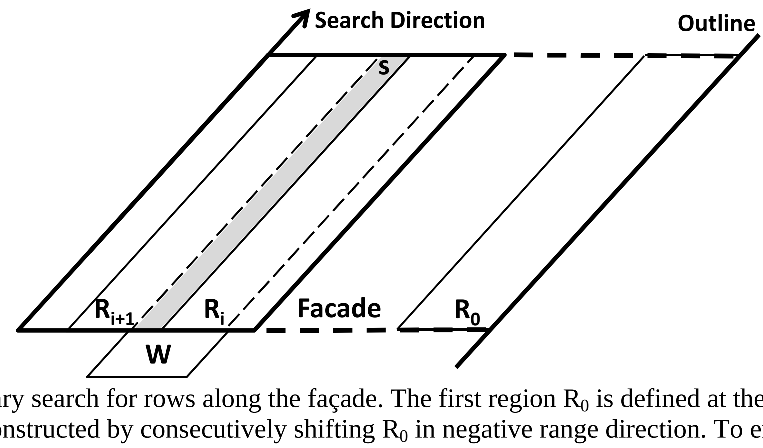

Figure 4: Preliminary search for rows along the façade. The first region R_0 is defined at the outline of the façade. The other rows are constructed by consecutively shifting R_0 in negative range direction. To ensure not to miss groups at the margins, the regions overlap.

The distance from the triggering PS to the search area depends on the expected spacing of the PS at the façade. In case a successor is found, its height is compared to the height of the triggering PS. If the modulus of the difference is below a threshold, the successor is added to the group. Checking the height is necessary to sort out points, which are not located at the façade of interest, but mapped to the same area in the slant range geometry of the SAR image due to layover [9].

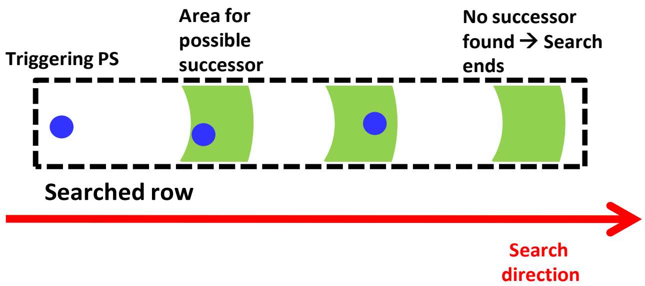

Figure 5: Illustration of the search process. Starting with a PS (triggering PS) a search area is defined. If a PS is found therein, it is added to the group and a new search area is defined. The process terminates if no successor is found.

This process is repeated until no valid successor is found anymore. The use of height, estimated in the PS processing, to facilitate the grouping process is indeed not unproblematic, since we wish to improve exactly this quantity using the results from pattern recognition. Fortunately the height difference between façade PS and those from other targets mapped to the same area in the SAR image is usually quite big. Consequently the threshold can be chosen to be quite relaxed (3 meters in this case) compared to the dispersion of the height estimates we seek to minimize. Since a pattern could be interrupted by a missing point or one PS could have been erroneously assigned to a group, but is actually the starting point of another pattern of slightly different frequency, every PS is checked as starting point once. Additionally, a predefined set of spatial frequencies are tested according to the typical horizontal spacing of windows. As mentioned above, PS may appear in several groups. In such case, a point is removed from all groups but from the one with the most members. Finally, groups with less than three PS are discarded in the current implementation of the approach.

5. Experimental results

The performance of the grouping procedure is evaluated for the test site shown in Figure 1a and Figure 2 respectively. In Figure 6, the selected candidates are shown as blue dots together with the used building outlines, which are indicated as red lines, overlaid to the mean amplitude image of the data stack. The looking direction of the sensor is bottom to top. At first glance, the quite different point distribution at the particular façades strikes the eye. While some façades show a strictly regular pattern, others exhibit a more cluttered point distribution. One of the façades even hosts hardly any PS. This obvious difference in the radar response is not understandable from the oblique view aerial image (Figure 1a), where all façades seem to share the same setup. The main reason for this very different point distribution seems to be mainly different window types at the different façades. In Figure 1b, 1c, and 1d the window type to be found are shown. Some of the corresponding façades are indicated by the coloured rectangles in Figure 1a. The windows lead to a characteristic return pattern in the SAR image. Windows of type 1c lead to a very sharp and localized return. This is presumably due to a trihedral reflection mechanism with its center located in the lower left or right (depending on the façades orientation) corner of the window. The very regular pattern at the corresponding façades is most likely due to the absence of other scattering mechanisms. Thus the grid-like appearance of the windows is directly transferred to the point pattern. The point pattern at façades comprising windows of type 1b is less regular. Firstly, a lot of points seem to be missing and, secondly, instead of having one row of PS per floor there seem to be two rows.

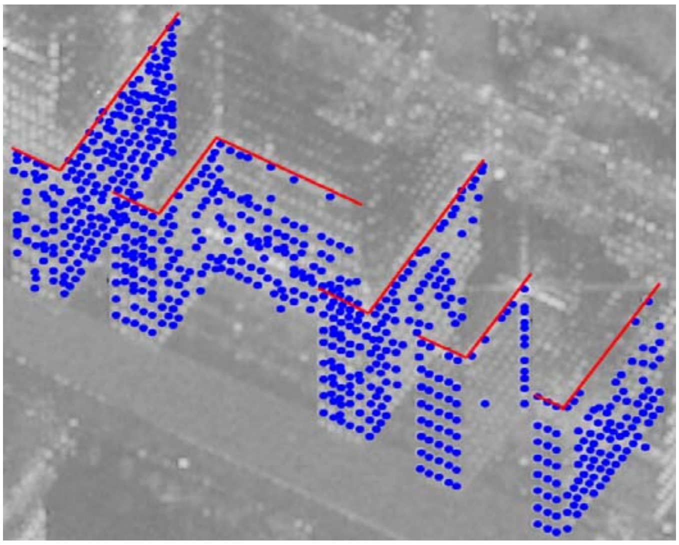

Figure 6: Selected base primitives (blue) and used building outlines (red) overlaid to the mean amplitude image of the data stack. The range direction of the sensor is bottom to top.

The latter observation may be explained by reflections at the vertical structure dividing each window. The large number of missing PS is, however, hard to elucidate. Possibly the involved reflection mechanisms are less strong or less stable compared to the ones generated by windows of type 1c. But certainly also random-like influences may lead to a loss of some PS. Supposing for instance a window is opened during some acquisitions and closed during all others. The expectable change of reflection may lead to a rejection of the point. Finally, façades with windows of type 1d host hardly any PS. As visible from Figure 1d the window is almost aligned with the façade and thus a corner reflector of sufficient size is not formed. Furthermore, the SAR specific imaging properties, especially layover, have to be kept in mind. Two strong reflectors, which are not even close to each other in the real world, may be mapped to the same position in the SAR image. In such case, both points are rejected since PSI can only deal with a single strong scatterer per resolution cell. An example for such a case can be seen at the center part of the building having a smaller building in front of it. In principle several scatterers sharing the same position in the SAR image can be resolved by tomographic techniques [4]. However, such approach is beyond the scope of this paper and will be addressed in future work.

The result of the grouping process on the basis of the outlined candidate selection is shown in Figure 6. The points, which were not assigned to any group, are shown as blue dots. Groups are indicated by lines connecting the dots. The colour (black over brown to red) codes the mean height of each group. The performance of the algorithm is quite good for façades exhibiting a clear and undisturbed pattern. However, it certainly deteriorates in cases where points are missing. This gets obvious from the group marked by the green rectangle. Two PS are missing in between, which leads to the identification of a pattern with a lower spatial frequency and an erroneous rejection of six points from the group. An extension of the production system could tackle problems like that quite easily, but is beyond the scope of this paper. As outlined in the beginning, grouping information can be used to improve the geocoding of the PS set due to the potential improvement of the estimated PS height. Considerations on the estimation of the group height from the single point results, determined within the PS processing, and the potential gain in precision can be found in [9].

Figure 8 shows a comparison of the geocoded point sets using the originally estimated PS heights (8a) on the one hand and the heights obtained for the groups (8b) on the other hand.

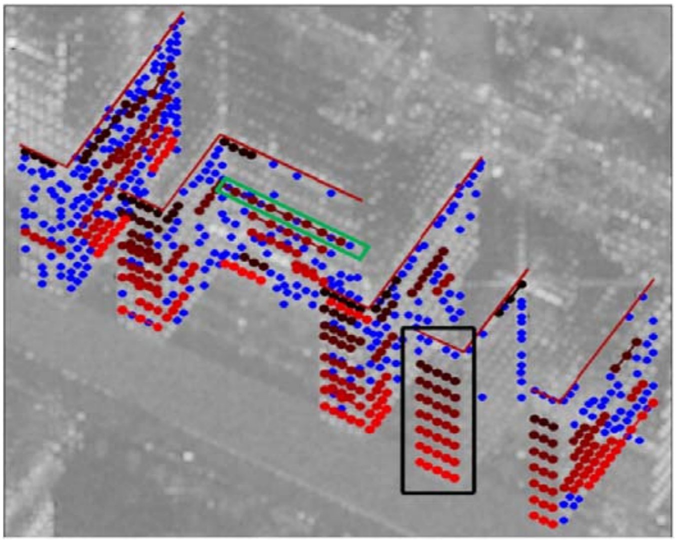

Figure 7: Result of the grouping algorithm. The selected PS are marked by dots, while the groups are indicated by lines connecting the dots. PS not been included in any group are shown in blue. Colors from black to light red indicate the mean height of the PS.

The result in Figure 7b certainly shows a way more regular appearance, which is expected since straight lines are enforced by the grouping and averaging procedure. However, also an alignment of the planimetric positions can be observed. One reason is that the height estimate is needed for geocoding by forward projection, which is done in the final step: the improved height value leads to a better positioning accuracy and eventually to a more uniform spacing.

6. Conclusions

A methodology was demonstrated to identify patterns in urban PS sets. The approach works quite well for simple cases: all points of a group have been found and the distance between consecutive PS is constant. In case some points of a group are missing or the pattern is more complex, the result will be incomplete. The former case occurs quite often in the presented results. As outlined before, the grouping procedure has to be adapted for such cases. As a byproduct one would obtain information that a PS is likely to reside at a certain position, which could in turn be used in a second iteration of the PS processing. The case of more complex patterns is, however, very hard to tackle due to the large number of possible combinations. Take for instance a residence comprising several flats per floor. At one façade one flat has a certain number of windows, which are not arranged equidistantly. The next flat at the same floor exhibits the same arrangement of windows and so does the next one etc. The resulting pattern is not periodic in the appearance of single points but in the appearance of groups of points. It is certainly very hard to tackle all cases with a rule based system due to the large number of combinations. In future work, we plan to switch from a rule-based framework to a probabilistic one such as Markov Random Fields or Conditional Random Fields. The latter method was already successfully applied for SAR image classification [10] and [8] used the former approach for a task very similar to ours, namely recognition of grid patterns in optical images. A very important point is the usage of the grouping information. Here, the improvement of the height estimation has been demonstrated, which in turn allows to better locate the PS in the real world. In future work we plan to use the grouping information also for data fusion.

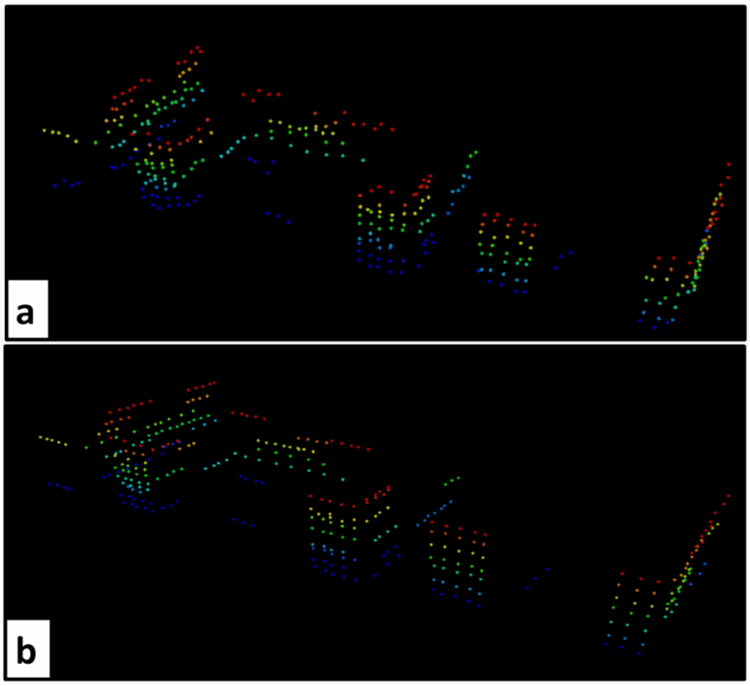

Figure 8: Geocoded PS using the originally estimated PS height (a) and the group mean (b) respectively. Since a height value is needed to determine the planimetric position of a PS, the grouping also improves the accuracy of the estimated PS position.

The main idea is to identify patterns in the PS sets and likewise in oblique view aerial images (Figure 1a). Using both results a mapping of the PS set to the optical data seems to be feasible. The result would be very helpful to investigate one of the main questions in PS processing. What are the physical entities leading to a PS?

References

[1] Bamler, R., Eineder, M., Adam, N. and Zhu, X., Gernhardt, S., 2009. Interferometric potential of high resolution spaceborne SAR. *Photogramm. Fernerkundung Geoinf 2009* (5), pp. 407-419.

[2] Ferretti, A., Prati, C. amd Rocca, F., 2000. Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, 38 (5), pp. 2202-2212.

[3] Ferretti, A., Prati, C. and Rocca, F., 2001. Permanent scatterers in SAR interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, 39 (1), pp. 8-20.

[4] Fornaro, G., Reale, D. and Serafino, F., 2009. Four-Dimensional SAR Imaging for Height Estimation and Monitoring of Single and Double Scatterers. *IEEE Transactions on Geoscience and Remote Sensing*, 47 (1), pp. 224-237.

[5] Gernhardt, S., Adam, N., Eineder, M. and Bamler, R., 2010. Potentials of very high resolution SAR for persistent scatterer interferometry in urban areas. *Annals of GIS*, 16 (2), pp. 103-111.

[6] Liu, G., Buckley, S. M., Ding, X., Chen, Q. and Luo, X., 2009. Estimating Spatiotemporal Ground Deformation With Improved Permanent-Scatterer Radar Interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, 47 (8), pp. 2762-2772.

[7] Michaelsen, E., Soergel, U. and Thoennessen, U., 2006. Perceptual grouping for automatic detection of man-made structures in high-resolution SAR data. *Pattern Recognition Letters*, 27 (4), pp. 218-225.

[8] Park, P., Brocklehurst, K., Collins, R. and Liu, Y., 2009. Deformed Lattice Detection in Real-World Images Using Mean-Shift Believe Propagation. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 31 (10), pp. 1804-1816.

[9] Schunert, A. and Soergel, U., 2012. Grouping of Persistent Scatterers in high-resolution SAR data of urban scenes, *ISPRS J. of Photogram. Remote Sensing*, (2012), in press, http://dx.doi.org/10.1016/j.isprsjprs.2012.04.002.

[10] Wegner, J. D., Hänsch, R., Thiele, A. and Soergel, U., 2011. Building Detection From One Orthophoto and High-Resolution InSAR Data Using Conditional Random Fields. *IEEE Journal of selected topics in applied Earth Observations and Remote Sensing*, 4 (1), pp. 83-91.