# PERCEPTUAL GROUPING FOR PERSISTENT SCATTERERS IN URBAN HIGH-RESOLUTION SAR IMAGES

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## ABSTRACT

Persistent Scatterer (PS) analysis of urban areas using high resolution SAR data is an important and by this time mature technique to estimate deformation and 3D information. Due to the high resolution a large number of PS is available per building. Beyond that the scatterers residing on one building often form patterns, which hold information about the relations between the PS. We present an approach to find horizontal rows of PS, utilizing some prior knowledge about the building under investigation. The found rows are then employed to facilitate the estimation of height information.

***Index Terms*—** PSI, Grouping

## 1. INTRODUCTION

Ever since the Persistent Scatterer Interferometry (PSI) was introduced in the late 1990s impressive results concerning the monitoring of surface deformation have been accomplished using this technique. Thereby PSI enables the estimation of movement and height for a set of radar targets exhibiting a stable backscattering behavior over time. These targets, referred to as PS, often coincide with salient bright point targets in the amplitude data. Within the modern high resolution SAR data sub-structures of buildings such as windows and balconies frequently induce these point targets, which often occur in regular patterns due to the preferred ordered and rectilinear setup of man-made objects. This regular structure can be exploited to group the point targets into meaningful gestalts. The obtained grouping information in turn can be particularly useful in a PS processing scheme. In this paper it is demonstrated how grouping may be used to facilitate height estimation. For that purpose rows of PS, which are likely to be horizontal in real world coordinates, are extracted from the SAR data. The grouping itself is essentially done with a one-dimensional search for a periodic PS pattern, where the search direction is given by prior knowledge, namely the building outlines projected into the SAR image geometry.

## 2. PS PROCESSING

The PS processing scheme used in this work is a rather standard approach mainly based on the ideas presented in [1], [4]. It is essentially a two-step procedure. In a first step the phase of every interferogram is calibrated for the atmospheric phase screen (APS). For that purpose a sparse network of very stable points is used. The phase of these seed points is first corrected for topography and linear motion. The obtained residual phase is subsequently unwrapped and high pass filtered in time. The result is taken as estimate of the atmospheric phase for every stable point per interferogram. In order to get a pixel-wise estimate of the APS, an interpolation is carried out.

In the second step height and velocity are estimated for every pixel using the calibrated interferometric phase. Here, the standard periodogram approach is chosen, which is also described in [1]. This yields height, velocity, and a quality measure, called inter image coherence, for every pixel. The latter describes the residuals between the assumed model (mainly the linear deformation model) and the data. While an inter image coherence value of one indicates perfect correlation between data and model, a value of zero shows complete incoherence. In order to avoid false positive PS and due to the fact that the height/velocity-estimates of pixels, exhibiting low inter image coherence, tend to be unreliable, all pixels having a quality measure below a threshold are discarded.

## 3. GROUPING

The grouping is conducted in a classical bottom-up and greedy manner. In a first step, primitive objects are selected. We just used the PS set identified in the previous step and applied a non-maximum suppression based on the inter-image coherence as selection criterion in order to focus on the best hypothesis only and neglect weaker ones close-by. This is done by sequentially adding PS to the set of base primitives starting with the one exhibiting the maximum quality measure. A PS is discarded if an already appended PS is closer than a certain threshold.

For the following steps we assume the existence of a simple geo-referenced building model – namely its 2D outline polygon on the ground and also its maximum height. Only elements of the polygon potentially visible to the SAR sensor are used. These lines are then utilized as context to foster the grouping of the PS.

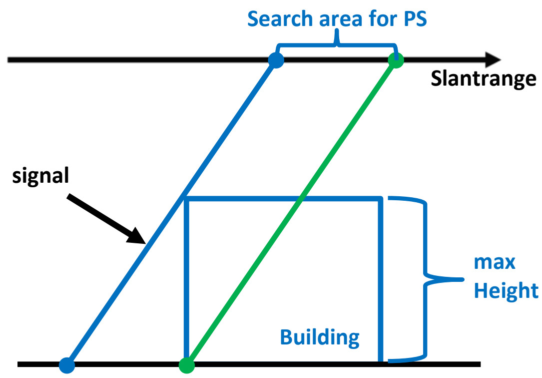


Fig. 1: Derivation of the search area for building PS shown as cross-section. The building is modeled by an outline and a maximum height

The PS belonging to the modeled facade are subsequently identified by considering just a subset of the scene, defined by the buildings outline parts projected to the SAR image and the maximum building height. A cross section of the setting is displayed in Fig. 1. The building outline projected to the SAR image determines the end of the search area (i.e., the furthermost point).
It should be mentioned, that by doing so, some points on the roof may be discarded. However, in this study we are just interested in investigating facade structures. The begin of the search area is in turn determined by the assumed maximum building height. Fig. 2 sketches the same situation as a top view. It is easy to see, that the search area for the PS is shifted in range direction if the outline of the building is rotated with respect to the flight path of the sensor. The second step of the proposed grouping algorithm aims at finding horizontal rows of PS.

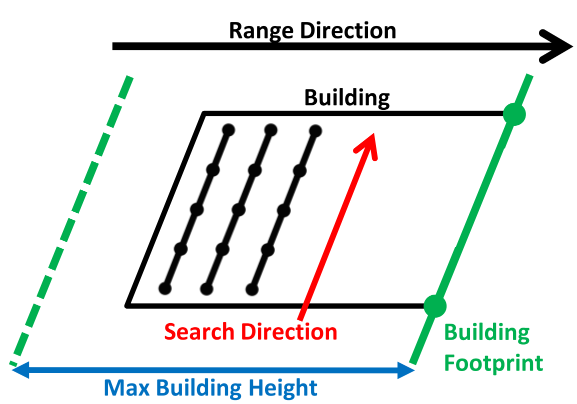


Fig. 2: Building model in the slant range geometry. The search direction is parallel to the building footprint.

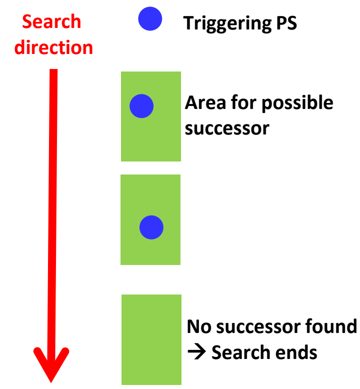


Fig. 3: Illustration of the search process. Starting with a PS (triggering PS) a search area is defined. If a PS is found therein, it is added to the group and a new search area is defined. The process terminates if no successor is found.

In contrast to the approach described in [3], which searches for regular patterns in two dimensions without introducing much prior knowledge, we propose a one-dimensional search here. The main advantage of this is a significant reduction in the number of admissible combinations, which makes it possible to reduce the computation time considerably and neglect many false possibilities. The one-dimensional grouping algorithm is now carried out for the area determined by the building outline and the assumed maximum building height. Every possible row is thereby examined for a periodic pattern of PS. The procedure is displayed in Fig. 3. First of all a PS is picked as starting point (called the triggering PS). For this PS an area is defined, which is searched for a possible successor.
The distance of the triggering PS to its center is the assumed spatial frequency of the pattern. The extension of the search area in both directions is done to cope with digitalization effects. If a PS is found, it is added to the group and a new search area is defined. The search ends in case no successor is found. Every PS is tested as triggering PS once. Since the frequency of the pattern is not known, several spatial frequencies are tested, which are common for urban window patterns. If a PS is contained in several groups with different frequencies just the longest group is kept, while the rest is discarded.

## 4. TEST AREA AND DATA

In this work a stack of 20 TerraSAR-X high resolution spotlight images of Berlin are used. The main test area is located close to the Potsdamer Platz. In Fig. 4 an oblique view aerial image of this area is shown. We focused our study on the building complex dominating Fig. 4. The reason for that can be seen in Fig. 5, which depicts the same area in the SAR data.

Fig. 4: Oblique view aerial image of the building under investigation (© Microsoft® BING™).

The height of the PS is shown color coded overlaid to the mean amplitude image of the data stack. It is easy to see, that the height changes in the direction perpendicular to the building outline, while the variation in the direction of the outline is small. Furthermore the PS form a regular pattern in both mentioned directions. Comparing the PS pattern in Fig. 5 to the facade structure visible in Fig. 4 a connection between windows and PS is immediately evident. In this study we concentrate on finding rows in the direction parallel to the building outline, where the height (see Fig. 5) exhibits just little changes.

## 5. RESULTS

In the first step PS are identified by setting a threshold on the inter image coherence of 0.8. Subsequently, the non-maximum suppression is applied in a 3x3 neighborhood to produce the set of primitive objects. The result is displayed in Fig. 5. The estimated PS height relative to a reference point located on the outline is shown color-coded. For the following PS selection based on the considerations depicted in Fig. 1 and Fig. 2 a maximum building height of approximately 30 meters is set. That will partly exclude the PS located on the left part of the building complex.

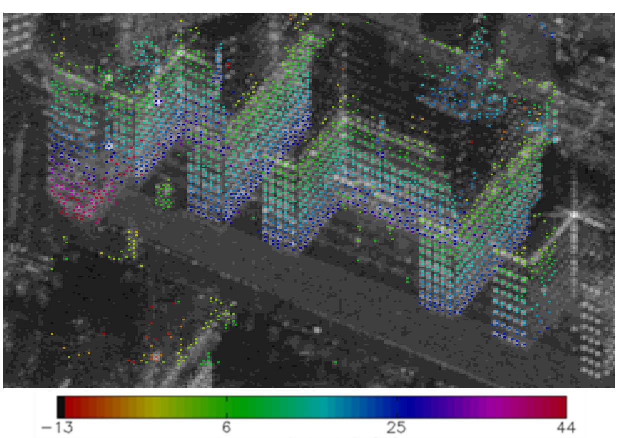


Fig. 5: PS set used in the grouping step. The height of the PS with respect to a reference PS is shown in color.

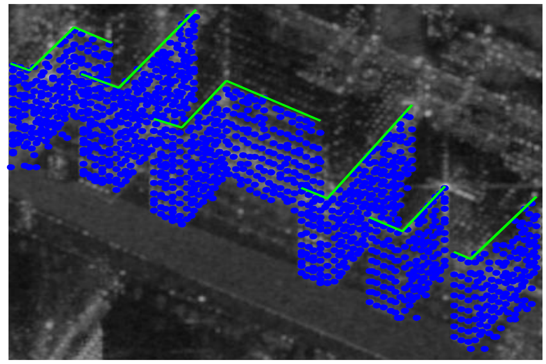

Fig. 6: PS set after pre-selection based on the outlines and the assumed maximal building height.

However, since this building is curved the proposed algorithm is not going to work properly anyway.The result of this step together with the used building outlines is shown in Fig. 6. For every part of the facade, the possible rows are now examined for periodic patterns of PS. Thereby a set of spatial frequencies ranging from 1.5 to 5 meters are tested. The extension of the search area is chosen to be one pixel in every direction. The result is displayed in Fig. 7. The groups are indicated by lines connecting the PS. The colors show the height difference within a group (i.e., the difference between maximum and minimum). While black stands for a value of almost zero, light red means approximately 20 meters. Most of the groups found by the algorithm show a small height difference. However, there are some, which exhibit quite large values. This is most likely due to the layover effect. Scattering contributions from different parts of the facade are mapped closely together in the SAR image. The pattern in the amplitude image is thus not caused by a real connected component in the 3d world, but rather result of the loss of one dimension by projection into the 2d range-azimuth grid.

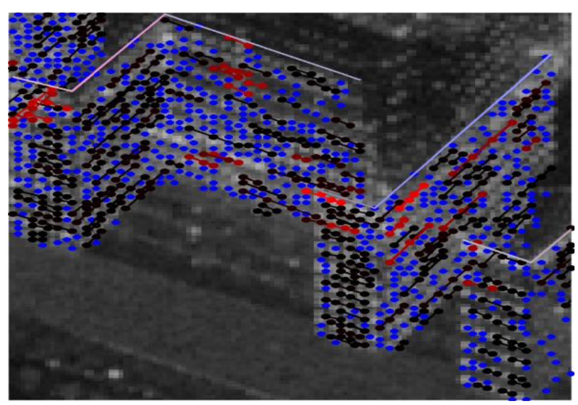

Fig. 7 Result of the grouping. The height is not used here. The color indicates the difference between the minimum and the maximum height within a group (black corresponds to approximately 0 meters, light red corresponds to approximately 20 meters).

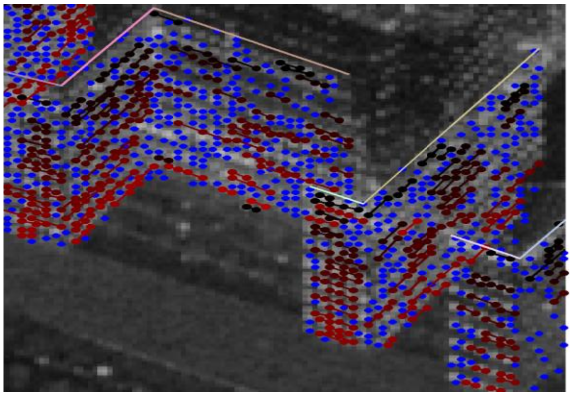

Fig. 8: Grouping results using height information. The mean height of the PS within a group is shown in color.

This underlines the necessity to consider height in the grouping step. In order to clean the result from those pseudo-patterns we introduced the height estimated in the PSI analysis as additional information. A PS is just added to a group if the height difference to the triggering PS is below a threshold (in this case 3 meters).The corresponding result is displayed in Fig. 8. The coloring indicates the mean height of the group. Considering the large facade in the center, lots of PS haven't been grouped at all. However, the frontage to the right shows quite complete results. This is due to the less regular distribution of points on the center facade, which is caused by the small building in front of the investigated frontage (as can be seen in Fig. 4). In order to examine that, we would need a real tomographic reconstruction (see for instance [2]) to check if there are pixels having two main scattering contributions (i.e., one from the facade and one from the small building in front). Our coherence maximization approach just preserves pixels dominated by a single scatterer. The obtained groups may be used to improve the height estimates of the PS. In the simplest case, this may be done by just taking the arithmetic mean of all height values within a group. To demonstrate the effect of this, Fig. 9 shows the geocoded PS, that have been assigned to a group during processing. On the left the results using the height originally estimated within the PS analysis are shown. The right side depicts the results including the grouping information. The height of a PS is thereby replaced by the mean height of the corresponding group. The effect of this is the enforcement of linear structures, which at first glance looks more correct. However, we have to investigate if the result shown on the right is geometrically more accurate than that on the left by comparing both to ground truth.

## 5. CONCLUSION

The results obtained for grouping and height estimation shown in Fig. 9 and Fig. 10 left seem to be promising. However, one problem is the lack of completeness. Most of

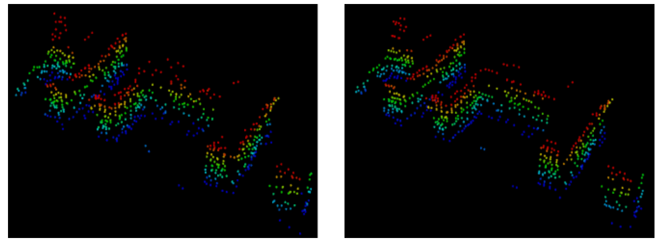

Fig. 9: Geocoded PS using originally estimated height of PS (left). Geocoded PS using the mean height of the group (right).

the found rows just consist of two or three PS. In order to achieve more complete results we need to advance the grouping algorithm to cope with missing points. We also have to reconsider the selection of base primitives regarding coherence threshold and non-maximum suppression. So far just the strongest scatterer in a certain neighborhood is included in the set of base primitives. The alternative - namely investigating all hypothesis - has to be evaluated.
Another important point is to fine-tune the threshold on the inter-image coherence, which was set to 0.8 for this study.
Finally the results shown in Fig. 10 have to be evaluated against ground truth, to assess the benefit of the proposed method regarding.


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