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Image Enhancement and Evaluation: SAR Layover and Shadows

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Abstract

The use of SAR images includes the need for co-registration of individually acquired, yet jointly processed imagery. Topographic effects must therefore be well understood to be able to remove them, or to consider them as a source of information about the terrain. We describe those topographic effects that most distinctly obstruct the joint use of multiple SAR images, for example taken from ascending and descending orbits, or from West- and East-looking aircraft sensors. These effects are the radar layover and shadows. While they obstruct the co-registration of overlapping images, they also hold promise as a source of topographic detail independent of stereoscopic or interferometric methods of analysis. We show by means of Magellan's Venus images and of ERS-1 terrestrial coverages how the layover manifests itself, and we point the direction towards unlocking the information contained in layover and shadows.

1. Introduction to SAR Image Enhancement and Evaluation

The enormous amount and variety of SAR data delivered by current and future earth-orbiting sensors such as the European ERS-1 and ERS-2, the Japanese JERS-1, the Shuttle imaging radar X-SAR/SIR-C, the Russian Almaz, the Canadian Radarsat, and Europe's Envisat, provide new, challenging tasks for the processing and analysis of remotely sensed data. Whereas during earlier campaigns in the late 1970s and 1980s, such as Seasat, SIR-A, and SIR-B, investigations were limited to imagery delivered by one particular sensor, repeated coverage by present satellite-based sensors results in time-series of images acquired with varying frequency, polarization, and incidence angle. Additionally, data available from optical sensors need also be taken into account. This leads to the development of data fusion techniques, which aim at exploiting the information contained in the whole data set available from different sources. Examples of recently published work on data fusion for remotely sensed data include studies carried out by Pierce et al. [18] on the joint use of ERS-1 and JERS-1 data, and by Schistad et al. [20] on the fusion of Landsat TM and ERS-1 images.

Another issue of growing importance is the processing and archiving of the large data quantities delivered by both earth-observing and extraterrestrial missions. As an example of the latter one, during NASA's Magellan Mission to planet Venus more than 400 Gbytes of imaging data were collected, which now need to be processed. Parallelization, at both data and program level, seems to be a promising strategy to reduce computing times. The principle of data decomposition can be applied to images in a straightforward way, namely by splitting up the original image into subimages of smaller sizes, which are then distributed over several processors. A possible area of application for the principle of program decomposition is the group of hierarchical algorithms: Different levels in the hierarchy are assigned to different processors, and processing is done in a pipeline-fashion.

With regards to archiving and distributing remotely-sensed data and derived products, the development and evaluation of efficient data compression methods for both gray-value and color-encoded images has been addressed recently by, e.g., Hadenfeldt and Sayood [11] and Datcu et al. [7].

Generally, most image analysis techniques currently applied to SAR data were originally designed for optical data. This includes basic image processing operations such as thresholding, edge detection, and filtering, as well as higher-level operations such as segmentation, texture analysis, image matching and classification. When adopting these techniques to SAR, radar speckle noise constitutes a significant problem. Therefore a wide range of speckle filtering techniques have been developed and are still under development. In addition to speckle noise, the influence of topography and illumination direction on image gray values need also be taken into account when extracting thematic information from SAR images, especially in hilly to mountainous terrain.

Apart from conventional image analysis techniques, approaches that can be found in recently published literature include

- wavelets
- fuzzy logic

- fractal analysis
- simulated annealing

For example, the use of wavelets for noise reduction and stereo image matching is described by Carlson [4] and Djamdji and Bijaoui [8] , respectively. Liew et al. [16] and Bourissou et al. [3] employ fractal concepts for texture analysis and classification of SAR images. An application of fuzzy logic to SAR imagery is described by Barni et al. [2], and the use of simulated annealing is reported by Hadenfeldt and Sayood [11].

The considerable scientific effort going into radar image enhancement and evaluation, however, typically ignores the complications induced by topographically accentuated terrain. Yet, multiple coverages such as those from free-flying orbital platforms such as ERS-1 or 2, Radarsat or Magellan, are of particular interest when the topography is non-trivial.

2. SAR Layover and Shadows

An investigation carried out by Leberl et al. [15] shows that the performance of conventional image matching algorithms, which were originally designed for optical data, deteriorates significantly when they are applied to radar data. It is speculated that the main reasons for that reduced accuracy are radar-specific peculiarities such as differences in illumination in the two stereo-images, and effects of foreshortening, layover, and radar shadows, as well as speckle noise.

Two of these features, namely layover and shadows, are now studied in more detail. The idea is to convert these radarspecific features, which are currently a source of perturbation, into an additional source of information for the reconstruction of the corresponding Digital Elevation Model (DEM) and the geocoding of SAR images. This approach is motivated by the observation that in SAR scenes of mountainous terrain the most prominent features of the image are often the layover and shadow areas. Although, from a radiometric point of view, shadows contain no useful information about the reflectance properties of the viewed terrain, and layover is also considered to be unusable, the geometric information (i.e., the location and shape of these features) can be exploited. We are concerned with the refinement of DEMs in layover and shadow areas, and we hope to create derived geocoded image products with useful image detail even in areas of layover and shadows. We thereby deal with multiple image data sets, often in an effort to convert such multiple images into co-registered "image stacks" ready for applications-specific computer analyses or visual image interpretation.

As a first step, the layover and shadow regions of a SAR image need to be identified. We can distinguish between two cases, namely (a) a DEM is available from external sources, and (b) no DEM is available for the imaged terrain. A DEM can be used together with knowledge about the sensor flight path and the imaging parameters to predict the layover and shadow areas in the image. An algorithm for the calculation of these areas is, for example, described by Meier et al. [17]. Without a DEM, the layover and shadow areas have to be extracted from the image itself by applying suitable image processing algorithms. Here again we find several different avenues; one in the event of a stereo-image pair from which a DEM may be developed; a second one if multiple, yet non-stereoscopic data sets such as opposite-side pairs are available; and finally, layover and shadow regions may have to be found in a single radar image. The layover and shadow regions are a result of the range-sensing geometry of a SAR (Figure 1).

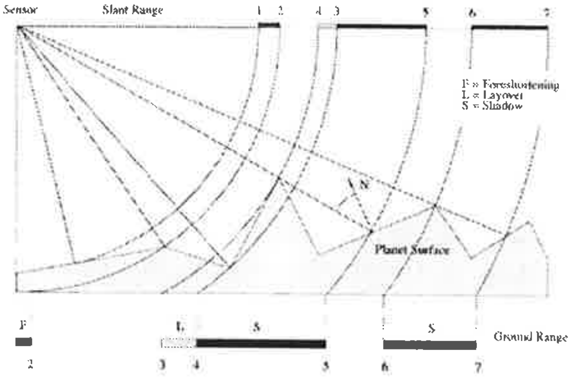

Fig. 1. *The geometry of layover and shadow regions in radar images (after Schreier [21]).*

The layover region is produced by multiple scatterers from different parts of the terrain, which lead to an increase in backscattered energy. Layover is therefore often rather bright. However, mere low-level image processing algorithms based on image gray values are normally not sufficient to detect layover reliably, since bright features in the image may also be caused by extreme foreshortening or high reflectivity of the terrain surface. Similar considerations hold for radar shadows, which, due to the lack of reflected energy, appear as dark regions corrupted by thermal noise. The use of multiple images taken with different imaging geometries is expected to reduce these ambiguities. In our current project, we aim at using SAR images taken from the same side, but with different look angles, as well as images taken from the opposite side.

Once the layover and shadow regions are identified, this information is stored in a so-called layover and shadow map. As stated by Schreier [21], the conventional use of such a map is nearly exclusively limited to masking those areas of an image which should be excluded from further radiometric analysis. In the following, we propose further applications. One deals with real-simulated image matching for SAR image geocoding, a second one with terrain reconstruction from stereo imagery, a third one with co-registration of opposite-side radar images, a fourth one with the creation of desired image-map products where the layover and shadow areas are filled-in with useful image detail.

The ideas presented in the following sections are illustrated for the case of radar layover. Analogous considerations are applicable to radar shadows.

3. Matching Radar Images with Existing Elevation Models

The use of a simulated radar image for subsequent matching of the simulated and real imagery is denoted as "real-simulated image matching" and is applied to automated geocoding of SAR images. This has, for example, been reported by Curlander and Kober [6], Kwok et al. [13], and Guindon [10]. The principle is to establish a relationship between the real and simulated image, which can then be used together with the known mapping equations between DEM and simulated image to determine the geometric relationship between DEM and real image. Traditionally, authors have employed the entire grey value image, although Curlander and Kober [6] focussed on shadows only. The technique described in the following differs from the typical methods since it only uses layover areas. It is suited to imagery acquired of high-relief terrain. A study on the use of layover in an interactive system for the geocoding of SAR images was presented by Plößnig et al. [19] . In that work the simulated layover map is only determined in DEM geometry, and not in SAR image geometry. Due to the apparent differences between DEM and image geometry, the determination of corresponding points between real and simulated image requires support by a human operator. In the following, we illustrate our method which relies on computing the binary overlap between a layover map produced by simulation and the presumed layover areas extracted from a real SAR image by thresholding.

An original ERS-1 image of the Otztal test site, a rugged terrain in the Austrian Alps, is given in Figure 2. Figure 3 shows the corresponding layover map. The simulation program used to compute the layover map is part of the RSG software package (JR Graz) [12]. High geometric precision was achieved by using a parametric mapping model based on SAR range and Doppler equations, and additional tuning of the simulation input parameters delivered by the SAR processing facility. As was proven by manual collection of control points, the positional difference between the real and simulated image is only translational. The task is now to determine this offset automatically.

Fig. 2. *A 1805 x 973 pixels ERS-1 sub-scene of Otztal, Tyrol. The image was acquired during an ascending orbit with a look angle of 23 deg. The area shown covers approximately 22 km x 12 km, pixel size is 25 m x 25 m. Copyright esa.*

Fig. 3. *Layover map produced by simulation. Bright areas indicate layover. The source is a DEM at a mesh size of 25 m. The simulation is produced with the program RSG (JR Graz) employing the ERS-1 orbit details of the scene in Fig. 2.*

In order to extract the layover areas from the real image, the percentage of layover pixels in the layover map is calculated and used to select a suitable threshold value. The result of the thresholding can be seen from Fig. 4. Comparison with Fig. 3 shows differences which are mainly caused by varying surface reflectance properties and speckle noise, as already discussed before. In order to determine the offset between the two masks, a search window of size 30 x 30 pixels was defined. For each position within this window, the number of overlapping pixels was computed, and finally the position with the maximum overlap was calculated. This represents a so-called SSDA method (Barnea and Silverman [1]) of image matching. The difference between the two positions is thus automatically determined

Fig. 4. *Presumed layover areas extracted from Fig. 2 by thresholding. The threshold value was determinated automatically from the percentage of layover pixels in Fig. 3.*

and represents the offset of the real image vis-a-vis the assumed sensor and orbit parameters. It differs from the manually measured offset by less than one pixel. The result of the binary overlap is illustrated in Figure 5.

The experiments carried out up to now have shown the feasibility of this approach. As a next step, an extension to the algorithm will be implemented to cope with those cases where insufficient knowledge of the simulation input parameters leads to additional distortions between the real and simulated image.

The idea is to select subwindows of a suitable size, for which the assumption of a mere translational difference is still valid. The resulting set of match points can then be used to compute the parameters of an affine transform for the geocoding process. Another possibility is to use the match points for a refinement of the simulation input parameters.

An advantage of this method over conventional real-simulated image matching techniques is the reduced computing burden, since only the layover areas have to be determined, and the gray values of the simulated image need not be calculated explicitely. Further tests will be performed to assess the accuracy and robustness of this approach, compared to other automated matching methods between an image and a simulation based on a DEM. This is particularly interesting if the accuracy and density requirements are being relaxed that are being put on the underlying DEM.

4. No DEM is Available

One of our applications deals with the processing of SAR images acquired during NASA's Magellan mission to planet Venus. One of the goals of the post-mission work is the computation of a high-resolution map of the planet's surface. This map will allow researchers from different scientific communities to improve the knowledge of Venus' geologic history, geophysics, etc.

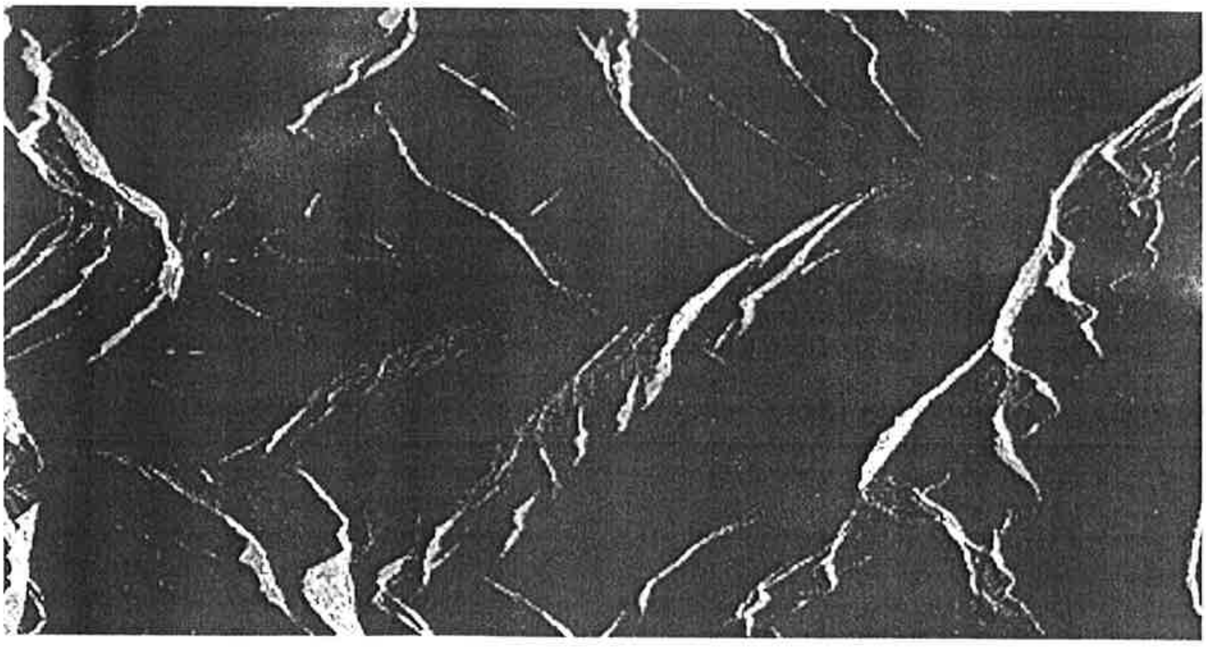

Fig. 5. *Overlap of the masks shown in Figs. 3 and 4. White pixels indicate layover in both masks, gray pixels in only one of them.*

Although our current research focusses on this particular data set, the problem can be seen as a representative of those applications where no DEM of sufficient resolution and accuracy is available. Hence, the reconstruction of the terrain itself becomes one of the primary goals.

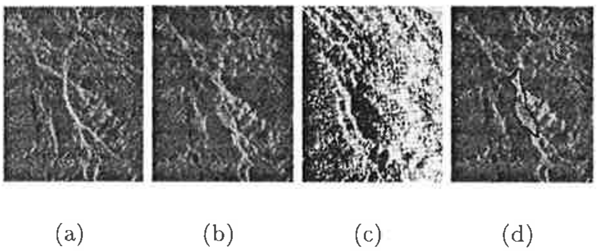
(a) (b) (c) (d)

Fig. 6. *Three views of an area on Venus, located at 1.8 deg S, 73.4 deg E. The images were acquired from the left at 44 deg (a) and 25 deg (b) look angle, and from the right at 25 deg (c). Layover in (b), originally recognized by Ford and Pettengill [9] , is illustrated in (d).*

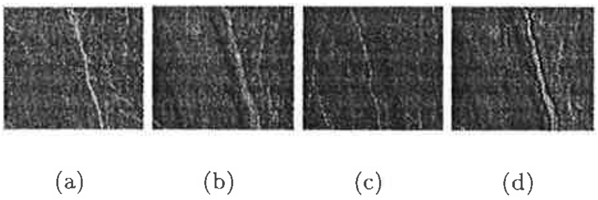
(a) (b) (c) (d)

Fig. 7. *Again three views of a section of Venus' surface (29.5 deg S, 142.5 deg E), illuminated from the left at 34 deg (a) and 17.5 deg (b), and from the right at 25 deg. Layover in (b), classified by Connors [5], is marked in (d).*

Figures 6 and 7 show an example of layover in Magellan imagery from three different imaging cycles (see Leberl et al. [14]). The apparent differences in the central part of images 6(a), (b) were originally recognized as layover by Ford and Pettengill [9]. Layover areas pose special problems in both manual and automated acquisition of match points: When collecting match points manually by stereoscopic viewing, layover areas do not fuse properly. Automatic stereo matching algorithms result in missing or inaccurate match points, which lead to errors in the reconstructed terrain.

However, since layover is an indicator of sharp transitions in the terrain surface, a proper treatment of these areas can be of special interest for future users of the computed DEM. In the context of geophysical investigations, Connors [5] developed an algorithm for recognizing foreshortening, layover and shadow areas, and extracting height information from them. The image processing tasks involved are currently done manually. "Recognizing" in this case implies visual inspection of opposite side image pairs and interpreting certain image areas as a layover.

The fully automated recognition and treatment of layover areas in Magellan imagery still remains a challenging task. In order to identify the layover areas, we plan to use the matching results themselves as indicator for a possible layover situation. Once the regions of interest are identified, the next step is to use their geometric properties to reconstruct the corresponding 3D surface. The accuracy of the computed DEM will be verified by simulation. Experiments are needed to combine the recognition and reconstruction processes, so that both processes are guiding each other.

5. Towards the Analysis of Image Stacks

Layovers and shadow regions need to be identified in radar images to avoid mis-interpretations of image contents. However, once multiple images enter into an analysis there exists the issue of co-registration of dissimilar component images into an image stack (Fig. 8).

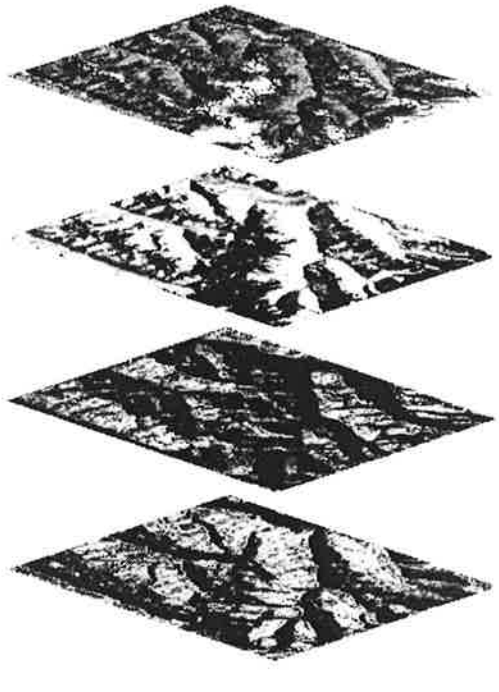

Fig. 8. *A stack of dissimilar remote sensing images, showing (from top to bottom) an optical SPOT-image, a thermal map obtained by LANDSAT/TM, ERS-1 radar images from ascending and descending orbit. Note how the bright layover regions in ERS-images of highly alpine terrain manifest themselves in geocoded renderings as a dominant feature.*

At that point a segment in layover of one image may be in a useful image of another coverage. Again, however, it will be important to understand where layover and shadows exist.

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