Utilizing Phase for the Grouping of PS in Urban High-Resolution in-SAR-Images

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Abstract—**Persistent Scatterer (PS) analysis of high-resolution space-borne SAR images has become an important means for remote sensing in urban regions, since many PS result from building facades. This offers the opportunity to recognize building structures (e.g., number of floors) from such pattern. In this contribution an approach is proposed to group sets of PS according to Gestalt principles. Stacking data from multiple similar orbits not only yields repeatability and enhanced visibility of object features in amplitude data– but also interferometric phases as a clear hint for height above ground. Here we compare Gestalt grouping utilizing this additional attribute against neglecting it. The experiments indicate that the use of such phase clearly helps improving recognition and reducing search effort.**

I. Introduction

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. The PSI technique 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 point targets in the amplitude data. Since such bright point features may be generated by trihedral structures with an edge length of only 6 cm for the case of modern SAR data of the finest resolution [1], a very high density of PS in urban areas can usually be observed. Moreover these bright point-like features often appear in regular patterns caused by the setup of man-made structures. A good example for that are windows or balconies evenly distributed over a façade. However, these regularities have not been exploited in PSI so far. We propose to combine pattern recognition methods like production systems, which group a set of primitive objects to more complex objects by applying production rules constituting the available expert knowledge. Both grouping and PSI can benefit from each other. The grouping of PS could for instance be facilitated by the PS height or phase inferred by a standard PS algorithm. The PSI analysis on the other hand could benefit from grouping thus improving deformation and height estimates.

II. Persistent Scatterer Interferometry

The Persistent Scatterer Interferometry is an extension of the classical InSAR technique [1]. A stack of interferograms is used to estimate elevation and movement in line of sight of the sensor for a set of temporally stable radar targets. The restriction of the analysis to the PS tackles the problem of decorrelation, which is mainly caused by changes in the surface reflectivity. The use of a stack of interferograms enables the separation of the signal components of interest from disturbing contributions like the atmospheric phase delay caused by water vapor in the troposphere. The PS approach used in this analysis follows the main ideas outlined in [3], [6]. In order to separate the several phase contributions, one exploits their different correlation properties in space and time. While the deformation is usually modeled as a function of time, the phase contribution due to atmospheric delay is modeled as a low-pass component in space and a high-pass component in time. The estimation of the signal components of interest is then conducted by means of signal processing.

The model for the interferometric phase as described above expresses the phase of every PS to some extent independently from the other PS. Only the assumption, that the phase difference between two neighboring PS is largely free of atmospheric influence takes relationships between PS into account. In doing so one neglects a big part of the structural information contained in a SAR image stack. One may for instance take a group of PS located on the same building. Due to the structural properties of the building, the movements of the PS in this group should exhibit certain regularities (see for instance [5]). In order to segment PS automatically into meaningful groups, pattern recognition techniques may be employed. It is conceivable to use the amplitude information as an outcome of a standard PS method to group the PS. This grouping information could then in turn be the input for a PS algorithm, which exploits the found relationships between the PS.

III. Grouping

The grouping of the PS is performed with a production system, which basically joins simple objects to build step by step more complex ones. This is a typical data driven strategy. In the case at hand the knowledge is coded in a declarative manner in the form of rules (called productions and elucidated in sub-section A. A very crucial point is the separation of this knowledge base from the control assembly, which regulates the order in which certain productions are applied. The latter is hard to maintain for larger systems. To get a satisfying result in an acceptable timeframe a special interpreter featuring top-down control and any-time capability is used, which is briefly indicated in sub-Section B. In sub-Section C we report on preliminary experiments conducted with this set-up.

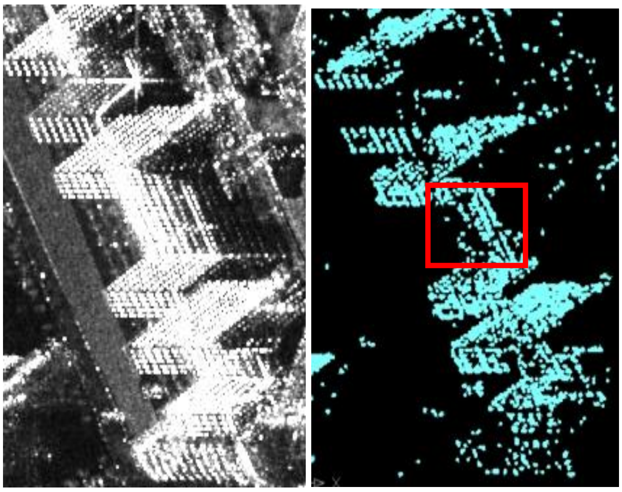


Figure 1. Building block with many point scatterer (left), Examples of PS (instances of CPhasedPix) the phase is indicated by the hand pointing between 0 and 2π

TABLE I. PRODUCTIONS FOR GROUPING HIGH-RES. SAR-PS

No	Productions not using phase		
	Gestalt	***Constraint***	***Parts***
1	CBrightSpot	proximity	CBrightPix,…,CBrightPix
2	CRow	proper spacing & lighting direction	CBrightSpot CBrightSpot
3	CRow	good continuation	CRow CBrightSpot
4	CLattice	proper spacing & not lighting direction	CRow CRow
5	CLattice	good continuation	CLattice, CRow
	Productions using phase		
6	CPhaseSpot	proximity & similar phase	CPhasePix,…,CPhasePix
7	CPhaseRow	proper spacing & similar phase	CPhaseSpot, CPhaseSpot
8	CPhaseRow	good continuation & similar phase	CPhaseRow, CPhaseSpot
9	CLattice	proper spacing & lighting direction	CPhaseRow CPhaseRow
10	CLattice	good continuation	CLattice, CPhasedRow

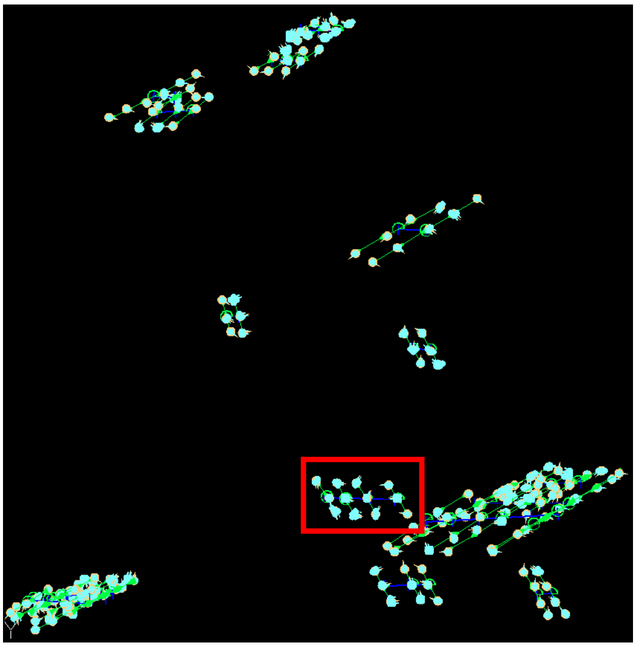
A. Declarative Knowledge Representation

The available knowledge is represented as a set of rules. In this case two different sets have been used (1-5 and 6-10 respectively). Both are listed in Table 1. As can be seen each rule is described by its outcome (column Gestalt), a set of constraints and the parts involved in the production. Thereby the constraints determine conditions that have to be fulfilled, in order for the production to make sense. The difference between the two sets of rules is the use of the interferometric phase taken from one interferogram within the second set of rules (see 6-8). Besides the requirement of a similar phase most constraints embody classical gestalt principles of rather universal use in perception [2]. The two systems of productions 1-5 and 6-10, working on data as displayed in Figure 1, yield a combinatorial growth in the number of objects in case they exclusively use the gestalt constraints. However, we can exploit knowledge in order to simultaneously limit computational load and to improve results by preferring feasible directions. For example, production 2 (CRow) is applied in range direction only (i.e., grouping vertical rows like windows of different floors), whereas CPhaseRow looks across for PS featuring a similar phase (i.e., grouping horizontal rows like windows of the same floor).

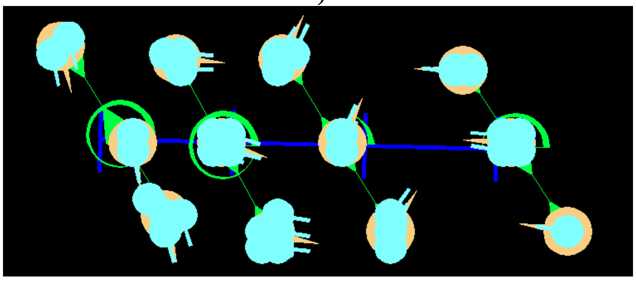
B. Search Strategies in the Presence of Combinatoric Growth

Apart from the knowledge used in a production system a vital point for the result is the order in which the productions are applied to the objects. The administration of this process is done in a queue sorting admissible hypotheses according to their attached assessments. Each hypothesis consists of an object instance and a production containing such object on the Parts side. Processing such a hypothesis is computationally expensive since it involves a query to the database for possible partners and the construction of (sometimes many) new Gestalt objects. The quality of primitive objects must be determined by the extraction process – in our case the PS identification. The quality of non-primitive Gestalts is mainly influenced by how good the given constraints are met. This kind of bottom-up quality driven search is the first choice if exhaustive exploration of the search space is not feasible. The algorithm definitely terminates when all possible hypotheses have been processed. However, this hardly ever happens in realworld examples, which is due to the huge number of possibilities. The search is therefore terminated when a previously set stopping condition is met (in this case the processing time). Stopping the algorithm at a certain point involves the risk that possibilities deducible from low quality object instances are not explored. A problem that arises if only such bottom-up control is used concerns the complexity of the resulting Gestalts. A satisfying result should contain a large number of extended Lattices, because this is the structure we are interested in. Bottom-up control does not incorporate a mechanism, which facilitates the fast production of complex objects. One way to focus the search in a depth first manner is to incorporate the complexity of the resulting Gestalts in the rating, for instance by adding a bonus for more sophisticated outcomes. In order to reduce the number of possible objects and hypotheses another search heuristic called local inhibition is employed. Hypotheses build on objects lying close to processed hypotheses of the same type, are suppressed, since they would most likely lead to the same or a very similar Gestalt.

Finally the order of the hypotheses is influenced by the results obtained in prior grouping steps. One could for instance focus



a)



b)

Figure 2. Structures found with pases (by productions 6)…10)), a) result on the section given in Figure 2; b) central lower Gestalt in more detail

on the search for a *Gestalt*, which is needed in a later grouping step. This approach called focus of attention is very effective but is also problematic since it mixes the declarative knowledge with the control. The main problem with such heuristics is the risk to construct phantom-Gestalts.

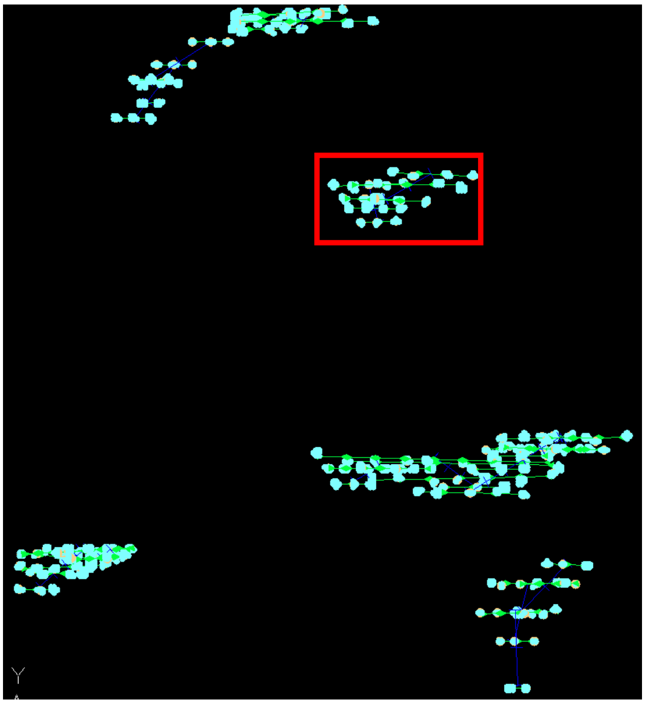
Both local inhibition and focus of attention are top-down control mechanism (we mimic here again human perception: for example, similar processing takes place in the retina to enhance local contrast). The detailed flow of the interpreter is described in [9]. The following experiment applies all three mechanisms. After stopping the search a choice has to be made among the possible deductions found. The best evaluated object of the highest class (here CLattice) is chosen. The next best instances are usually slight variations or parts of this best gestalt. Therefore, these are inhibited by a re-evaluation function similar to the one used in the top-down control. So the second best instance will be somewhere else in the image – and so forth, until either a maximal number or a pre-defined minimal quality is reached. Such inhibitive conclusion control is described in more detail in [14].

C. Experiments

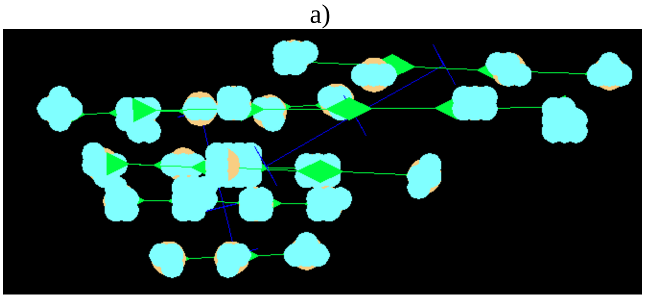
From a stacked high-resolution TerraSAR-X image showing an urban region of Berlin a section was picked which contains complicated mutual overlay of facades – as can be seen in Fig. 1. The grouping is applied to PS candidates selected by a threshold on the amplitude dispersion measure [4], which is also used to assign a quality needed for every object in the production system. The mean amplitude map of this section is shown in Fig. 1 on the left. The extracted PS candidates are highlighted as blue dots on the right side of Fig. 1. One of the main problems is immediately evident from the extracted PS candidates. If two structures with certain patterns of bright and stable scatterers are overlaid, the number of PS candidates is significantly reduced. This effect can be seen in the central part of the section (indicated by the red rectangle). The signal from the upper part of the facade mixes with the signal from a smaller building in front of it leading to an area containing no PS candidates at all. Both production systems given by the two sets of rules in Table 1 have been applied to the PS candidates as shown in Fig. 1 left. The outcome of the system given by the rules 6-10 is displayed in Fig. 2, while the result obtained with the rules 1-5 are shown in Fig. 3. All common parameter settings are the same. Both figures show the 16 best Gestalts constructed after a runtime of 15 minutes in 8 parallel threads on a standard server. CLattice instances are displayed in blue. CPhasedRow instances are displayed in green (with the phase attribute indicated as arc). CPhasedSpot instances are displayed in orange (with the phase attribute indicated as pointed hand). CPhasedPix instances are drawn in blue with the phase indicated by the hand pointing between 0 and 2π.

It is apparent, that the use of the phase leads to a much better result. Although the result in Fig. 2 lacks completeness, all Gestalts are correct. We can see that by considering the phase at the found façades. It changes by 90° while going from one floor to the next (i.e. to the right) as can be nicely seen in Fig. 2b) showing the group indicated by the red rectangle in Fig. 2a in more detail . In contrast to this the result obtained with the productions 1-5 would require a much more tolerant meaning of correctness though still most of the Gestalts correspond to parts of real facades. But often the orientations of the CLattice instances do not coincide with the real façade orientations.

Figure 3b) displays a section from the upper right region in more detail (again notified by a red rectangle). These two gestalts can be regarded as success with also the orientations being roughly correct. Finally the overall number of Gestalts deduced by both systems (System 1-5: 840 Spots, 5653 Rows, 37935 Lattices; System 6-10: 2196 Spots, 14682 Rows, 11163 Lattices) implies, that System 1-5 spends much more time with the production of Lattice objects than system 6-10, which produced a lot more row and spot objects. This might be due to an over-tuning of the latter system with respect to depth first search.



a)



b)

Figure 3. Structures found without pases (by productions 1)…5)), a) result on the section given in Figure 2; b) central Gestalt in more detail

IV. Conclusion and Discussion

Our results indicate success in finding some of the facades present in urban environments without relying on much prior knowledge about the buildings. In case the phase is not used, the grouping encounters difficulties – either one has to be aware that some of the gestalts are illusory, i.e. they do not correspond to real facades or the grouping of the CLatticeOfLattice gestalts should be guided in terms of its preferred direction by knowledge about the expected façade directions (e.g. from additionally included GIS data). Moreover, the earlier grouping of CLatticeOfSpots assumes similar structures on the facades to be vertically aligned, which may be violated sometimes. Another problem, which we haven't addressed so far, is the erroneous aggregation of CBrightSpot instances in layover areas. PS candidates lying nearby in the SAR image may originate from different overlaid façade structures. Production rule 1, which just considers proximity, might thus group such PS candidates.

Including the phase attribute into the gestalt grouping turns out to work a lot better. It prefers façades where similar structures are aligned horizontally (along the stories of a building) which seems rather natural. Moreover the problem of overlaying structures is mitigated. Therefore the system using the phase seems to be more promising for future work. However, the inclusion of the phase attribute in the grouping step and its exploitation in the subsequent PS analysis may lead to problems, which is to be investigated. One of the most crucial points is to get a more complete result, which might be achieved by adding knowledge to the system (for instance by considering GIS information) or adjust the control mechanisms for the particular case at hand.

Acknowledgment

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