MATCHING OF PERSISTENT SCATTERERS TO BUILDINGS

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ABSTRACT

Persistent Scatterer Interferometry (PSI) aims at estimating the topography and deformation for a set of sufficiently stable radar targets, referred to as Persistent Scatterers (PS). Thereby, a stack of SAR images is exploited to distinguish between signal of interest and disturbances caused by, for instance, changes of the atmospheric conditions over time. The achievable sampling density mainly depends on the resolution of the employed sensor, and the characteristics of the scene at hand (i.e. the number of sufficiently stable reflectors). In case spaceborne SAR data of the highest resolution is used, very high PS densities, potentially enabling the mapping of structures at sub-building level, can be achieved. This offers a big and completely new range of possible applications. For instance, it is possible to monitor single buildings using PSI. But with this also new questions and challenges arise. Two of those would be: which buildings are sampled dense enough for monitoring purposes, and to which actual building structure does the PS correspond? In order to investigate those questions, the PS results are aligned with building outlines. This easily enables to map the PS density of buildings, which partly answers the first question. Admittedly, also the distribution of the PS and the shape of the building as well as its structure play a role. But a map of the PS density would be definitely helpful to assess which structures can be monitored adequately. The correspondence between actual building structures and PS is a good deal harder to answer. In this work, we attempt to improve the geocoding of the PS with the help of the GIS data, in view of the fact that this may be very helpful for the given task.

***Index Terms*—** Synthetic aperture radar, Radar interferometry, Urban areas

1. INTRODUCTION

The main idea of this work is to align the PS set with GIS data to, firstly, determine the coverage of buildings by PS and to, secondly, enhance the geocoding of the PS. Methods to realize the two mentioned applications are demonstrated for a test scene in the inner city area of Berlin. The PSI results have been obtained using a stack of 20 high resolution spotlight images acquired by the TerraSAR-X satellite. Identification of the PS and the following parameter estimation has been conducted using a standard method following the main ideas described in [1, 2]. More information about the actual PS processing can be found in [3]. The building outlines on the other hand are manually generated using Google Earth™ map data and contain only the outer boundaries of the buildings. Internal structures like inner yards are omitted in the current implementation. While this may cause problems for the fusion and especially for the improvement of the geocoding, it makes the generation of the map data and its handling significantly easier. Both, PS results and map data are displayed together in Figure 1 overlaid to a Google Earth™ map. The datasets are misaligned with respect to each other and their true positions. In order to align both datasets an Iterative Closest Point (ICP) procedure is employed. Once this is done the determination of the PS density per building and the refinement of the geocoding can be conducted. The former product is an important prerequisite for the operational applicability of PSI as a monitoring tool (i.e. to identify buildings which are not sufficiently covered by measurements). The latter would be very helpful to assign PS to the corresponding building structures. In the following, the alignment of the two datasets and the two described applications are outlined. Particular attention will be given to the question if the accuracy and the Level of Detail (LoD) of the map data is sufficient for both purposes.

Fig. 1. Geocoded PS before the application of the shift together with the building outlines overlaid to a Google Earth™ map

2. ALIGNMENT OF PS AND BUILDING OUTLINES

In order to jointly exploit PS results and building outlines the misalignment between both datasets has to be removed. The PS set could be systematically shifted from its actual position in elevation direction of the SAR sensor due an inappropriate choice of the reference point (see [4] for details). Additionally, the position of every PS is affected by errors resulting from inaccuracies in the determination of the PS height and pointing and positioning errors of the satellite. The outlines share all systematical errors present in the Google Earth™ map data and are of course deteriorated by digitization errors. In order to align both datasets the Iterative Closest Point (ICP) algorithm is used, which traces back to [5]. Here, the misalignment is modeled by a two dimensional shift only. Given two point sets $X = \{\vec{x}_i\}$ and $P = \{\vec{p}_i\}$, the following steps are iterated until a certain convergence criterion is met:

- For every $\vec{x}_i$ find the closest element $\vec{p}_j$
- Calculate transformation using the found pairs
- Apply the transformation

It is worthwhile to mention that the ICP as just described cannot be applied to the problem at hand. First of all, the map data is given as a set of polygons, which in turn consist of line segments. An appropriate definition of the distance reducing the problem to a point to point correspondence is given in [5]. A more critical point is, that the algorithm, as stated above, inherently assumes a one to one correspondence between elements in X and elements in P. This is certainly not the case here, since not every PS has a corresponding point in the map data. In order to cope with that, just PS which are located at facades, are used during the ICP procedure. At that, the separation between facade and non-facade PS is done with a filter similar to the one used in [4] to remove PS located at facades. It essentially checks if the height variance of all PS in a local neighborhood around the point under investigation exceeds a certain threshold. This is quite effective to filter out PS on building roofs and on the ground. However, it certainly does not remove PS at vertical structures inside the outline of the building like facades bounding interior courtyards. An investigation if the resulting blunders bias the registration result, is quite difficult due to the limited accuracy of the map data. A result of the alignment for a part of the scene is shown in Figure 2. The PS before application of the shift are shown in blue, while the shifted PS are displayed in green. The building outlines are indicated in red. It can be seen, that most of the linear arrangements of PS are aligned with the building outlines, implying a quite good match between both datasets. However, this does not hold true for the whole scene. In Figure 3 another part of the test site is shown. The PS marked by the black rectangles do not match the corresponding outlines very well. The two boxes encircle five groups of PS respectively, which show a linear arrangement. The PS in each group approximately share the same planimetric position. The visible dispersion of the positions along the line (actually corresponding to the LOS of the sensor projected to the xy-plane) can be explained by inaccuracies of the height estimates. Assuming the height error to be symmetrically distributed around zero, one would expect the outlines to be located roughly in the middle of every group. Since the offset at the center part of the building is less pronounced, it is reasonable to assume the geometry of this building to be inconsistent with itself. This is certainly to be expected since the digitization of the outlines uses the 3D models available in Google Earth™, which are not scrutinized. In the following two sections the aligned PS set is utilized for the two applications described above.

3. ASSIGNMENT OF PS TO BUILDINGS

An inventory of the number of PS per building is crucial for the operational application of PSI as a monitoring tool. The necessary assignment of PS to buildings can be easily achieved using the aligned datasets. For every PS the closest line segment in the map data is determined. Certainly some PS are not located on buildings contained in the map data. In order to cope with that, all PS assigned to a building have to be situated inside a region defined by the padded building outline. The size of the buffer around each outline usually ranges from one to two meters. The number of PS alone is admittedly not a good measure for the PS coverage since a big building potentially hosts more PS than a small one. For that reason the number of PS is normalized by the approximate volume of the building. In order to calculate this, a 3D model of the building is necessary, which is simply generated by assigning a mean height to every outline leading to a prismatic model. The result of the assignment and the density map are shown in Figure 4. The left side shows the assignment, which is indicated by the respective colors of the PS. On the right the resulting density map is shown. The color of the prismatic models codes the number of PS per 1000 m^3. The density is in general quite

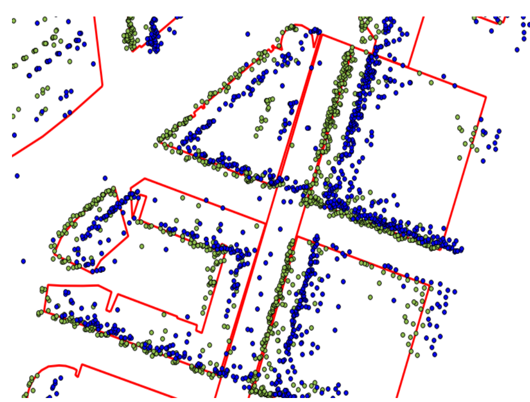

Fig. 2. PS before (blue) and after (green) application of the shift together with the building outlines (red). Both datasets are in good agreement

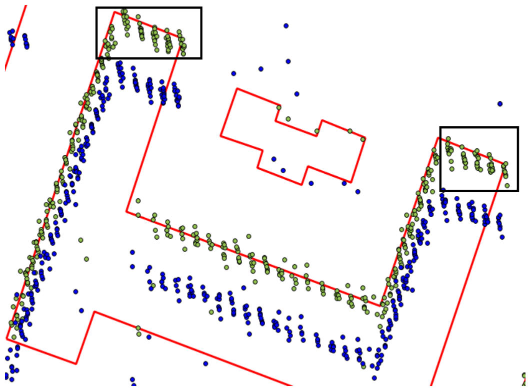

Fig. 3. PS before (blue) and after (green) application of the shift together with the building outlines (red). The datasets do not match very well

heterogeneous and depends strongly on the facade and roof structure of the building under investigation. Since PS are very likely to be induced by trihedral reflection mechanisms [6], facades and roofs featuring a plethora of small rectangular structures usually exhibit a quite high density. Additionally, the orientation of the building is an important factor. Buildings, having its main axis almost perpendicular to the LOS of the sensor, potentially host more PS. Finally, the PS density depends on random-like factors. A window, which would induce a PS under stable conditions, may be opened sometimes during the acquisition of an image, which could lead to the loss of the PS. Such a case is highlighted by the dashed box overlaid to the density map in Figure 4 on the right side. One part of the building features an average PS density, while the other part hosts almost none. In Figure 5 on the left side a closeup of the PS density map together with the PS assigned to the two building parts is shown. A corresponding oblique view aerial image (©MS-BingMaps) is displayed on the right side. In that, a scaffold is visible, suggesting that the reason for the highly different densities is ongoing construction work at one building part. In conclusion, the available outlines are sufficiently accurate to allow for an attribution of PS to buildings or building parts. Certainly, wrong assignments happen at the margin between two buildings, which are very close to each other. However, in most cases this error is negligible. With the shown result we get an information about complete buildings or at best major building parts. For a decision if a structure is covered adequately, a more detailed itemization may be necessary. For that, 3D models of the buildings could be used, enabling a mapping of PS to the bounding surfaces. The resulting map would give much more information about which parts of the building are covered sufficiently by measurements.

4. IMPROVING THE GEOCODING OF PS

As most of the PS are induced by structures at the facades, it seems rather natural to use a map of the building outlines, to improve their geocoding. The key idea is based on one assumption: the uncertainty of the PS positions is mainly due to errors in their height estimates. The effect of such an error would be a shift in the elevation direction of the sensor proportional to the height error. That has been already mentioned in Section 2 and can be nicely seen in Figure 3. In case this assumption holds and the outlines are sufficiently accurate, the position can be improved by mapping of the PS to the outlines along the LOS of the sensor projected to the xy-plane. In order to exclude non facade PS, just points which are close to a polygon edge, are considered. A result for two buildings is shown in Figure 6b. The original PS positions are illustrated in Figure 6a for comparison. The chosen buildings are especially suited for investigating the performance of the proposed method, since the PS appear in a very regular pattern along their facades (for more information see [3]). Comparing the original and the rectified positions an alignment regarding planimetry as well as height is obvious (i.e., a lattice-like setup becomes visible). The red and the green box highlight cases, where the problems of the method get obvious. From previous research [3] we know that the PS, situated in the red box, should be arranged exactly on a lattice (i.e. vertical groups having a constant horizontal distance to each other and horizontal groups exhibiting a constant vertical distance to each other). The most obvious deviation from that can be observed for the column on the very left being out of line regarding planimetry as well as height. But also the right four columns do not show perfectly straight and equidistantly spaced rows and columns. The PS in the green box are shown in close-up from a slightly different aspect in Figure 6c. Comparing the vertical position of the topmost row at the front and the lateral wall, a misalignment is nicely visible. The outlined shortcomings are due to errors in the map data already described in section 2. The misalignment in vertical direction is due to the fact that each PS is shifted to the associated outline along the elevation direction of the sensors (i.e. along a 3D line). This problem may be fixed in two ways: first of all, more accurate map data can be used, which is not available in most cases, or, secondly, the buildings outlines could be fitted to the PS data once the shift has been removed. This option is appealing, but would require a quite good discrimination between facade and non-facade PS. Finally, PS situated at roof structures, which are very close to an outline, are problematic. The resulting positions will be grossly incorrect. Obviously this problem may be solved by the use of 3D models.

5. CONCLUSIONS

An approach for the fusion of PS results with map data has been shown. Two applications based on the aligned dataset, namely the assignment of PS to buildings and the improvement of the geocoding have been outlined. While the former application is without any doubt possible with the available data, the latter would require more accurate map data or a refined

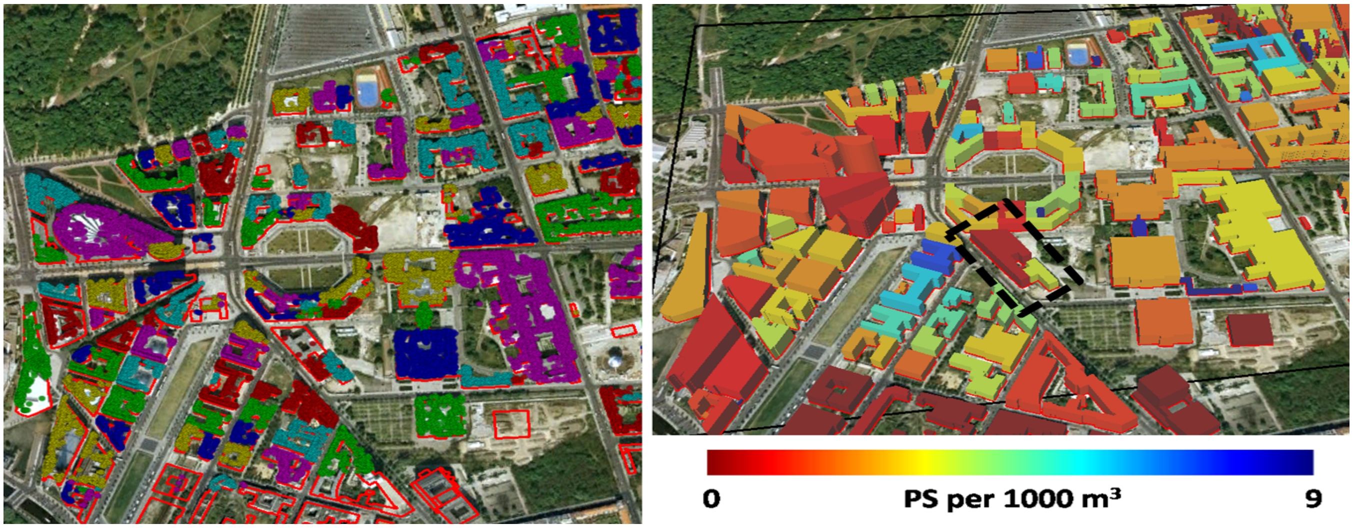

Fig. 4. Assignment of the PS to the building outlines (left) and the resulting PS density map (right)

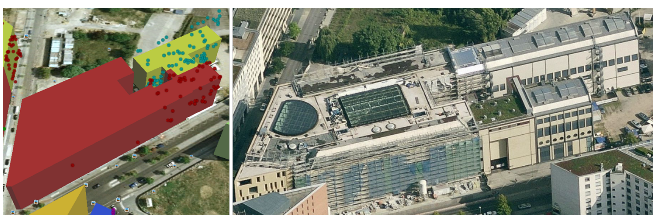

Fig. 5. Close up of the density map overlaid with the assigned PS (left). Corresponding oblique view aerial image (©MS-BingMaps) (right). The scaffold visible in the optical image indicates ongoing construction works leading to a loss of almost all PS for this part of the building

fusion method. The use of 3D data instead of just building outlines would finally enable to enrich the results of the first application and would solve some of the main problems of the second.

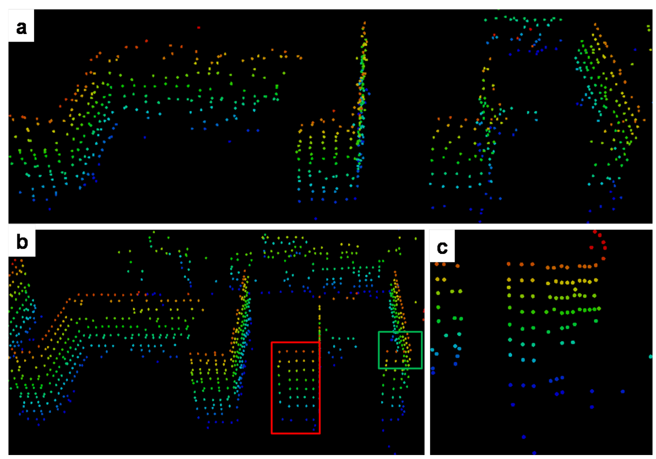

Fig. 6. (a) Original geocoding results. (b) Positions after mapping to the outlines.(c) Close-up of the area indicated by the green box shown b.

6. REFERENCES

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