AUTOMATIC TIE-POINTING IN OVERLAPPING SAR IMAGES

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ABSTRACT:

Within the German ground segment for ERS-1 SAR data the geocoding system GEOS has been developed for the operational generation of geocoded ERS-1 products. Among other contractors, the Institute for Digital Image Processing has contributed essential modules to this system. With regard to individual ERS SAR scenes, these mainly cover the set-up of SAR mapping parameters, the optimisation of these parameters using least squares adjustment techniques and tools for a meaningful quality control of geocoded products. Recent developments have been related to the automatic detection of tie-point candidates in overlapping SAR scenes being acquired either along one satellite track or from adjacent satellite orbits. Therefore, in a first step candidate points, i.e. points showing very specific features, shall be automatically detected in the respective overlapping areas of a selected SAR reference scene. In a second task the corresponding points have to be detected in the areas of the other image(s) overlapping the reference image. This is based on automatic image matching techniques. Potential application areas for such points are given for instance through SAR image coregistration and SAR block processing tasks, respectively.

1. INTRODUCTION

Since the launch of the European ERS-1 sensor, SAR images are available on a continuous basis. Meanwhile also ERS-2, the Japanese ERS-1 and the Canadian RADARSAT are in orbit and SAR data become increasingly used for various applications. With regard to the ERS ground segments the Institute for Digital Image Processing is involved in the German PAF and contributes to the development and maintenance of the geocoding system GEOS, which has been developed for the operational generation of geocoded ERS-1 products. In this concern, recent developments at the Institute have been related to the automatic detection of tie-point candidates (TPCs) in overlapping SAR scenes. Such points may be particularly useful for the geometric modelling and processing or for coregistration of multiple SAR images including stereo models.

In general, the tie-point detection has been designed as a two-step procedure as follows:

1. candidate points in a reference scene, i.e. points showing very specific features, shall be automatically detected in the respective overlapping areas of the SAR image;
2. the corresponding points in the areas of the other image(s) overlapping the reference image shall be found automatically using proper image matching techniques.

Emphasis in this paper is put onto the developments related to the automatic detection of candidate points in a SAR image. Experience has shown, that this is a rather complex task as SAR images are particularly sensitive to certain operations included in the processing. The algorithms and methods, which have been implemented for the detection of tie-point candidates in SAR images, are presented in detail.

Automatic image matching techniques are used in order to find the corresponding points of the detected tie-point candidates in the overlapping areas of the other image(s). Therefore, a technique based on image feature vectors is used, which makes use of particular derivatives of a SAR image, so-called features, being created by filtering the image with methods as mentioned above. The performance of the matching algorithm is analysed for those points provided by the automatic tie-point detection procedure.

2. TIE-POINT CANDIDATE DETECTION

The tie-point candidate detection procedure aims at the automatic definition of characteristic points and regions, which presumably can be detected in the overlapping area of another SAR scene with high probability. In the ideal case, man made features like streets or railroads or crossings of such linear features should be typically detected. However, such features may either not always be available or may not be clearly visible in SAR images due to the SAR speckle noise.

Moreover one has to cope with other SAR specific peculiarities like layover, foreshortening and so-called strong scatterers. Therefore, respective preprocessing steps like prefiltering or preclassification have been implemented in order to increase the detectability of characteristic points in a SAR scene. For the final detection of such points the so-called Geometrical Ratio Operator (GRO) has been implemented. In this context the work carried out by Desnos and Matteini (1993) or Touzi et al. (1988) has been considered.

2.1. Prefiltering

In a first preprocessing step prefiltering algorithms may be applied to the images to be treated in order to reduce the SAR inherent speckle noise. For that, commonly used adaptive filter methods may be used like, for instance, the Frost, Lee, Kuan, or MAP filter, all of them being based on local statistics. These filters reduce the speckle noise as a function of heterogeneity measured by the local coefficient of variation. The MAP filter additionally considers geometric informations.

2.2. Preclassification

In another preprocessing step the image information may be classified into homogeneous areas, where the SAR image signal shows little variation, and into heterogeneous areas where the SAR signals varies significantly due to textured areas, edges or point targets. Subsequently, homogeneous areas can be considered to be of no further use in this concern and can be excluded from further processing. This may significantly reduce the computational effort for the subsequent procedures.

A very efficient and robust index for textural information which measures the image heterogeneity is given by the local image coefficient of variation (COV). Image reduction methods based on the Gaussian kernel filter may be applied in order to eliminate micro structures in the SAR scene and to make the detection procedure more sensitive to macro structures.

A frequent problem particularly in built-up areas is the presence of strong scatterers, being small bright features with point-like shape. These in general could represent well defined tie-points, but are very critical within the subsequent tie-point matching procedure as their shape may be different in other SAR images or they even may completely disappear. A possibility to identify and eliminate strong scatterer areas was therefore included into the preprocessing and preclassification procedure. A selected percentage of the brightest pixels in the image is therefore interpreted as strong scatterers and region growing is applied in order to mask respective areas.

2.3. Geometrical Ratio Operator

The SAR speckle noise makes the extraction of textural features very difficult. As gradient operators are strongly dependent on the main reflectivity, ratio operators are considered to be more appropriate. Therefore, the so-called Geometrical Ratio Operator (GRO) has been developed for the detection of tie-point candidates. A particular objective of this operator is the detection of structural information like edges between extended areas and curvilinear structures like roads, shapes, hedges, shadows etc. Further advantages of this operator are the constant alarm rate, the possibility to implicitly determine threshold parameters and its simple implementation.

The ratio operator is defined as the ratio of the pixel average of two non-overlapping neighbourhoods on opposite sides of the inspected point. To be sensitive to any geometric location and orientation of edges, the filter is applied in the usual four directions, i.e. horizontal, vertical, and twice diagonal. Using neighbourhoods of increasing size in combination with variable thresholds allows to detect both micro edges as well as extended features.

Subsequently, the four directional GRO results are exploited in order to detect corner points. Such points are defined by their high probability to be an edge in at least two directions. Finally, the most useful tie-point candidates are selected taking into consideration a given minimum distance between two neighbouring points.

2.4. Tie-point Detection Example

The principle of the tie-point candidate detection procedure is demonstrated for a small SAR image chip of 200 by 200 image pixels. This image chip shows a major river body appearing in rather dark grey values (see Figure 1). Figure 2 shows some examples of intermediate results of the various optional preprocessing steps mentioned above, like particularly:

- Kuan-filtered SAR image with a 3 x 3 filter kernel.
- Preclassified image chip showing the separation of the image into homogeneous areas (black) and heterogeneous areas.
- Removal of areas containing strong scatterers, which were defined in this example by the 0.01 brightest pixels in the image chip. Region growing with 7 pixels was further applied to define respective strong scatterer areas.

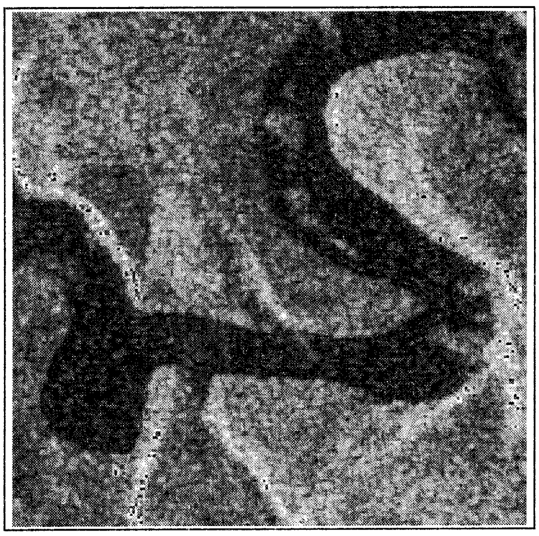


Figure 1: Selected image chip.

For an exemplary detection of tie-point candidates, all these preprocessing steps have been applied to the test image. In a next step the geometrical ratio operator was applied in order to detect edges in the four main directions with a 5 x 5 filter kernel. The respective results are shown Figure 3 (a-d). These images are further input for the another ratio operator, which determines likelihoods for the individual pixels to be corner points along an edge. The result of the operator is shown in Figure 3 (e), where the likelihood increases with the darkness of the pixels.

Finally Figure 4 shows the tie-point detection result, which has been generated for the selected image chip. The detector allows the definition of a number of „best“ tie-points to be found in the selected area. In the present case the detection of 15 and 5 tie-points, respectively, was envisaged (see Figure 3, left and right). A minimum distance of 40 pixels between individual candidates was further specified.

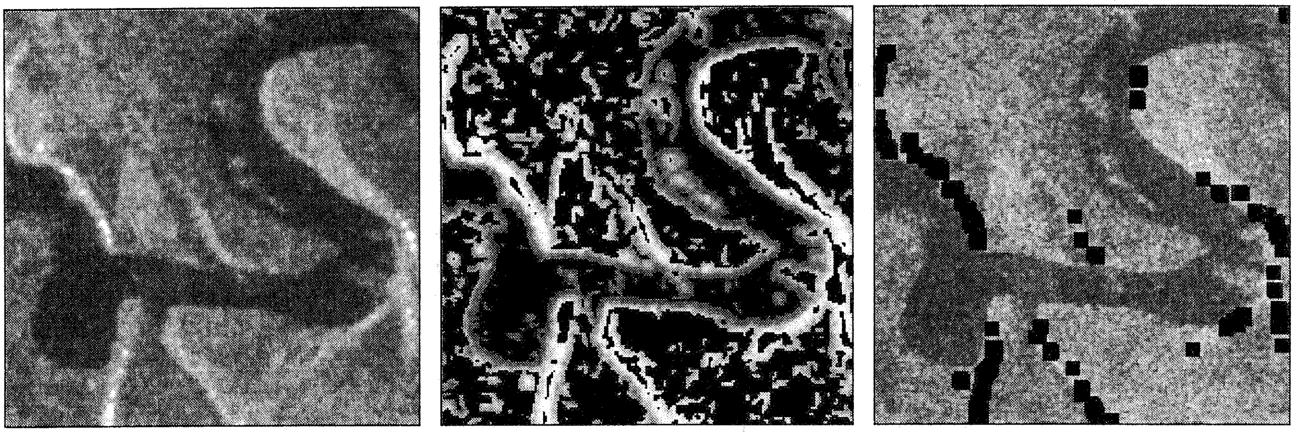
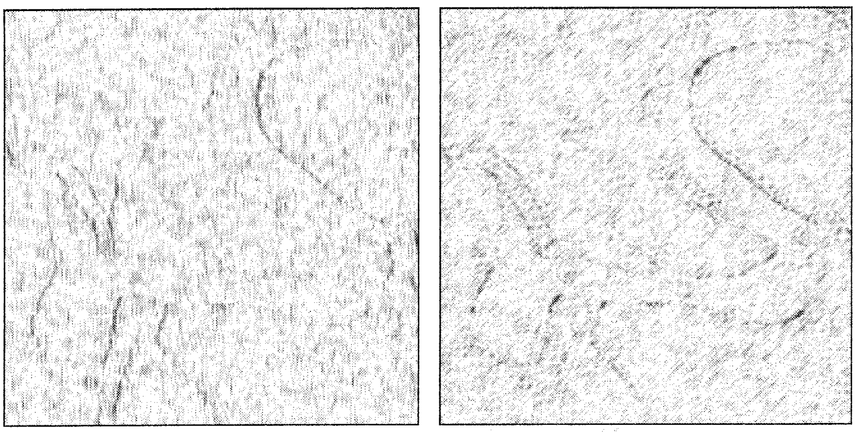


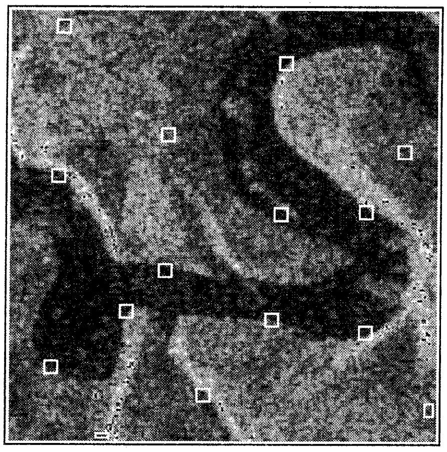
Figure 2: Preprocessing products: Kuan-filtered SAR image (left), preclassified image (mid), strong scatterers (right).

(a) (c) (e)



(b) (d)

Figure 3: Results of GRO, applied in horizontal (a), vertical (b) and diagonal direction (c and d), and of ratio edge/corner point detector (e).



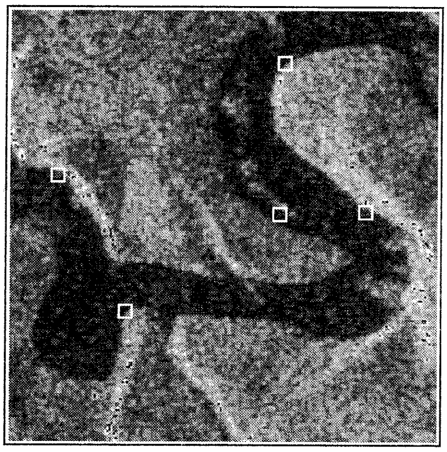


Figure 4: Tie-point detection results showing 15 best (left) and 5 best (right) point candidates.

3. TIE-POINT MATCHING

3.1. HFVM Method

In a next step the corresponding points of the detected tie-point candidates have to be found in the overlapping areas of the other image(s). Therefore, an automatic matching tool, the so-called Hierarchical Feature Vector Matching (HFVM) is applied, which has been developed by Paar et al. (1991, 1992). The HFVM method integrates particular derivatives of a SAR image, so-called features. While conventional matching techniques usually exploit just one local image property (e.g. grey level, edge, corner, local phase), the HFVM tool analyses a combination of several local features in connection with a hierarchical image representation. This allows to consider SAR specific image properties on the one hand and to correspond with the tiepoint candidate detection on the other hand, as similar or same filters and features can be applied within the tie-point detection and the tie-point matching procedure, respectively. By the large variety of features particular disadvantages can be equalised.

The principle of the HFVM method can be summarised as follows:

- A set of feature images for both the reference and the search image is CertEd. The features are derived from local properties in the surrounding of each pixel. The contents of these feature images describe a feature vector for each pixel location in both images.
- For each pixel of the reference image its feature vector is compared to the feature vectors in the expected search range in the search image. Using the Euclidean distance, the minimum distance vector defined the corresponding pixel.
- The columns and row disparity images are smoothed using median filters. Then, errors are removed and undefined disparities interpolated. This is done from the lowest to the highest necessary resolution, using the low resolution results as prediction.

HFVM provides a dense disparity map which gives access to the disparity of every pixel of the input image. HFVM allows fast and robust matching together with a large variety of choices in terms of accuracy, resolution, consistency checks, an computational effort. Originally, HFVM has been developed to compute dense disparity maps for optical stereo images including rugged terrain. It is a general method also suitable for SAR imagery. In fact this algorithm is shown to be just as efficient as methods being specifically suited for SAR imagery corrupted with speckle noise (Gelautz et al., 1996).

For the matching of tie-point candidates the HFVM method has been slightly adapted as follows:

- Only the surrounding of a TPC has to be considered in the matching process. Thereby, potential pixel disparities due to terrain relief should be taken into account.
- SAR mapping mechanisms based on initial imaging parameters are used to map the reference area of interest to the search image.
- Backward matching from search to reference image is used and the pixel difference between reference TPC and „back-matched“ TPC serves as a quality measure in order to accept or reject the correlated result.

3.2. Tie-point Matching Example

The performance of the HFVM algorithm is analysed for those points being provided by the automatic tie-point detection procedure, i.e. the detection results presented in Figure 4. Figure 5 shows the reference image chip together with the respective area of the search image. For the matching of the TPCs a backward correlation was performed with a maximum mismatch distance of 1 and 1.5 pixels, respectively. Figure 6 presents the reference image chip with those areas exceeding this backward matching limits shown in white. It can be seen that for SAR images the areas fulfilling the specified backward matching criteria are rather limited. Obviously for less than 50% of the entire area the backward matching is accurate within 1 pixel.

The matching results of the HFVM method for the 5 best tie-point candidates (see Figure 4, right) are shown in Figure 7 for both the 1- and 1.5-pixel backward matching criteria. While for the 1.5 pixel limit 4 points were successfully correlated, only 2 tie-points were accepted in case of the 1 pixel limit.

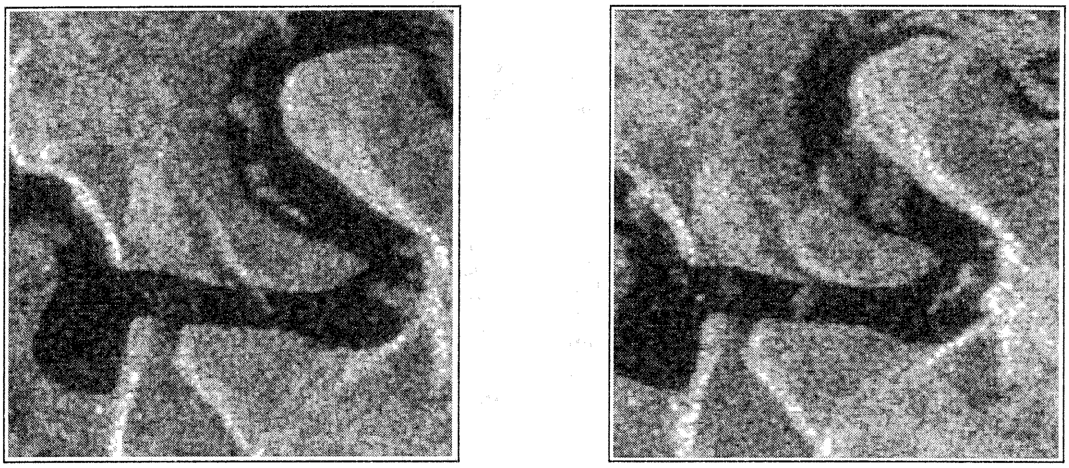


Figure 5: Reference image (left) and search image (right) for tie-point matching.

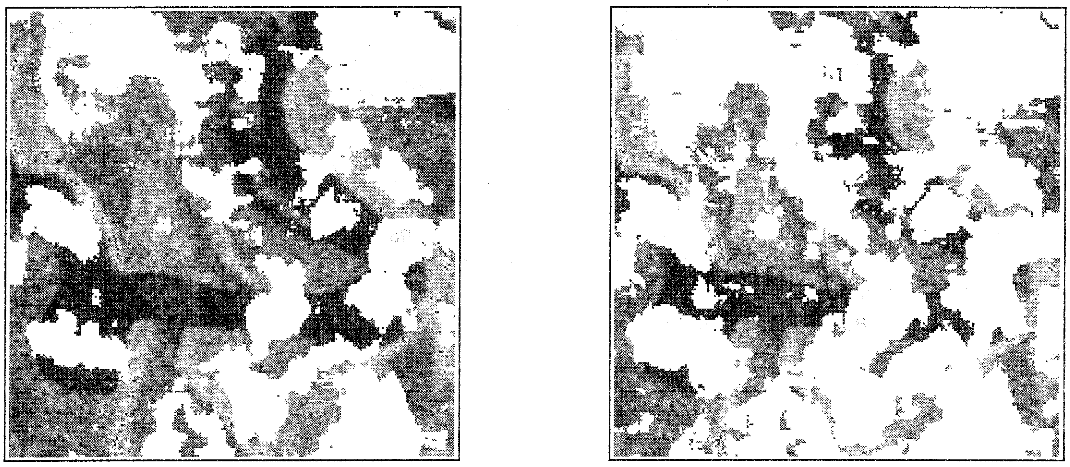


Figure 6: Masks of areas exceeding a backmatching limit of 1.5 pixels (left) and 1 pixel (right).

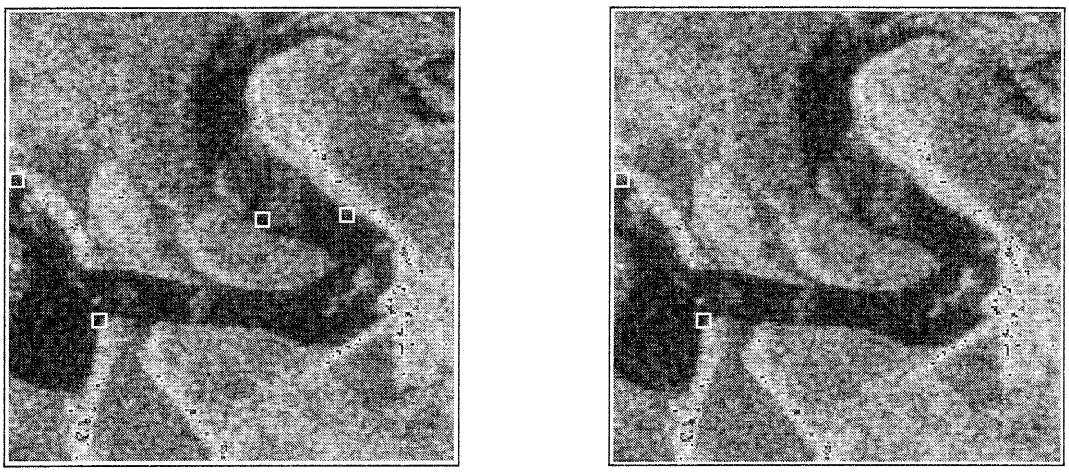


Figure 7: Matching results for tie-point candidates for backmatching limits of 1.5 pixels (left) and 1 pixel (right).

4. APPLICATION ASPECTS

The output of this procedure are tie-points being automatically determined in 2 or more SAR images. Potential application areas for such points are given for instance through SAR image coregistration and SAR block processing tasks, respectively.

In the first case the tie-points can be used to register multitemporal sets of SAR images (time series) automatically. In the second case the basic intention is the treatment of SAR image blocks in analogy to photogrammetric procedures. Here, the main objective is to use tie-points being detected in the SAR image block together with ground control points within a least squares SAR image block adjustment in order to determine the SAR mapping models simultaneously for all images of the block. The background idea is to cover large areas with low ground control point density on the one hand and, if necessary, to bridge over areas with no ground control at all on the other hand.

Typical application areas for SAR block processing could be third world areas being insufficiently mapped until today. Based on related examples over well-mapped Mid-European areas the potential of automatic tie-pointing for such applications shall be demonstrated.

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