ON THE DETECTION AND EXPLOITATION OF LAYOVER IN MAGELLAN SAR IMAGERY

Margrit Gelautz, Fritz Weinbergmair, Franz Leberl
Institute for Computer Graphics
Technical University Graz
Münzgrabenstraße 11
A-8010 Graz
Austria
e-mail: gelautz@icg.tu-graz.ac.at
Commision IV, Working Group 5

KEY WORDS: Remote Sensing, SAR, Matching, Magellan, Layover

ABSTRACT
In this paper we present a concept for the refinement of Digital Elevation Models (DEM) derived from Magellan SAR images of planet Venus. We deal with the automated extraction of height information in foreshortening and layover areas, as well as the associated recognition of layover. A stereo matching algorithm specially suited to the geometric properties of foreshortening and layover regions was developed and implemented. First tests carried out on simulated layover maps indicate that the match points obtained can be utilized for estimating terrain height in SAR layover areas.

KURZFASSUNG

1 INTRODUCTION
During NASA's Magellan Mission (1989 - 1994) to planet Venus, more than 95% of the planet's surface was imaged by the onboard radar sensor, resulting in over 400 Gbytes of SAR imaging data. One of the major goals of the mission was the computation of a high-resolution map of the whole planet, a tool which plays a crucial part in the geophysical analysis of all planetary processes [Ford, 1992]. Therefore, special attention needs to be paid to the development of techniques for extracting height information from SAR imagery which are suited to this particular data set.

Magellan SAR images were acquired in three cycles, denoted as Cycles I, II and III. In Cycles I and III the radar was looking to the left, whereas in Cycle II the imaging configuration was right-looking. This means that for many areas on Venus a same-side stereo pair as well as a corresponding opposite-side image are available. Information from same-side stereo images can be extracted by using conventional stereo matching techniques, which were originally designed for optical data. Contrarily, SAR images illuminated from opposite sides exhibit a high degree of geometric and radiometric dissimilarities, which obstruct the joint use of such imagery for the automated reconstruction of topography.

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. 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., [Leberl, 1990] or [Schreier, 1993]. Fig.1 illustrates how a decrease in sensor look angle leads to a successive compression of the foreshortening areas, and finally to layover. Note the reversed positions of A' and B' in the ground range projection, when compared to the true positions A and B in the terrain. Further decrease in sensor look angle would cause a growing of the layover region. According to [Kropatsch, 1990], one can distinguish between so-called active and passive layover areas. Active areas are those which produce layover, because the local terrain slope exceeds the sensor look angle. Passive layover areas are only affected by layover because of an adjacent active layover. (In Fig.1, the passive regions are part of the flat areas at the bottom and top of the slope.)

In Magellan SAR data a considerable amount of layover can be found, due to the steep look angle used in Cycles II and III (between 11 deg and 25 deg). Examples of layover in Magellan images are given in Figs.2 and 3. The layover area shown in Fig.2 is located on Venus at about 8 deg S, 74 deg E. The layover was recognized by stereoscopic, since due to geometric and radiometric perturbations layover areas do not fuse properly in stereoscopic vision. Fig.3 shows a 26 km x 43 km section of the Venustian surface at 29.5 deg S, 142.5 deg E. The technique used to identify the layover regions in (a) and (b) was developed by [Connors, 1994], and will be briefly described in the next section.

When automated matching methods are applied to stereo images, the geometric and radiometric differences associated with layover result in inaccurate or missing match points, which lead to errors in the derived Digital Elevation Model (DEM). Similar problems arise when employing shape-from-shading techniques, which use the pixel gray values to cal-
Foreshortening 1

Foreshortening 2

Layover

Figure 1: Illustration of foreshortening and layover. A decrease in sensor look angle (from top to bottom) leads to successively narrower foreshortening areas, and finally to layover.

Figure 2: A stereo image pair from the Magellan data set, captured with a look angle of 40 deg (a) and 21 deg (b). Image size is approximately 17 km x 22 km. The apparent changes in the central part of the image were classified as layover by stereoscopy.

(a) (b)

Figure 3: Three views of an area on Venus’ surface, acquired from the left with a look angle of 34 deg (a) and 17.5 deg (b) during Cycles I and III, respectively, and from the right at 25 deg (c) during Cycle II. The region marked by an arrow was classified as layover in (a) and (b) by [Connors, 1994].

(c)

(a) (b) (c)

2 CONCEPT AND PREVIOUS WORK

Our approach is motivated by a study on the extraction of height information from Magellan data carried out by [Connors, 1994]. In that work, discretely dipping surfaces related to faulting were investigated in the context of geophysical applications. The features of interest appear in the SAR image as bands of increased brightness, which are either foreshortening or layover areas. The proposed algorithm reconstructs terrain slopes, and at the same time distinguishes between foreshortening and layover. Its basic idea can be outlined as follows (see Fig.3): First, corresponding areas are identified in the Cycle I/III same-side stereo pair. Then, the across-track widths of the two areas of interest are used along with knowledge about the corresponding sensor look angle to calculate two possible solutions for the terrain slope. These two solutions reflect an ambiguity between foreshortening and layover which arises for one of the stereo images. In order to resolve this ambiguity, the opposite-side image ac-
quired during Cycle II needs to be taken into account. Once
the corresponding feature is identified in the opposite-side
image, its across-track width serves to decide which of the
two candidate solutions is the correct one, thus resolving the
remaining foreshortening/layer ambiguity. The image pro-
cessing tasks involved in the procedure (i.e., the identifi-
cation of the areas of interest and the establishment of correspon-
dences between them) were done manually.

The purpose of the project described in this study is twofold.
On the one hand the goal is to automate the image pro-
cessing tasks described above, so that the whole process of
height estimation requires no, or at least very little, human
interaction. On the other hand, we intend to extend the ideas
originally developed for the special case of discretely dipping
surfaces to the more general problem of improving the accu-
cracy of stereo-derived DEMs in foreshortening and layover
areas. As already mentioned before, the different geometric
appearance of both foreshortening and layover regions in the
two partners of a stereo image pair poses special problems
when applying conventional stereo matching algorithms, nor-
mally based on gray value correlation. Therefore, a match-
ing algorithm which is able to cope with foreshortening and
layover needs to be robust to the variations in across-track
width produced by the change in ground range resolution asso-
ciated with foreshortening and layover. Furthermore, in
those cases where the same feature is foreshortened in one
stereo image, but laid over in the other one, an appropriate
reversal of match points needs to be carried out, in order to
obtain correct height estimates. Possible interactions be-
tween different layover regions can lead to even more com-
plex situations. Two layover regions which appear as separate
features in one SAR image may have merged into one single
layover region in another image of the same scene, acquired
with a steeper look angle. A thorough discussion of possible
scenarios arising from fusion between different layover areas
is given by [Kropatsch, 1990]. At the current status of our
project, interactions between different layover areas are taken
into account by a simplified model which assumes that lay-
over regions which are separate in one image, but joint in the
corresponding stereo image, are just at the initial stage of
merging, where relationships between adjacent pixels are still
preserved. The validity of this assumption is currently being
tested on simulated imagery, and, if necessary, the model will
be refined.

3 IMPLEMENTATION AND RESULTS

The realization of the concept discussed above can be di-
vided into several steps, two of which are presented and il-
ustrated in the following. First, a simulation program was
implemented in order to provide a test environment for the
newly developed algorithms. The second issue we address is
the development of an image matching algorithm specially
designed for SAR foreshortening and layover areas.

3.1 Simulation

In our project, the need for simulation arises for several dif-
f erent reasons. First of all, simulation is an important tool
for verification when dealing with planetary data, due to the
lack of ground truth. Secondly, simulation provides inexpen-
sive and flexible test data for the development of new image
processing algorithms, which often cannot be obtained from
other sources. A third particular need for simulation comes
up when trying to combine SAR images taken from opposite

sides: Due to the strong geometric and radiometric differ-
ences caused by opposed illumination directions, the identi-
fication of corresponding features in such kind of imagery
requires knowledge about the radar imaging geometry. When
automating the identification process, this knowledge can be
incorporated by using simulation. Finally, we also employ
sequences of simulated images acquired with varying sensor
look angle in order to get a better understanding of how the
layover manifests itself in the image, and to observe the ef-
ects of interactions between different layover regions. An
example of such a simulation series can be seen from Fig.4.
Input to the simulator was a DEM of the Ötztal, a rugged
terrain in the Austrian Alps, where layover occurs frequently.

Figure 4: The simulated views (a) - (d) correspond to look
angles of 40 deg., 26 deg., 20 deg., and 15 deg., respectively.
They demonstrate the transition from extreme foreshorten-
ing in (a) to beginning layover in (b), and the growing and
overlapping of the layover regions in (c) and (d).

The implemented SAR simulation program is based on a co-
sine reflectance model and the assumption of a straight sensor
flight path. In addition to the simulated SAR image, a so-
called layover map is generated, which marks those parts of
the image affected by layover. Fig.5 shows again a SAR stereo
image pair generated by simulation, with the corresponding
layover maps given in Fig.6. These layover maps were em-
ployed as test data for the matching algorithm presented in
the following section.
3.2 Matching

The aim was to develop a stereo matching algorithm which is able to cope with the variations in across-track width associated with foreshortening and layover. In other words, the determination of corresponding widths, a task which was performed manually by [Connors, 1994], should be automated. Further design goals were to achieve robustness to speckle noise, and the proper treatment of those situations where originally separate layover regions start to merge.

The developed algorithm works on binary images. It is assumed that in a previous step possible foreshortening and layover regions have been identified as areas of interest by thresholding. Once an appropriate initial position between the two stereo images has been determined, the search for match points is restricted to lines, according to the nature of SAR images. At the moment we deal only with those cases where either foreshortening or layover occurs in both stereo partners. The combination of foreshortening in one image and layover in the other image will be the subject of future extensions to the algorithm.

The principle of the binary matching algorithm can be briefly summarized as follows. Matching is performed in two passes. Pass (1) serves to gather information about the number of possible match partners within a certain search area. This information, which is recorded for each pixel to be matched, is then used in pass (2) to establish the actual matching correspondences, according to an overall best fit. The incorporation of knowledge about neighboring pixels, as acquired in pass (1), enables the algorithm to deal with problems such as changing across-track widths, merging layover areas, and speckle noise.

The matching procedure is illustrated in its application to the simulated layover maps from Fig.6. The result of the matching can be seen from Fig.7, where corresponding match points are displayed in the same gray value. For performance evaluation, the match points were converted to terrain height.
Figure 7: The layover maps from Fig. 6 after matching. Corresponding match points were assigned the same gray value.

Figure 8: Terrain elevations in active layover areas reconstructed from match points (a) in comparison with the corresponding real terrain (b).

by stereo intersection. The obtained relative height values were then adjusted by an offset, in order to compare them with the corresponding reference DEM. The result is shown in Fig. 8, where terrain elevations in active layover areas are encoded as gray values. Elevations in the displayed areas range from about 2500 m to 3700 m. In the central part of the image, both the shape and the height of the reconstructed regions in (a) correspond well to the real terrain in (b). The arrow in Fig. 8 (a) denotes an area with layover regions that are separate in one stereo image, but joint in the other one (see Fig. 7). Note that the reconstructed active layover areas in Fig. 8 are also separated, which means that this situation was properly recognized by the matching algorithm.

4 SUMMARY AND OUTLOOK

We presented a concept for the detection and use of layover information in Magellan SAR imagery. The simulation program and matching algorithm described in the previous section constitute a first step towards the automated terrain reconstruction in foreshortening and layover areas, as well as the distinction between them. The matching results obtained from tests on simulated layover maps are encouraging. As a next step, the matching algorithm will be applied to Magellan stereo images, and the results will be compared to the manual measurements carried out by [Connors, 1994]. Then, the DEM derived from same-side stereo images will be input to the simulation program, in order to generate a synthetic image which resembles the corresponding opposite-side SAR image. The simulated image is expected to facilitate the identification of corresponding features in dissimilar SAR images, which is a prerequisite for resolving the remaining ambiguity between foreshortening and layover. Although the aim of the current study is the development of new algorithms for the topographic surface reconstruction from Magellan imagery, the results obtained in this context are not limited to this particular data set, but will also be applicable to other SAR data from both planetary and terrestrial missions.
Acknowledgements

The authors would like to thank Johann Burgstaller for his help in preparing this manuscript. This study was partly supported by the Austrian "Fonds zur Förderung der Wissenschaftlichen Forschung" under Grant 7001.4.

REFERENCES


