Characterisation of Buildings using Polarimetric Interferometric Multiple Track L-Band SAR Data

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Abstract — In this paper a multiple view POL-InSAR approach for the analysis of urban areas is introduced: As a first step, a polarimetric classification scheme is applied that allows the identification of three basic scattering mechanisms: volume diffusion, double bounce and surface reflections. A relation between the interferometric phases of the Pauli polarization basis and the polarimetric scattering mechanisms is established. A method to estimate the phase corresponding to the surface is introduced. These phases are used to extract the height of buildings. Finally, the data is geocoded in order to synchronize images acquired from different positions. The proposed methods are applied to fully polarimetric and repeat pass interferometric data at L-band acquired by the DLR’s experimental E-SAR system on August 1st, 2000 over the city of Dresden in Germany. The flight tracks form a rectangle.

I. INTRODUCTION

The analysis of urban scenes via SAR data at moderate resolution has turned out to be a very difficult task mainly because of two reasons: the diffusion is normally complex with very different contributions in one resolution cell, and layover and shadowing phenomena occur in radar images. Recently new methods using polarimetric, interferometric and POL-InSAR data have been developed to overcome these problems and to extract information such as the height of buildings from SAR images of urban zones [1]. The height estimation using POL-InSAR data from only one direction is perturbed by shadowing and layover effects. Interferometric data from different looking angles do not allow the determination of scattering mechanisms. In this paper a polarimetric interferometric multiple track approach for the analysis of urban areas is introduced.

II. POLARIMETRIC CLASSIFICATION

To identify the three basic scattering mechanisms, the polarimetric coherency matrix is decomposed into eigenvectors and eigenvalues. The entropy H as a measure of the randomness of the polarimetric scattering and the anisotropy A revealing the importance of secondary scattering mechanisms are computed by the pseudo-probabilities of the eigenvalues in descending order. The $\alpha$ and $\alpha_1$ parameter of the eigenvectors describe the type of scattering mechanism [2].

A high value of entropy indicates volume diffusion (VD) [3]. For low entropy or medium entropy with low anisotropy the single scattering mechanism is determined by $\alpha_1$ as surface reflection (SR) or double bounce scattering (DB). Medium H and high A signify two mechanisms that can be assigned to SR or DB class via the first two diagonal elements of the Huynen matrix.

Fig. 1 and 2 show the result of this classification: the Pauli colour coded image of an urban area (Fig. 1), the classification into VD (green), DB (red) and SR (blue) (Fig. 2). The streets, sports fields and the river are attributed to the SR class, some, but not all built-up areas to DB and forests and some buildings to VD due to their complex backscattering. Globally, the same results are obtained using data acquired from the opposite position (Fig. 3 and 4).

Figure 1. Pauli colour-coded image, the arrow indicates azimuth.

Figure 2. Identification of three scattering mechanisms: VD (green), DB (red) and SR (blue).
III. POL-INSAR HEIGHT ESTIMATION

The height of buildings is estimated by the interferometric phase. First, the behaviour of the phases of the Pauli polarization basis is associated with the scattering mechanisms. In the amplitude image of HHI polarization (Fig. 5) the line of samples is marked in blue colour. Going from left to right, the $\alpha$ parameter (Fig. 6) describing the scattering mechanism attains first medium values, suddenly falls to low values implying surface reflection and makes a jump to quite high values related to double bounce scattering. This behaviour can also be observed via the phases (Fig. 7): starting from left, the phases are biased. This is caused by a complex scene that contains vegetation, surfaces and man made objects leading to a mixture of scattering mechanisms and layover effect. Then the phase of the first component of the Pauli basis corresponding to surface scattering increases abruptly due to the walls of a building. The phases of different polarization behave rather homogeneously on top of the building. On the right, the leap of the second Pauli phase related to double bounce coincides perfectly with the scattering mechanism found by the polarimetric analysis. The other phases seem to be biased by shadow. This interpretation is confirmed by an optical image of the site (Fig. 8).
To estimate the height of buildings another approach is introduced: The polarimetric coherency matrices 
\[ \mathbf{T}_i = \langle \mathbf{k}_i, \mathbf{k}_i^H \rangle \] and the matrix 
\[ \mathbf{\Omega}_{12} = \langle \mathbf{k}_1, \mathbf{k}_2^H \rangle \] containing polarimetric and interferometric information are calculated by the two scattering vectors in the Pauli polarization basis

\[ \mathbf{k}_i = \frac{1}{\sqrt{2}} [S_{HH}^i + S_{VH}^i, S_{VH}^i - S_{HH}^i, 2S_{VV}^i]^T \]  

(1)

for the interferometric pair \( i = 1, 2 \). The polarimetric-interferometric coherence can be computed by

\[ \gamma(w_1, w_2) = \frac{w_1^H [\mathbf{\Omega}_{12}] w_2}{\sqrt{w_1^H \mathbf{T}_{11} w_1 w_2^H \mathbf{T}_{22} w_2}}. \]  

(2)

First, the coherence values for the lexicographic and Pauli basis and the optimized coherences [4] are calculated. The line that fits these values in a least-squares sense intersects the complex unitary circle at two points [5]. The intersection point that is closest to the coherence values is selected as the phase \( \phi_0 \) corresponding to the surface. The characteristic of this phase is very similar to the one of the phase in \( HH+VV \) polarization (Fig. 9). This suggests that these two phases are most appropriate to estimate the height of buildings (Fig. 10) since they are related to surface reflection. Further studies will show which of these phases is best suited to extract the height of buildings.

IV. GEOCODING

The first step in geocoding consists in projecting slant to ground range by interpolation and oversampling. Then one image is chosen as a reference and two original images acquired from different viewing directions are transformed in the following way: \( N \) ground control points (GCP) in the reference image and the corresponding points in the two original images are selected yielding for each original image the pairs of coordinates \( (x_i^{orig}, y_i^{orig}) \) and \( (x_i^{trans}, y_i^{trans}) \) for \( i = 1, ..., N \). Distinctive points on the ground like crossroads are chosen as GCPs. Finally the images are coregistrated by affine transformations of the two original data.

The quality of geocoding is evaluated by adding the amplitude of the reference image to those of the transformed images in \( HH \) polarization (Fig. 11). As the pattern of streets with low backscatter and hence low amplitude is preserved, the accuracy of geocoding is high.

In Fig. 12 the three geocoded images in \( HH \) channel are colour-coded in such a way that the amplitude of the reference image is set to red and those of the two transformed images to green and blue respectively. The layover effect is clearly discernible in the magnified view (Fig. 13) of the rectangle marked in Fig. 12, the tower leaning towards the respective positions of the radar sensor. The enlarged view (Fig. 14) of the marked box in the lower left corner of Fig. 12 reveals the structure of a particular building. The edges of the walls that are directed to different sensor positions, a specific mural structure and the pattern on the roof are intelligibly visible. This analysis is backed by an optical image of the site (Fig. 15).

The combination of data acquired from different viewing angles permits to eliminate distortion phenomena such as layover and shadow. In the future this will improve the determination of the shape and height of edifices.
V. CONCLUSION

It is possible to identify three basic scattering mechanisms in radar images of urban areas by means of polarimetric classification. In the future these techniques shall be refined to extract the shape of buildings via scattering mechanisms. The height of buildings is extracted by interferometric phases of the Pauli basis and a newly introduced phase that is related to the surface. It has to be further studied which of these phases is best suited to estimate the height of buildings. Data acquired from different sensor positions are synchronized by geocoding techniques allowing the elimination of distortion phenomena such as layover and shadow. At a later stage this will enhance the determination of the shape and height of edifices.

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Figure 11. Sum of amplitudes of reference image and of transformed images in HH channel. Dark pixels mean low amplitude, light pixels high amplitude.

Figure 12. Colour-coded overlapping of geocoded images. The arrows indicate the azimuth direction for each image.

Figure 13. Layover effect of a tower.

Figure 14. Edges and structure of a particular building.

Figure 15. Optical image of the site of Fig. 14.