Advanced InSAR coregistration using point clusters

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***Abstract*— In this study, we introduce a refined algorithm for the fine InSAR image coregistration which could be used in highly decorrelated scenes. The refinement is introduced at the point of selection of points necessary for the estimation of the offset vectors between master and slave image. A new approach for point selection based on the Harris corner detector algorithm is presented. The new point selection algorithm results with the clusters of point candidates for the offset vectors over a scene. Consequently, the number of points and their spatial distribution are improved, which results in a better global quality of the coregistration model.**

I. Introduction

InSAR coregistration aims to find an optimal transformation model which transforms the slave (distorted) image, known as an input image, back into spatial alignment with a master image. The precise coregistration increases the coherence of the interferogram, improves the quality of the phase unwrapping procedure and therefore leads to a more accurate phase in the final interferogram, [1]. If the coregistration errors are in order of geometric resolution, the coherence of the interferogram is significantly reduced and the phase noise is considerably increased [2].

The conventional coregistration techniques are based on the cross-correlation of the powers (squared amplitudes) and the optimization of the fringe contrast or the coherence. In the first case, the offset vectors, necessary to align the slave image to the master are computed with sub-pixel accuracy for a number of locations in the master. Over the total image, for a large number of windows (e.g. 500 windows of size 32×32 pixels or more), the offset between master and slave is estimated by computing the correlation of the magnitude images for shifts at the sub-pixel level. Using these offsets, the two-dimensional coregistration polynomial of a certain degree is computed.

Accordingly, in order to guarantee an appropriate accuracy in the scenes with low coherence, the size of the correlation window may need to be increased, the windows may be repositioned, and the threshold on the correlation may be lowered. This way, the global quality of the coregistration model is dependent on the number of input points and their spatial distribution over the scene.

In this study, we introduce a refined algorithm for the fine InSAR image (correlation based) coregistration which could be used in highly decorrelated scenes. The refinement is brought in at the point of selection of (control) points necessary for the estimation of the offset vectors between master and slave image. In this way, the clusters of point candidates for the offset vectors over a scene are built. Consequently, the number of points and their spatial distribution are improved, which results in a better global quality of the coregistration model. Further on, the point selection is performed with a more sophisticated and "intelligent" algorithm then simple thresholding on the amplitude. We selected the Harris corner detector for the point selection algorithm. For these reasons we refer in this paper to the point candidates for the offset vector computation selected in this way, as control points, because we can control their detection and more important their distribution in a much better way.

The next section explains the reasons for choosing the Harris corner detector and its introduction to InSAR. Section III presents the implementation of the presented algorithm in the computation of the offset vectors. Finally, the concluding remarks are presented in Section IV.

II. The Harris Corner Detector

A. Control points

Before we proceed with a detailed analysis of the Harris corner detector and its application in InSAR, it is necessary to define the image feature corners and edges.

- *Corners (control points)* of local SAR image features are characterized by locations, where variations of intensity $I(x,y)$, as a function of pixel position, in both range (x) and azimuth (y) directions are high. In this case both partial derivatives of I are large, Fig. 1.
- *Edges* are locations in the SAR image where the variation of intensity $I(x,y)$, as a function of pixel position, in a certain direction is high, while in the corresponding orthogonal direction is low. In the edge oriented along the range axis, partial derivative is large, while in the azimuth direction is low, Fig. 1.

As previously stated, in this paper we refer to corners as the control points.

B. Theory

The Harris corner detector [3] selects points for which the autocorrelation function significantly drops in two perpendicular directions. That way the control points can be

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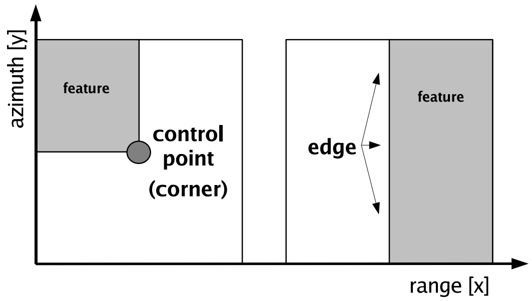

Fig. 1. A corner and an edge

optimally retrieved from the SAR scenes. For the decision on the selection of the appropriate algorithm for control points detection in SAR images we followed [4].

The algorithms presented in [4] were compared in regard to their performance by means of the repeatability rate of the control points selected in the master/slave combination. The tested algorithms were the Harris corner detector, the Cottier algorithm and the Horaud algorithm. Analysis showed, that even though all tested algorithms have the same background idea, i.e. the partial derivatives of the intensity, the Harris algorithm gave the best results. The Harris model gave the good results even in the case of master/slave combinations, where it would normally be a low coherence interferogram. Of course, like it will be indicated a set of arbitrary parameters has to be adapted for a successful InSAR application.

The mathematical description of the detector is that first, the locally averaged moment matrix is computed from the image gradients, and then the eigenvalues of the (pixel) moment matrix are combined to compute a corner "strength", of which maximum values indicate the control (corner) positions. The detection of control points is based on the local structure matrix (tensor), $\mathbf{C}$ which represents the local statistics of the first order derivatives around a pixel (x, y):

$$\mathbf{C} = G(\sigma) \otimes \begin{pmatrix} I_x^2 & I_x I_y \\ I_y I_x & I_y^2 \end{pmatrix} \quad (1)$$

where $G(\sigma)$ is an optional Gaussian with standard deviation σ and $\otimes$ is the convolution operator. The first derivatives I_x and I_y are estimated by convolving the intensity value of the image $I(x, y)$ with the derivatives of Gaussian, in order to reduce noise and aliasing effects.

Control points are pixels for which $\mathbf{C}$ has two big eigenvalues. The so called corner response function ("cornerness") R allows a direct control point sub-pixel detection:

$$\begin{aligned} R &= \det(\mathbf{C}) - \alpha \operatorname{trace}^2(\mathbf{C}), \quad 0.04 \leq \alpha \leq 0.06 \\ \det(\mathbf{C}) &= \alpha_1 \alpha_2 \\ \operatorname{trace}(\mathbf{C}) &= \alpha_1 + \alpha_2 \end{aligned} \quad (2)$$

The sub-pixel positions of control points are found at local maxima of R above a given threshold T ($T > 0$). For InSAR application the following arbitrary parameters are introduced, $\alpha = 0.06$ (empirical constant), $\sigma = 1.0$ and for threshold the 25 times larger value of the maximum intensity inside the search window. Please note that in this case threshold is on the corner response and not on the intensity value. The accepted values are evaluated on their performance in the control points selection within the test data set of SAR images. Since these parameters are arbitrary, they could be always fine tuned for the specific demands on the control points.

Obviously, the accuracy of the sub-pixel control point position strongly depends on the oversampling factor applied to the search window. In our implementation the oversampling factor is 2, since for the matching of corner points by master and slave image the correlation approach is used where further oversampling of the "correlation windows" located at control points is done, [1].

The imaginary radar data is generally highly sensitive to any kind of data smoothing and therefore is important to further elaborate on the application of Gaussian in Eq. (1). The reason for the smoothing operator is to avoid control points due to image noise. This is however not done on the input image but on the image window containing the squared intensity derivatives. In our approach, through the Harris corner detector we estimate positions of the control points within a certain window which is at a later stage oversampled and the intensity peak is then estimated with the sub-pixel accuracy and used as the input for the correlation matching step. However, experimentally the influence of the Gaussian operator with $\sigma = 1.0$ is evaluated and is less then 0.1 pixels. That is within the range of 0.5 pixels for the accuracy of the control point detection with oversampling factor of 2.

C. Practical application and basic properties

This subsection summarizes the basic properties of the Harris corner detector algorithm, [4], which are realized from the eigenvalue analysis of the local structure matrix, see Eq. (1). As previously indicated, the eigenvalues are incorporated in Eq. (2) which serves as a measure for the control point response.

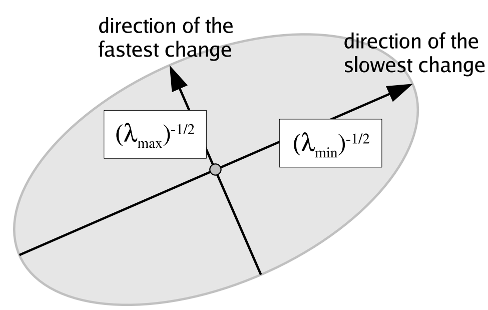

Fig. 2. Intensity change in the control point selection window: eigenvalue analysis

From Fig. 2 which visualizes the "cornerness" equation, Eq. (2), the following conclusions on the properties of the Harris corner detector algorithm can be drawn:

- *Rotation invariance:* The ellipse rotates but its shape (i.e. eigenvalues) remains the same. Hence, the "cornerness" function R is invariant to rotation.
- *Partial invariance to (affine) intensity change:*
  - Invariance to intensity shift $I \rightarrow I + b$, since only partial derivatives are used in the definition of the local structure matrix;
  - Invariance to intensity scale $I \rightarrow I + b$.
- *Non-invariant to image scale.*

From the properties of the local structure matrix and "cornerness" function the general and the implemented condition for the control point selection using the Harris corner detector algorithm are listed and depicted by Fig. 3.

- R depends only on eigenvalues of $\mathbf{C}$,
- R is large for a control point,
- R is negative with large magnitude for an edge,
- $|R|$ is small for a flat region.

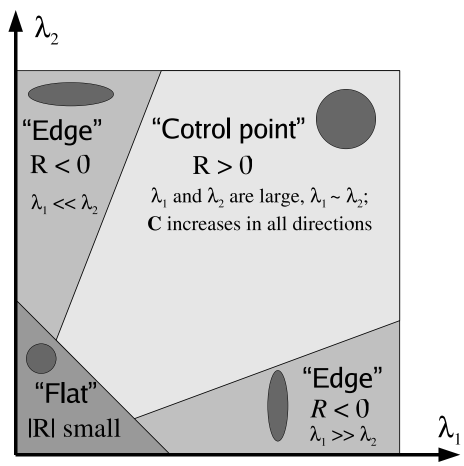

Fig. 3. Classification of the control points using eigenvalues of the local structure matrix $\mathbf{C}$ or the "cornerness" function R.

III. Algorithm Implementation and Numerical Results

As pointed out in introduction, the implementation of the presented concept is within the algorithm for the (fine) coregistration of two SAR images. In this section we give more details on the particular application in the coregistration algorithm. Please note, that the initial offset parameters, coming from the coarse coregistration, between master and slave images should be known.

The starting point is selection of an area for which the cluster of control points will be created, i.e. cluster window. Of coarse this is an arbitrary value, but for the full scene processing the cluster window of size 512×512 pixels should give satisfactory results. For urban areas, even larger windows 1024×1024 pixels are acceptable. This cluster windows are then distributed over the whole scene.

In the next step the feature control points are detected within the cluster windows. As previously discussed, the selection is performed with the following set of arbitrary parameters $\alpha = 0.06$ (empirical constant), $\sigma = 1.0$, and $T = 25 \times \max(I_{window})$. However, it is important to give more information on the control point search window. The size of the window depends on the number of features within the cluster windows, e.g. urban or non-urban area. If the cluster window covers a non-urban area, the size of the control point search window should not be more then 5 pixels, in order to detect control points even of small features. In an urban area, the control point search window of 10 pixels (or even more) is recognized to give good results.

The following figures illustrate the influence of the control point window size on their selection and distribution.

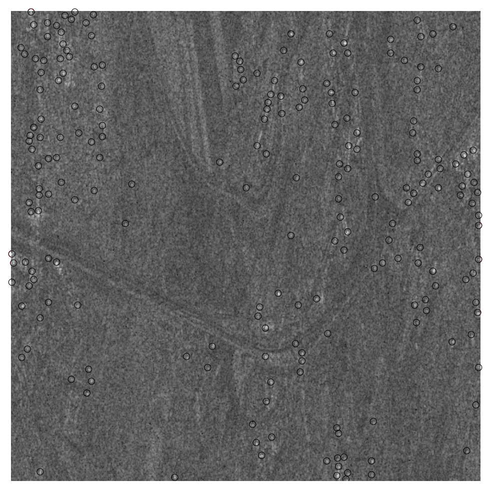

Fig. 4. Performance of the control points selection window of the size of 5 pixels.

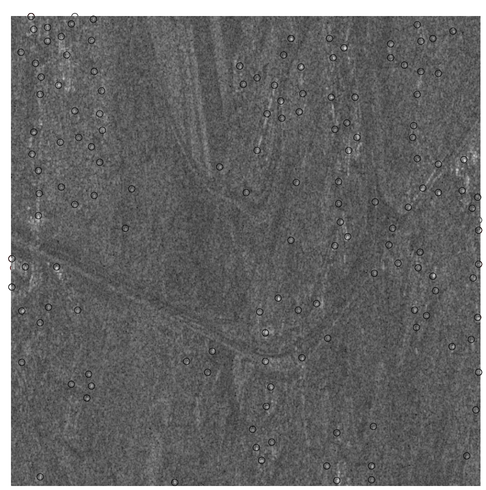

Fig. 5. Performance of the control points selection window of the size of 10 pixels.

The proceeding steps follow as in the conventional way, [1]. The only remark is that, optionally, the correlation matching between the control points of master and corresponding points in slave could be done inside the cluster window, which would improve the computational performance.

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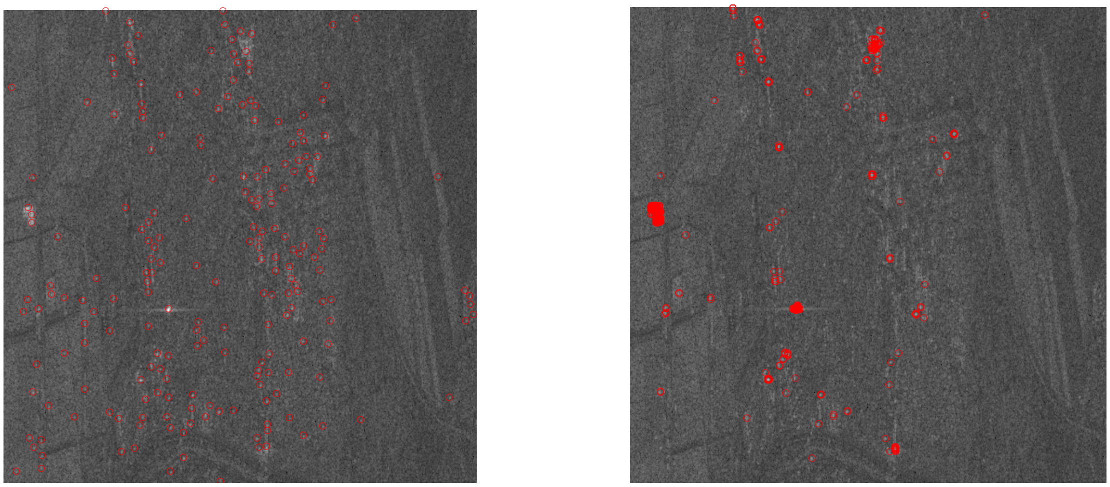

(a) Spatial distribution of points selected with the harris corner detector

(b) Spatial distribution of points selected by thresholding

Fig. 6. Comparision between (a) the modified approach and (b) the conventional approach

As in the conventional methods, this refinement involves arbitrary parameters, which allow fine tuning for the specific application. For example, if the input master image is not a full scene, consequently the cluster window and control point selection window would have to be resized.

As the final step in the evaluation of the presented algorithm the comparison between the points selected by simple thresholding on the intensity and the Harris corner detector algorithm is given.

The results, depicted by Fig. 6 confirm the significantly better performance of the presented algorithm.

IV. Conclusion

We have introduced a new point selection strategy for the fine (correlation based) coregistration. Our approach takes the advantage of features present in the SAR image. By utilizing, for InSAR application modified, the Harris corner detector algorithm, we achieve a significant improvement in the number of control points selected as well as their better spatial distribution. Furthermore, the algorithm is highly adoptable and gives good results even in the case of highly decorrelated scenes. Conclusively, it gives a better global quality of the coregistration model.

A drawback of this approach could be a demanding computation, where the necessary processing time could play a role. Nevertheless, the given advantages of this approach present a strong case for its future applications in InSAR.

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