Preliminary Pattern Recognition in Polarimetric Signatures

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Abstract

In the presented paper the idea of a new method of quad-polarimetric SAR data decomposition is presented. The proposed decomposition is based on the pattern recognition in polarimetric signatures. In the described decomposition four basic scattering mechanisms are taken into consideration: single bounce, double bounce, helix and volume scattering. In this paper, the first proposed method of pattern recognition in polarimetric signatures is described. The preliminary results of its application are shown. The method was tested for selected pixels from real SAR image which response is very similar to the response of trihedral, dihedral and right and left helix. The approach to more complicated objects is also described.

Index Terms— decomposition, polarimetric signature, pattern recognition

1. INTRODUCTION

The radar polarimetry is a dynamically developing method of SAR images processing. The development is associated both with searching of a new areas of application for radar polarimetry as well as with improving the image processing methods. The second task has impact mostly on the accuracy of obtained results and possibilities of extraction of a new information from SAR images. One of the most important issues in the quad and dual polarimetric data processing is a decomposition problem. Up to now, there has been a few decomposition methods proposed in the literature. The most widely used are H/A/α [1], Yamaguchi [2], Cameron [3] and Huynen [4] decompositions. Each of them has its advantages and disadvantages in the identification of particular scattering mechanisms. In this paper, the authors present the new idea of polarimetric data decomposition method. This decomposition is based on the pattern recognition in the polarimetric signatures.

2. PROPOSED DECOMPOSITION METHOD

The idea of polarimetric signature was introduced by van Zyl [5]. The polarimetric signature fully describes the polarimetric properties of a scatterer. The proposed decomposition method considers four basic scattering mechanisms: single-bounce, double-bounce, helix scattering and volume scattering. The scattering mechanisms can be represented by following canonical objects: trihedral (single bounce), dihedral (double bounce), left and right helix (helix scattering). The volume scattering mechanism is modeled using three types of randomly oriented dipoles according to the Yamaguchi theory [1]: cloud of randomly oriented, very thin, horizontal cylinder-like scatterers, cloud of randomly oriented, very thin, vertical cylinder like scatterers and cloud of randomly oriented dipoles with a uniform probability function for orientation angle. In the figure 1, as an example, the polarimetric signature of a trihedral is presented.

Fig. 1 The polarimetric signature of trihedral

The polarimetric signatures of the mentioned seven objects are well described in the literature [1] and the observed real polarimetric signatures can be compared with them. Because the signatures strongly depend on the target orientation angle, in this work, each pixel of the SAR data is firstly preprocessed to rotate the target orientation angle to zero according to the Huynen’s theory [4]. This way, the
decomposition results are invariable with target orientation angle. The analysis of the polarimetric signatures is based on the fact that the polarimetric signature of the particular pixel of a radar image is a sum of polarimetric signatures of many individual objects located within this pixel area [5]. This information is used to determine the amount of four scattering mechanisms in each pixel of the analyzed SAR image. In the proposed decomposition algorithm the different pattern recognition methods will be tested. Firstly, the method described in the next chapter was applied. This method considers only three scattering mechanisms: single bounce, double bounce and helix scattering. The volume scattering mechanism, due to its complexity, will be included in the further analysis.

3. PATTERN RECOGNITION IN POLARIMETRIC SIGNATURES

The polarimetric signature can be represented by the two dimensional matrix. Assuming this, the objects to be recognized are the polarimetric matrices of size 180x90. The aim of the described pattern recognition algorithm is to classify the polarimetric signatures into four given a priori classes: trihedral, dihedral, left helix and right helix. In this method, the polarimetric matrices are treated as vectors consisting of 16200 components. Each of the recognized classes is represented by one correct pattern, say \( \bar{u}_1 \) (dihedral), \( \bar{u}_2 \) (left helix), \( \bar{u}_3 \) (right helix), \( \bar{u}_4 \) (trihedral). The applied methodology is based on the fact that a distinctive feature separates the classes' representatives clearly [6]. This means that there exists sufficiently large neighborhood of each representative which does not intersect with neighborhoods of the other ones. It is assumed that the vector direction is one of the distinctive parameter in the set of patterns. In order to verify this assumption, the angles between patterns were calculated. The assumption was positively verified which means that the angles between patterns are sufficiently large – see section 4. The angles were calculated using a standard scalar product (Eq.1)

\[
\langle \bar{x}, \bar{y} \rangle = \sum_{i=1}^{n} x_i \cdot y_i
\]  

(1)

where

\[
\bar{x} = [x_1, ..., x_n]
\]

\[
\bar{y} = [y_1, ..., y_n]
\]

according to the formula in Eq. 2

\[
\cos(\bar{x}, \bar{y}) = \frac{\langle \bar{x}, \bar{y} \rangle}{\|\bar{x}\| \cdot \|\bar{y}\|} = \frac{\|\bar{x} - \bar{y}\|}{\|\bar{x}\|}
\]  

(2)

where \( \|\bar{x}\| \) is introduced by the scalar product \( \langle \bar{x}, \bar{y} \rangle \).

The described procedure is an algebraic realization of the Kohonen neural network which is not trained but weights of neurons are vectors encoding correct patterns. The described method allows to divide the set of analyzed objects into two subsets. The first one consists of these elements which has been univocally classified to one of four classes. The second one is the set of elements which cannot be classified because the distance from at least two correct representatives is comparable. In such a case all these representatives are used to represent the recognized object. Then the vector \( \bar{y} \) representing the vector \( \bar{x} \) is constructed in such a way that (Eq. 3)

\[
\|\bar{x} - \bar{y}\| = \min_{i=1}^{4} \|\bar{x} - \bar{u}_i\|
\]

(3)

where

\[
\bar{y} = \sum_{i=1}^{4} \alpha_i \bar{u}_i
\]

If the analyzed object has been recognized univocally then only one of the coefficients \( \alpha_i \) differs from zero. Otherwise at least two coefficients differ from zero. The norm of the residual vector \( \|\bar{x} - \bar{y}\| \) is the measure of how well the vector \( \bar{x} \) is represented by \( \bar{y} \). The value \( \|\bar{x} - \bar{y}\| \) is a relative error of representation. The above method is applied independently to co-polarization and cross-polarization matrices.

4. RESULTS

The method described in the previous section has been tested preliminarily i.e. for such objects which can be assigned univocally to one class. In table 1 and 2 the calculated angles between correct representatives of four considered classes (trihedral, dihedral, right and left helix) are presented.

Tab. 1 Angles between co-polarized matrices of canonical objects

<table>
<thead>
<tr>
<th>Co-pol</th>
<th>( \bar{u}_1 )</th>
<th>( \bar{u}_2 )</th>
<th>( \bar{u}_3 )</th>
<th>( \bar{u}_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{u}_1 )</td>
<td>0</td>
<td>45</td>
<td>45</td>
<td>51</td>
</tr>
<tr>
<td>( \bar{u}_2 )</td>
<td>45</td>
<td>0</td>
<td>85</td>
<td>61</td>
</tr>
</tbody>
</table>
The classification was carried out for the set of 200 real signatures which consists of 50 examples from dihedral class, 50 examples from left helix class, 50 from right helix class and 50 for trihedral class. The tested signatures were selected from the real polarimetric SAR image with the previously removed orientation angle shift. Only these pixels were taken into consideration for which the correlation coefficients with the canonical objects’ polarimetric signatures was relatively high. The received results of proposed method application are presented in table 3. The left helix and right helix classes for cross-polarization matrices are undistinguishable, the angles between given data and correct patterns for them are always the same. However, it is not a problem because for co-polarization matrices they differ significantly. For each of the four classes the percent of correctly recognized objects is equal or very close to 100% in the co-polarized channel. For cross-polarized channel of dihedral and trihedral classes the percents of correctly recognized object are also very high.

<table>
<thead>
<tr>
<th>Tab. 3 The results of classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly recognized</td>
</tr>
<tr>
<td>Co-pol</td>
</tr>
<tr>
<td>Dihedral</td>
</tr>
<tr>
<td>Left helix</td>
</tr>
<tr>
<td>Right helix</td>
</tr>
<tr>
<td>Trihedral</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

The presented project corresponds to the actual problems investigated by the scientific community. Its goal is to develop a new method of fully polarimetric data decomposition based on the pattern recognition in the polarimetric signatures. The introductory studies on the proposed method of pattern recognition in polarimetric signatures gave promising results. It allows to classify simple objects to correct scattering classes. In case of the complex examples for which the proposed method does not work, the alternative method of recognition, based on a different approach will be worked out. In such a way the hierarchical classifier will be designed according to the methodology described in [7], [8].

6. REFERENCES


