CHARACTERIZATION OF SAR IMAGE PATTERNS PERTINENT TO INDIVIDUAL FAÇADES

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ABSTRACT

This paper presents a new algorithm for recognizing patterns pertinent to the layover of façades in very high resolution SAR images, serving the increasing demand for monitoring individual buildings. The grouping of signatures is based on the combination of a weighted Hough transform and the analysis of spectrum peaks. First results of pattern extraction are shown for an office building located in the Munich city area.

***Index Terms*—** Very high resolution SAR, building reconstruction, TerraSAR-X

1. INTRODUCTION

Current very high resolution (VHR) SAR missions like TerraSAR-X or Cosmo-SkyMed enable the monitoring of individual buildings. Still, most concepts are focused on individual scatterers even if patterns of signatures may be exploited for characterizing large building façades as well as selected façades of small buildings.

First concepts and practical attempts in grouping salient signatures in satellite SAR data are reported in [1] and [2], respectively, developed in the course of persistent scatterer interferometry (PSI). In the latter publication, a 1D-grouping algorithm is applied to persistent scatterers (PS), based on the testing of different spatial frequencies and the consideration of height information derived from PSI processing.

The algorithm presented in this paper extends the signature analysis to two dimensions in the SAR image plane. After an initial extraction of linear image features, the testing procedure of [2] is avoided by the identification of dominant regularities in frequency domain. Eventually, the spatial signature relations are described in index matrices, applicable for grouping of persistent scatterers as well as for object-based change detection applications.

2. PROCEDURE

In order to enable pattern recognition, image pixels within the layover of individual façades have to be extracted from the SAR image. Moreover, an approximate value for the façade orientation with respect to the azimuth axis is required (shearing angle θ_S). This a-priori information can be provided by integrating knowledge about the building geometry (e.g. a LiDAR DEM) and simulation methods based, for instance, on rasterization [3] or ray tracing [4]. As the integration of the simulation step is still under development, the layover area used in this paper has been extracted manually.

The analysis of signature patterns is based on three assumptions: **A.)** façade signatures are linearly organized, **B.)** façade patterns are characterized by spatial regularities, and **C.)** façades may be composed by two or more sub-patterns (see simulated test grids in Figure 1).

Following the outlined assumptions, the algorithm for characterizing signature patterns includes three methodical parts. First, a weighted Hough transform, exploiting the full range of pixel intensities, enables the assignment of dominant signatures to linear structures. Second, the spectrum of the layover area is analyzed for extracting spacing parameters (azimuth and range components) and the pattern orientation angle. Finally, a directed region growing is conducted for describing the pattern topology. In an iterative manner, secondary patterns are identifyied after removing image parts assigned to the primary pattern.

3. ASSUMPTION A - LINEAR ORGANIZATION

3.1. Generating a signature set

The first step aims at assigning dominant signatures to line intersections extracted in the layover area. In this regard, the signatures may be identified in single SAR images (e.g. for change detection applications) or in SAR temporal average images (e.g. candidate pixels to be grouped for persistent scatterer interferometry (PSI)).

The case study presented in this paper was carried out for a façade located on the Technische Universität München (TUM) campus and is based on the analysis of a single VHR TerraSAR-X spotlight image (see Figure 2; resolution and spacing: 1.1m x 0.6m and 0.42m x 0.36m in azimuth and range, respectively). Figure 4a shows the image layover area representing the TUM façade.

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In order to be considered as possible pattern candidates, dominant point signatures have to fulfill a mean difference criterion with respect to the adjacent pixels in a 3x3 window (e.g. mean difference $> 10\%$ of the maximum intensity in SAR image). Thereafter, a local oversampling of factor 32 is applied for deriving the subpixel-position of the local maxima, in the following referred to as ”signature set”. The local maxima identified for the TUM façade can be seen in Figure 4b.

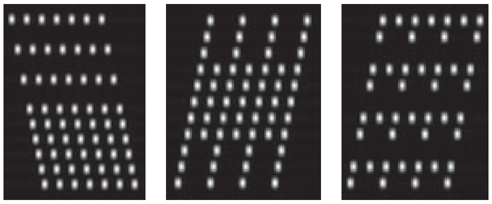


Fig. 1: Simulated layover patterns. Left and center: separated patterns, right: intersecting patterns.

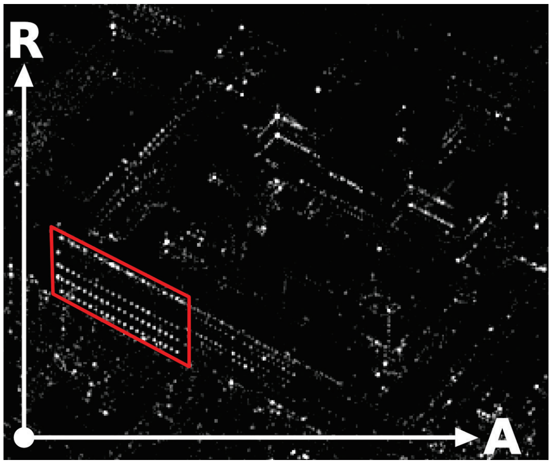


Fig. 2: TerraSAR-X spotlight image of TUM campus; red frame: façade of interest; A: azimuth, R: range.

3.2. Identification of linear structures

Even if dominant point signatures in the layover area seem to be isolated, the pattern structure of façades may be retraced by lines. Therefore, a Hough transform is conducted in order to identify dominant lines, regardless of any spatial distance criteria. The binary image required as input is created by selecting image pixels with intensities above the median intensity value of the layover image. As an extension, a weighting is intruced into the Hough transform by entering the 16 bit pixel intensities of the image into the Hough space. Thereby, dominant signatures are assigned with higher impact to the line extraction step.

Before detecting the dominant lines in the Hough space, a-priori knowledge about the layover area is included. The search space for the line orientation θ is reduced to two main directions according to the known façade shearing angle θ_S in azimuth, i.e.

$$\theta_S - \Delta\theta_1 < \theta < \theta_S + \Delta\theta_1 \qquad (1)$$

and the direction pertinent to the layover distortion of vertical oriented objects, i.e.

$$-\theta_{\min} < \theta < -\theta_{\min} + \Delta\theta_2 \wedge \theta_{\max} - \Delta\theta_2 < \theta < \theta_{\max} \quad (2)$$

where $\Delta\theta_1$ and $\Delta\theta_2$ are buffer integers to form the two subselections of the search space. Figure 3 shows the resulting Hough space for the TUM façade. The intervals for peak extraction (equations (1) and (2)) are marked by two nearby lines.

After detecting a sufficient number of maxima in both search areas within the Hough space, spatially redundant lines are removed in a post-processing step. Finally, the Hough lines of the two main directions are intersected in order to derive candidate positions for pattern signatures.

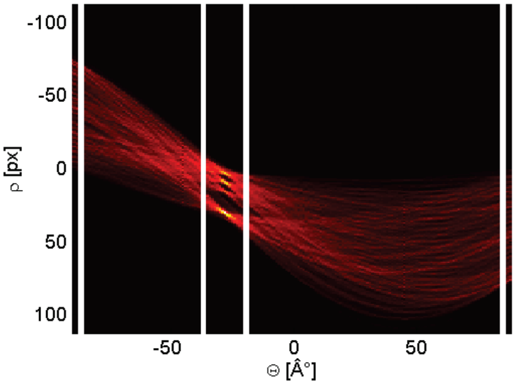
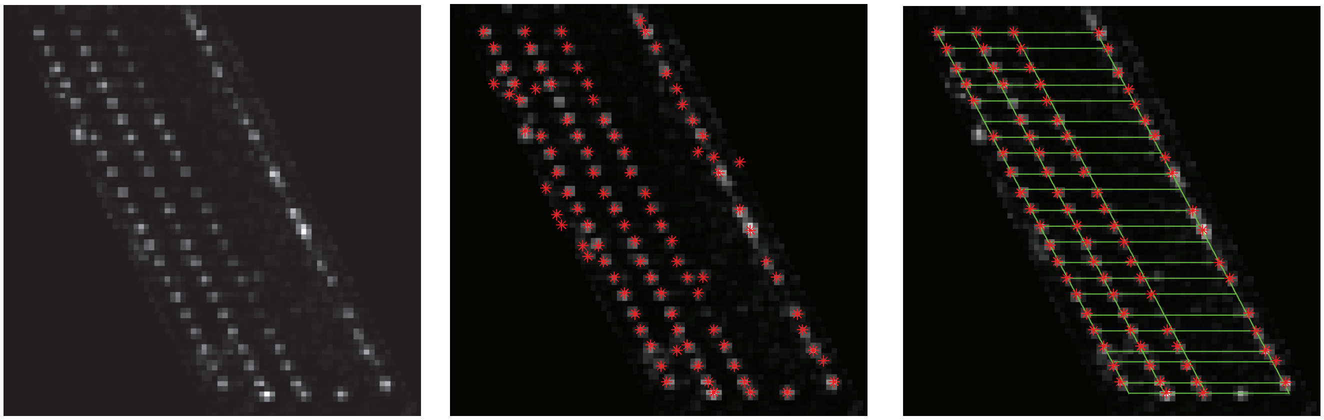


Fig. 3: Weighted Hough space for TUM façade

3.3. Check signatures with respect to grid and reduce image content

Next, the signature set (see Section 3.1) is tested with respect to assumption A: linear structure. To this end, the point signatures are assigned to the grid of Hough lines based on a threshold on the distance (e.g. 1 pixel). In this regard, only one signature may be related to each intersection point, resulting in a flag vector for the signature set (fit, no fit). Figure 4c visualizes the assignment result for the TUM façade.

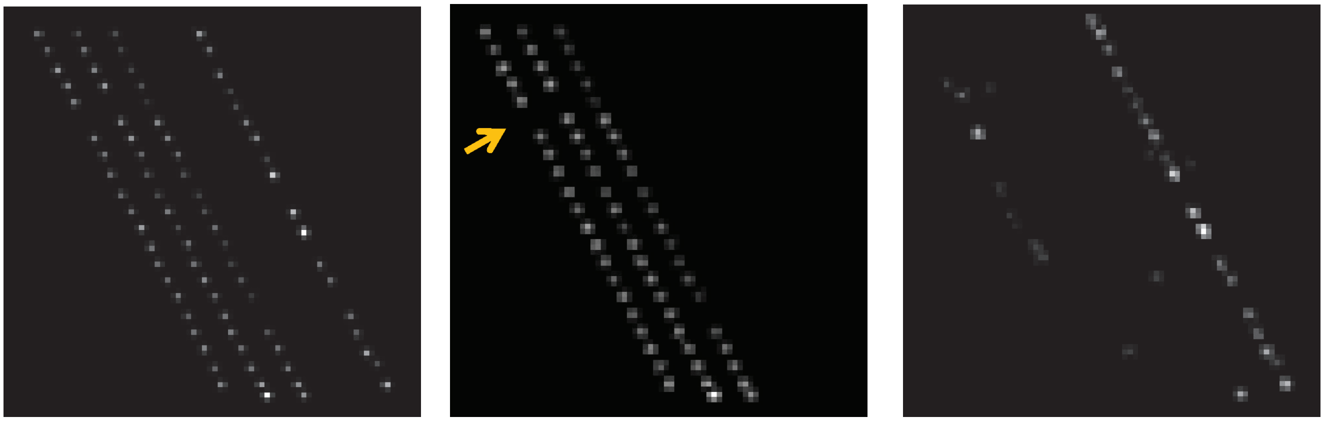
The flag vector is used for removing image parts without further interest, i.e. isolated signatures. In more detail, an image part of n x n pixels, weighted with an exponential function, is kept for all grid signatures (e.g. $n = 3$). Thereby, signals of interest are emphasized by a ”filtering” step. The resulting image serves as input for the analysis with respect to assumption B: spatial regularity. Figure 4d shows the reduced image content for the TUM façade.



(a) Manually extracted TUM façade layover area

(b) Signature set (red markers) generated by local maxima selection

(c) Subset of Signatures (red markers) fitted to Hough detected line pattern (green)



(d) Layover after "filtering" step

(e) Signature regions after spectral analysis and directed region growing

(f) Remaining isolated signatures

Fig. 4: Case study for layover area of individual façade (part of the TUM building complex). Image source: VHR TerraSAR-X spotlight image. Azimuth: bottom up, Range: left to right.

4. ASSUMPTION B - SPATIAL REGULARITY

4.1. Spectrum analysis

Based on assumption A, a subset of all point signatures has been related to line intersections. However, the grid of Hough lines may be composed by several subgrids with varying distances. For identifying the grid dominating the layover area, a detour to the frequency domain is helpful. A subset of the 2D image spectrum (1/4th of the full spectrum) is extracted depending on the shearing angle θ_S and is analyzed for dominant peaks. In this regard, the analysis is focused on the following assumptions: A.) a regular grid in space domain gives a regular grid in frequency domain and B.) a skew along the azimuth axis in image domain yields a skew along the range axis in frequency domain.

The distance to the dominant peak in the first range column in the spectrum part (peak 1 in Figure 5) gives a temporary value for the spacing in azimuth. The distance to the nearest dominant peak in the remaining subset (peak 2) gives a temporary value for the spacing in range as well as a refined shearing angle θ_S of the signature pattern. The expression "nearest dominant" primarily considers the peak strength but also prefers low frequencies. Back in image domain, the refined shearing angle is exploited for scaling the range spacing and for decomposing the azimuth spacing into azimuth and range components.

Figure 5 shows the spectrum part for the TUM façade. The spectrum origin lies in the lower left corner. Two frequency peaks, indicated by two red markers, describe the dominant spacing parameters characterizing the façade pattern. A secondary peak, marked in green, is included for stabilizing the extraction of the refined shearing angle, i.e. both detected angles (red and green) are averaged.

4.2. Directed region growing for pattern structure

The last step focused on the identification of the pattern topology. To this end, a directed region growing is started which

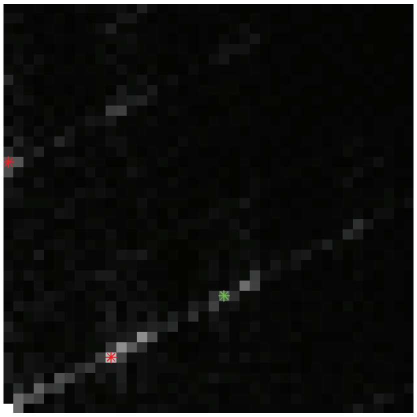


Fig. 5: Spectrum part exploited for parameter extraction (origin: bottom left); Red markers: primary peaks for spacing, green marker: secondary peak for extraction of orientation angle. Azimuth: bottom-up, Range: left to right

requires the subpixel positions of signatures, that have been selected with respect to the line intersections (see Section 3), and the pattern parameters extracted from the image spectrum (see last Section).

A seed point is selected (top-left signature in the layover for first run) and is assigned with coordinates (1,1). Thereafter, an adjacent pattern signature is searched in range based on the known spacing in combination with a distance threshold. In case of a hit, the signature is assigned with pattern coordinates (1,2) and the search in range is continued. If no further range signatures are identified, a jump to the next row is tried, again based on the known spacing values. All signatures of the last range row may serve as starting positions for the jump. If the jump was successful, the search is continued to the left and to the right, i.e. in positive and negative range direction. In this regard, the coordinates within the pattern matrix may become smaller than 1. For keeping the signature matrix flexible, the topology information is kept in a temporary matrix (pattern coordinates + signature index) which is finally exploited for generating the pattern matrix (rows and columns filled with signature indices). The region growing procedure is continued until all signatures have been checked with respect to the presumed pattern. In order to be considered as façade patterns, the detected grids have to fulfill a dimension criterion (e.g. more than two rows and columns, minimum number of elements).

The resulting spatial combination of signature indices can be used for grouping persistent scatterers in PSI as well as for an object-based comparison in change detection applications. Figure 4e visualizes image parts related to the detected grid of the TUM façade (3x3 image subsets centered at signature positions). At the current state of the algorithm, the pattern in Figure 4e is decomposed into two sub-patterns which occur due to A.) a missed local maxima and B.) an unsuccessful jump attempt (problem area marked by arrow in Figure 4e).

5. ASSUMPTION C - SECONDARY PATTERNS

Even if a façade reveals no change in orientation, its surface may be represented by several systematical structures, e.g. window rows with different spacing may yield subpatterns of dominant signatures (see left of Figure 1). The proposed algorithm aims at an iterative identification of secondary patterns mainly due to two reasons. First, less pronounced linear features may have been missed during the analysis of the Hough space, e.g. due to medium intensity level. Second, these secondary patterns may be characterized by different spacings which results in a different signature in frequency domain.

Therefore, image parts related to the primary pattern are removed from the layover image. The combination of Hough transform and spectrum analysis is repeated once more for the reduced image, followed by a new region growing procedure.

For the TUM façade, dominant signatures not fitting to the primary pattern are shown in Figure 4f. The second iteration step does not provide any additional result as the signatures are either isolated or linearly organized (fail of dimension criterion).

6. CONCLUSIONS AND OUTLOOK

Focusing on linear structures and spatial regularities of façades, a new concept has been presented for analyzing signature patterns in façade layover areas (combination of weighted Hough transform, spectral analysis, and region growing). Thereby, the topology of the pattern is obtained which can be used for grouping in PSI or for change detection applications.

Future work will focus on further case studies based on the full processing chain including the SAR simulation step. Moreover, the algorihm is to be enhanced with respect to robustness and flexibility, e.g. with regard to the appearance of gaps in patterns in the region growing process.

7. REFERENCES

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