Geocoding in SAR Layover Areas

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Abstract

In this paper we show how the radiometric appearance of the layover regions in the geocoded SAR image can be improved by proper redistribution of the power contained in the layover pixels. Geocoding of SAR images usually does not account for layover distortion. The proposed algorithm relies on simulation and the distribution of the intensities in layover areas according to their origin (under assumption of a backscatter model). Tests are carried out on real and simulated ERS-1 data of the Ötztal test site. They demonstrate how the underlying topographic relief, formerly covered by the bright stripe-structures typical of geocoded layover, now becomes visible in our "layover-corrected" geocoded products.

1 Introduction and Motivation

Radar layover is a special problem that arises when dealing with SAR imagery of mountainous terrain, with slopes steeper than the off-nadir look angle of the SAR sensor. For these slopes, the top of the mountain is closer to the sensor than the bottom. Since radar is a range measuring device, this configuration leads to particular geometric distortions, which are denoted as layover. As can be seen from **Fig.1**, different terrain points (e.g. A and C, or B and D) result in one point in the slant range image. More precisely, we can actually distinguish between two types of layover regions, denoted as "active" and "passive" layover: Active areas are those which cause layover because of the local incidence angle condition, whereas passive layovers are only affected by layover due to an adjacent active region (see Fig.1).

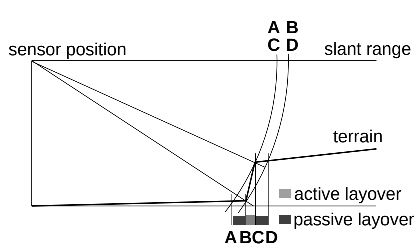

Figure 1: *Origin of active and passive layover.*

Due to the superposition of multiple scatterers from different parts of the terrain, layover areas appear in the SAR image as bright regions with the original geometric order being reversed. A more detailed discussion of the SAR imaging geometry, including the layover phenomenon, can be found in, e.g., [5], [3], or [7]. A theoretical analysis of different layover configurations as well as possible interactions between layovers and shadows was carried out by [4].

In order to improve the usefulness of SAR images, their inherent geometric distortions must be eliminated by generating a radar ortho-image that corresponds to a well defined map projection. Fundamentals on geocoding can be found in, e.g., [3] and [5]. [6] describes an operational algorithm for ERS-1. The approach we use in our study relies on simulation and subsequent transformation of the original scene into the geometry of the simulated image. The actual geocoding is then performed by inversion of the simulation process.

For the thematic interpretation of SAR imagery acquired of hilly to mountainous terrain, the correction of terrain-induced radiometric distortions constitutes a further important requirement (besides the geometric rectification), in order to separate brightness variations due to topography from thematic information. Calibration algorithms for SAR images are, e.g., discussed by [1] and [2]. Practically all the literature on radiometric correction deals with non-layover areas. According to the authors' knowledge, the reduction of radiometric distortions in layover areas has only been addressed by [8]. However, there the term "layover" is actually used in a broader sense, denoting the "focussing effect of slopes approaching or exceeding the radar look angle".

The overall radiometric correction procedure is normally divided into two steps: After the (theoretically) precise elimination of the so-called *area effect* (i.e., the compensation for the relief-induced change in radar ground resolution), further efforts to reduce the remaining topographic component need to be based on the approximation by a backscatter model. In SAR layover, however, the aforementioned division of the calibration procedure into two separate steps is no longer possible.

Due to the superposition of signals reflected from areas with different local incidence angles, the area effect cannot be separated from the angular dependency of the backscatter coefficient σ_0. This means that any attempt to correct for topographic effects in layover regions has to rely on the assumption of a backscatter model, and can therefore only be approximate.

Nevertheless, even though we cannot expect to recover a fully calibrated image in SAR layover, a reduction of the radiometric layover distortion would still be desirable. It is expected not only to improve the visual impression of the geocoded image, but also to provide additional information for subsequent image interpretation.

The investigations described in this paper were carried out using ERS-1 SAR images of the Ötztal test site, a rugged terrain in the Austrian Alps, where layover occurs frequently. The ERS-1 subscene (23 deg look angle, ascending orbit) can be seen from the bottom left picture in **Fig.2**. The image was illuminated from the left and covers approximately 6 x 6 km^2. The available DEM has a grid width of 25 m, and a height accuracy of better than 20 m. The DEM subregion corresponding to the test site is shown in the middle picture of the bottom row in Fig.2.

In the following, we first describe the proposed geocoding algorithm along with some aspects of its implementation. The method is then applied to ERS-1 imagery of the Ötztal region. The results are compared to those obtained from traditional geocoding, and the improvements achieved are discussed.

2 Algorithms

The implementation of the algorithm can be described as follows. For each pixel in the simulated image, information about those DEM cells which are mapped onto that particular pixel is recorded during the simulation process. Conventional geocoding, in the following denoted as method (A), is then performed by assigning each DEM cell the gray value at the corresponding image position, after applying an appropriate resampling algorithm (e.g., nearest neighbor).

A first modification of this algorithm consisted of dividing the gray value at the corresponding image position equally among all DEM cells contributing to that particular pixel [method (B)]. This principle was then further refined by storing during the simulation step not only the position but also the percentage contribution of each DEM cell to the final pixel intensity. This contribution depends on both geometric aspects (area effect) and the chosen backscatter function. The radiometric correction during the geocoding is then performed by assigning each DEM cell its associated fraction of the intensity of the corresponding image pixels [method (C)].

Although the goal of our current project was the reduction of the radiometric distortion in SAR layover, it should be noted that the implemented algorithms do not actually distinguish between layover and non-layover regions. Outside the layover zones, method (C) basically removes the area effect; the chosen backscatter function cancels out, since in foreshortening areas adjacent DEM cells mapped into the same image pixel typically exhibit similar local incidence angles, and hence backscattered intensities.

3 Tests and Results

The SAR simulator used in this investigation employs a high-resolution input DEM in combination with several simplified assumptions about the imaging geometry (straight sensor flight path and flat Earth approximation) to compute the synthetic SAR image line by line, perpendicular to the flight path.

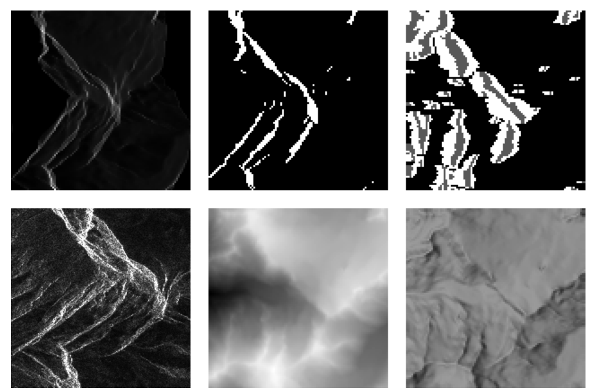

Figure 2: *Result of the simulation process. In the bottom row, from left to right, the original ERS-1 SAR image (©esa), the DEM (higher elevations are displayed as brighter regions), and the backscatter map in DEM geometry. In the top row, the simulated SAR image on the left, the layover map in the geometry of the SAR image in the middle, and the layover map in DEM geometry on the right, where white regions denote passive and gray regions active layover.*

During the first step of the simulation procedure, a backscatter map in DEM geometry is computed by using the local incidence angle information and assuming a cosine reflectance function. The distance between each DEM cell and the SAR sensor is recorded in a so-called range image. The simulated SAR image is then computed by sorting the range values line by line in increasing order, and adding up their backscatter values at the corresponding positions in the SAR image. The occurrence of layover is correctly treated by this approach, active and passive layover maps are also generated during the simulation. **Fig.2** shows a typical simulation result.

We started with tests on simulated imagery. The exact relations between DEM cells and pixels in SAR geometry are known and can be used directly for the inverse process.

3.1 Simulated Images

Ordinary geocoding procedures (A) assign the pixel intensities from the SAR image to every DEM cell which contributed energy to that SAR pixel. In layover areas, this procedure yields bright stripe-structured areas, spread over the whole area of active and passive layover, as can be seen from the left picture in **Fig.3**. A layover map could be generated from this image, using a simple threshold operation. It is quite obvious, that these layover areas must be excluded from further thematic investigations.

Figure 3: *Simulation of different geocoding processes. From left to right: ordinary geocoding (A), distribution of the intensities according to the number of DEM cells involved (B), and according to the refined method (C) using the backscatter map.*

Our first improvement to the geocoding process (B) in layover regions was to assign every pixel in the geocoded image according to the recorded list of involved DEM cells per SAR pixel the intensity of that SAR pixel divided by the number of DEM cells involved. Thereby the total intensity contained in the SAR image is distributed among the pixels of the geocoded image. The middle picture in Fig.3 shows the result of this geocoding procedure. As an improvement to the left picture in Fig.3, the stripe structures in the layover areas were removed. Striking in this picture are certain artifacts, caused by the quantization of the intensities. These errors could be reduced by adequate oversampling of the DEM.

A further improvement was made by dividing the intensities of the pixel in the SAR image by the portion each DEM cell contributed to the final SAR pixel intensity, denoted as method (C). Not surprisingly, for simulated images this procedure results in the backscatter map, as can be seen from the right picture in Fig.3 (in comparison to the backscatter map shown in the right picture in the bottom row of Fig.2). The stripe structures, visible after the ordinary geocoding process in layover areas, were removed. Also the artifacts due to quantization of the intensities were removed.

After having verified the principal functioning of our method on simulated data, our next step was to incorporate original ERS-1 SAR images in our investigation.

3.2 Original Images

In order to apply the algorithms tested before on simulated images to original images, first a transformation of the original images into the geometry of the simulated images was necessary. A simple 6 parameter affine transformation was found to compensate sufficiently for the observed geometric differences between the simulated and original image due to the simplified parameter assumptions for the simulation. **Fig.4** shows the results of this transformation process for the test area.

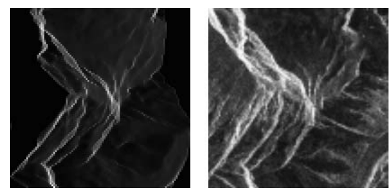

Figure 4: *The original ERS-1 SAR scene after transformation (right) into the geometry of the simulated image (left).*

This transformed original image was now input to the geocoding process. Instead of the intensities of the simulated image, the intensities of the corresponding location in the original image were distributed according to the three geocoding procedures described before.

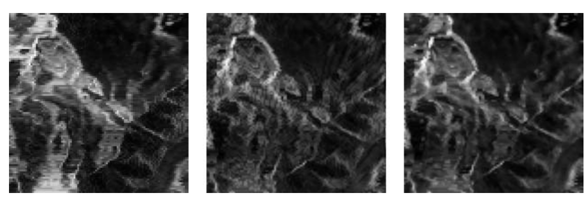

Figure 5: *Geocoding of the original ERS-1 scene. From left to right: usual geocoding (A), distribution of the intensities according to the number of DEM cells involved (B), and according to the refined method (C) using the simulated backscatter map.*

The results of applying method (A) to the original SAR image can be seen from the left picture in **Fig.5**. Note that the layover areas in the geocoded image are not so prominent compared to the corresponding geocoded simulated image (Fig.3), however the location of the layover areas could still be derived from this image applying a threshold operation. Also, the stripe structures of the layover regions spread over the whole active and passive layover areas are still visible.

The results obtained from applying method (B) to the original image are shown in the middle picture of Fig.5. It can be seen that the coverage of the layover pixels could be resolved by this approach, underneath structures became visible. The narrow areas of high intensities result from remaining deviations between the simulated and real image which were not fully compensated by the computed transformation. The artifacts which were visible in the distribution of simulated intensities (Fig.3, middle picture) are minor in the distribution of the original intensities. This is probably due to the existence of speckle noise in the original image.

Finally, the geocoded image produced by method (C) (i.e., the proportional re-distribution of the SAR pixel intensities under assumption of a cosine law) is shown in the right picture of Fig.5. In comparison to the picture in the middle of Fig.5, further improvements are visible. New structures that were covered by layover applying the usual geocoding process now become visible. The narrow stripes of high intensities caused by residual deviations between the original and simulated image are still visible in the right picture of Fig.5. From these artifacts, estimations about the accuracy of the geocoding process can be made.

Further examples of the radiometric correction were carried out on other subsections of the Ötztal test site. Similar results were obtained, with the layover-corrected images giving a more balanced radiometric impression and providing more topographic details.

4 Summary and Discussion

In this paper we have presented and tested a method to improve the geocoding process in layover areas radiometrically using simulation. In conventional geocoding, the high intensities in geocoded layover regions hide the underlying terrain structures and require layover areas to be excluded from any further analysis. We have shown that simulation of the image formation process in conjunction with an assumed cosine backscatter law can be utilized to refine the geocoding process by redistributing the backscattered intensities according to their origin.

The resulting geocoded images were found to be visually more appealing: the bright layover stripe-structures were removed and underlying terrain structures became visible, thus providing a better orientation to the user of the geocoded products. Some clearly discernible artifacts which were observed in the geocoding result (bright narrow structures arising at some layover borders) are related to remaining registration inaccuracies between the real and simulated image, and could hence be utilized in a next step to assess the geometric accuracy of the geocoded image.

Regarding a possible thematic interpretation of the geocoded layover zones, it should be noted that, due to the assumption of a particular backscatter model, a radiometrically calibrated image cannot be recovered in these areas. The question whether despite of that some thematic information can be extracted in the layover (e.g., by evaluation of differences between the assumed backscatter map and the geocoded image) would be a possible subject for future investigations.

Acknowledgment

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