Simulation Based SAR-Stereo Analysis in Layover Areas

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Abstract **We show in an experiment on three overlapping Magellan images of the Venusian surface how the special consideration of a possible layover situation can improve the stereo-derived terrain model. The implemented semi-automated procedures reconstruct terrain slopes and at the same time distinguish between foreshortening and layover. Simulation is used as a tool for quality control and to merge information from opposite-side SAR images.**

INTRODUCTION

Radar layover is a special problem that arises when dealing with SAR imagery of mountainous terrain. The formation of foreshortening and layover as a consequence of the range measuring principle of the radar is illustrated in Fig.1. If the local terrain slope exceeds the sensor look angle, layover occurs and the original geometric order of the imaged feature is reversed (Fig.1b). Due to the change in radar ground resolution and the superposition of multiple scatterers from different parts of the terrain, foreshortening and layover areas manifest themselves in the SAR image as bright regions. A more detailed discussion of the SAR imaging geometry, including the layover phenomenon, can be found in, e.g., [4].

In the following, we first demonstrate the shortcomings of conventional SAR stereo analysis in layover regions as a consequence of the strong geometric and radiometric distortions caused by the layover geometry. Then we describe a matching experiment carried out on a select test site taken from the Magellan data set. We show how the special consideration of a possible layover situation in combination with common image analysis techniques can improve the stereo-derived DEM. The implemented algorithms aim at automating the manual technique for determining heights and slopes of fault scarps on Venus proposed by [1]. Due to the lack of ground truth on Venus, the results are verified by simulation and comparison with the corresponding opposite-side SAR image.

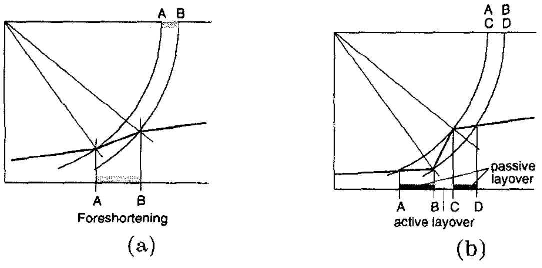

Figure 1: *Foreshortening (a) and layover (b).*

TEST SITE

In Magellan SAR data, a considerable amount of layover can be found due to the steep look angle used. Fig.2 shows three Magellan SAR F-BIDRs (Full-resolution Basic Image Data Records) of our test site on Venus. The images were acquired during Cycles I (left) and III (middle), both left looking with look angles of 33.5 deg and 17.5 deg, respectively, and during the right looking Cycle II (right) at 25.0 deg. Striking in the left two images are the bright, narrow stripes in the middle of the images from top to bottom, which are either foreshortening or layover. The corresponding structure in the right image is rather dark. Our investigations concentrate on these stripe structures.

CONCEPT AND PREVIOUS WORK

Our approach is motivated by a study on the manual extraction of height information from Magellan data [1]. In that work, a method to estimate local height differences and corresponding slopes in layover and shadow areas measuring the layover or shadow width is developed. The method is restricted to discretely dipping surfaces.

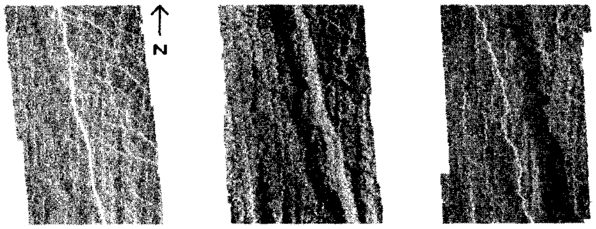

Figure 2: *F-BIDRs captured during Orbits 1202, 4793, and 3029. The area is approximately 24 x 38 km^2 and located on Venus' surface at 29.5 deg S, 142.5 deg E.*

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The height differences are computed using the parallax method. Due to a relationship between the width of the layover areas and the stereo parallaxes, the height differences and slopes can be determined by measuring the width of the layover areas. Because only the value of the width can be measured, but not the sign (which changes at the transition from foreshortening to layover), two possible solutions remain after the width measurement. The corresponding Cycle II image is then employed to resolve this ambiguity. For the two calculated heights, the widths of the regarded slope in the (opposite-side) Cycle II partner are computed. Comparing the derived theoretical widths with the actual width in the original Cycle II image yields only one correct solution.

The investigations in [1] were carried out using the images in Fig.2. A distinct place in the lower third of the image was inspected, stating that there layover occurred in both images. The resulting height and slope values were computed.

Our first attempt was to employ usual stereo analysis techniques [3]. Match points derived from an automated matcher [2] were fed into the stereo intersection and regridding program, delivering a digital elevation model (DEM) of the scene. The slope in this resulting DEM is too flat to yield layover or foreshortening consistent with the observations in the two images. Simulation with this DEM confirmed this expectation: the regions outside the layover area were sufficiently reconstructed, the layover area itself however did not arise in the simulated image. This first test showed that an improvement of the match points in the layover regions would be necessary.

IMPLEMENTATION AND RESULTS

To improve the results of the stereo analysis in layover areas and to automate the procedure described by [1], the question arises how to consider layover properly in the stereo analysis process. The intensities in foreshortening and layover areas result from an increase in ground range pixel size and the superposition of signals from multiple target locations. From Fig.1 it can be seen that the beginning (i.e., near range border) of the areas of higher intensities in case of foreshortening corresponds to the foot point of the slope, in case of layover to the top of the slope. The end points (i.e., far range border) of the areas of higher intensities correspond to the top of the slope in case of foreshortening, and to the foot of the slope in case of layover.

A simple method to consider foreshortening and layover zones in the stereo analysis therefore would be to assign just the start and end points of the regions of higher intensities in the first image to the start and end points in corresponding lines of the second image. Two possible assignments for the start and end points exist for the three possible cases: layover in both images (case a), foreshortening in both images (case b), or foreshortening in the first and layover in the second image (case c). For the first two cases, the start points of the high intensity zones in both images are assigned as first pair of match points, the end points as second pair of match points. In the case layover in both images (a), the order of the resulting points in line direction is reversed, the end match point lies nearer to the sensor than the start match point. In order to account for the third case (c), the start point in the first image must be coupled with the end point in the second image, and vice versa.

So our next step was to extract the start and end points of the layover areas using image analysis segmentation techniques. These new points were integrated into the already existing match points instead of the obviously wrong match points in the layover region. Further analysis showed that the matcher was already disturbed by layover in a wider area outside. Because the width of the passive layover areas (i.e., the areas on the ground that do not cause layover, but are affected by it) differs in the two images due to the varying look angle, some regions that are covered by layover in the second image are still visible in the first. (This can be regarded as an example of occluded surfaces, a problem that arises in many stereo analysis tasks.) These obviously erroneous match points in a border region outside the layover areas were erased, too.

The stereo intersection of the two new match point pairs per image line results in just two points for the digital elevation model, corresponding to the foot and top of the slope. The slope between the foot point and the top can only be linearly interpolated, because matching inside the areas of high intensities is not possible. The same is true for the passive layover areas, i.e., for the slope from the last match point before the layover area to the foot of the new slope and from the top of the slope to the first point after the layover area. These slopes will be interpolated by the regridding and interpolation procedure after the stereo intersection process.

Since it is not known a priori whether we are dealing with layover in both images (a), foreshortening in both images (b), or foreshortening in the first and layover in the second image (c), both possible assignments between start and end points of the layover area are stored at this stage and afterwards input to the stereo intersection program. The decision which case actually occurred will be made using simulation in the last step of our analysis.

The simulation with the DEM reconstructed for the case layover occurred in both images (a) can be seen in Figure 3. Especially in the layover region the reconstruction was improved. In those areas outside the layover where the erroneous match points were removed, surface details were lost due to the interpolation process.

The last step of our investigation was to decide whether

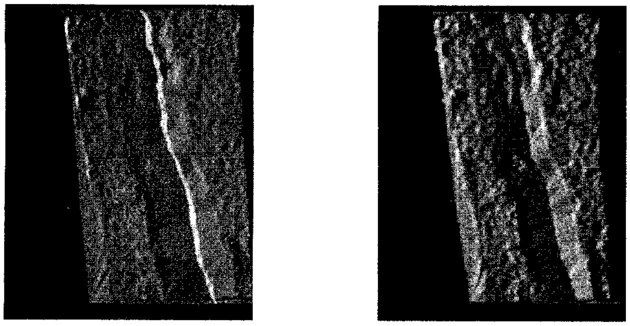

Figure 3: *Simulation of left looking Orbits 1202 und 4793.*

layover occurred in both images (a), or just foreshortening in the first and layover in the second image (c). The case foreshortening in both images (b) could already be excluded after the stereo intersection, basically because of the wider range extension of the segmented region in the stereo partner with the steeper incidence angle. To decide whether we were dealing with foreshortening or layover in the Cycle I image, the simulation of the corresponding Cycle II scene was necessary. Therefore, both possible combinations of match points were stereo processed and input to the simulator. The resulting Cycle II images can be seen in Figure 4. The left picture gives the result for case (a), the right picture for case (c). Comparing these pictures with the original Cycle II image (Fig.2 right) and measuring the widths of the real and simulated elongated (dark) slopes showed that obviously layover occurred in both images (a).

We then carried out tests in order to study the influence of segmentation uncertainties on the accuracy of the results. Table 1 shows height and slope values derived from three different segmentations S1, S2, and S3, which were generated by varying the input parameters of the automated segmentation procedure. For comparison, the results obtained from segmentation S1 under the assumption of case (c) are also listed. These figures can be compared to the manual subpixel measurements in [1], which are given in the last row. It can be seen that especially the height and slope values resulting from S2 correspond well to the manual reference measurements. Also, the deviations inside group (a) are clearly smaller than the differences between the listed (a) and (c) cases. This demonstrates the usefulness of the segmentation results for the automated distinction between foreshortening and layover.

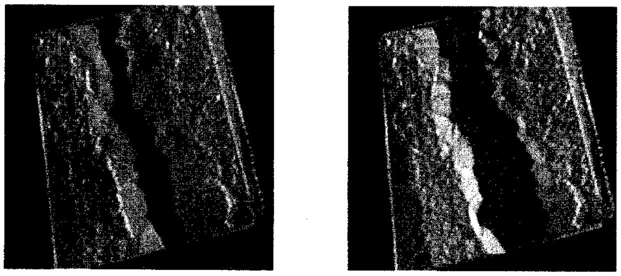

Figure 4: *Simulation of Orbit 3029 (right looking), case (a) on the left, case (c) on the right.*

Segmentation	Case	C I width	C III width	C II width	Height	Slope
		pixel	pixel	pixel	m	deg
S1	a	5	36	62	1430	36.4
S2	a	6	33	55	1244	38.6
S3	a	5	35	59	1383	36.6
S1	c	5	36	96	1902	29.2
Connors	a	6.33	33.8	57	1240	41.6

Table 1: Comparison of different segmentation results.

SUMMARY AND OUTLOOK

Tests carried out on two same-side and one opposite-side Magellan image indicate that, under the simplifying assumption of a discretely dipping surface, the refinement of stereo-derived DEMs in SAR foreshortening and layover areas is in principal possible. Between the automatically determined terrain slope and the corresponding manual reference measurement, differences of less than 6 % were found. Despite segmentation uncertainties, simulation and comparison with the corresponding opposite-side image could be employed successfully to distinguish between foreshortening and layover. A future study might focus on the refinement of the segmentation algorithm (e.g., based on edge or texture information), as well as the possibility to add surface details in the reconstructed layover zones by applying shape-from-shading to the opposite-side image.

ACKNOWLEDGMENT

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