Automated Matching Experiments with Different Kinds of SAR Imagery

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ABSTRACT

We carry out tests with two readily available automated matching algorithms in their application to (a) Magellan SAR stereo images, and (b) ERS-1 and X-SAR real-simulated images. The match points are examined visually, and an accuracy analysis on Magellan data is performed by comparison with manual measurements.

1. INTRODUCTION

Existing literature on SAR image matching can basically be divided into two groups: (a) matching of stereo image pairs for the computation of a Digital Elevation Model (DEM), and (b) matching of real with simulated imagery for the purpose of geocoding and the refinement of sensor parameters. Early automated stereo matching experiments on SIR-B data are reported in [10]. Reference [8] carried out investigations on Magellan and aircraft stereo images, and compared the results to those obtained from optical data. Magellan data are also included in the test data set we employ in this study, however the matching algorithms applied are different. Seasat data are the subject of real-simulated image matching investigations carried out in [2], [7], and [6]. In the last work, the authors show that the choice of the backscatter model used in the simulation has a significant influence on the accuracy of the matching results. The issue of accuracy analysis is particularly addressed in [3], a study on real-simulated ERS-1 data.

Two available matching algorithms are applied to Magellan stereo data, as well as to real-simulated ERS-1 and X-SAR data. The match points found are superimposed on the images for visual inspection, and an accuracy analysis on Magellan images shows that an rms error of less than 2 pixels can be achieved.

2. TEST DATA

The data set used for stereo analysis consists of SAR images of planet Venus from NASA's Magellan Mission. The pixel size is 75 m x 75 m, resampled from an original ground resolution of the radar of approximately 130 m x 120 m. It should be noted that the Magellan images we investigate are already geocoded to a low-resolution (over 26 km/pixel) DEM available from the earlier Pioneer Mission. Therefore, stereo analysis means the detection of remaining distortions between the two images, which can then be used to compute higher frequency topographic information not includud in the coarser Pioneer DEM.

The test site for our investigations on real-simulated ERS-1 and X-SAR imagery is the Oetztal, a rugged terrain in the Austrian Alps, partially covered with snow and glaciers. The simulation program used to generate the synthetic images is part of the RSG software package [5]. It assumes a cosine reflectance model, and no ground truth data is incorporated into the simulation. The 12.5 m x 12.5 m pixel size of the ERS-1 and X-SAR images was obtained by resampling from the original radar resolution of 25 m x 25 m. No previous speckle filtering was applied to the images.

3. MATCHING ALGORITHMS

We carry out tests with two different matching algorithms, a hierarchical correlation-based algorithm (ALG1) specially suited to SAR imagery corrupted by speckle noise, and a so-called Hierarchical Feature Vector Matcher (ALG2), which uses local image statistics to describe correspondence.

The mathematical background of ALG1 is described in [1], and its application to DEM generation from Magellan stereo data is reported in [4]. Therefore, the basic concepts of the algorithm are only briefly outlined. Matching is performed in a hierarchical manner, with successively smaller window sizes. At each level, a two-dimensional normalized cross-correlation is carried out, and the shape of the correlation surface along with a local scene noise estimate is then used to compute a confidence measure. This confidence measure is a two-dimensional covariance matrix for the match which can be used for weighting information differently in the two directions and propagating matching error forward in stereo solutions. The confidence matrix serves to filter out bad matches, and to suppress speckle noise. In our tests, the algorithm was run with the suggested default values, no attempt was made to optimize the parameters, which can greatly effect matcher performance.

ALG2 has originally been developed for stereo matching to compute dense disparity maps from optical stereo images of natural terrain. A detailed description of the algorithm can be found in [9]. Its principles can be described as follows: First, for each pixel of both images a

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feature vector is derived from local properties, e.g. convolutions, in the surrounding of each pixel. For each pixel in the reference image, its feature vector is compared to the feature vectors in the expected search area in the other image. Using Euclidian distance, the minimum distance vector defines the corresponding pixel. Median filtering is applied to smooth the resulting disparity images, and undefined disparities are interpolated. These steps are carried out for several resolution levels, using the low resolution results as prediction. In principle, on each pixel of the two matched images a disparity vector is gained. As confidence measure, a so-called backprojection error is computed, which is the inconsistency after left-right and right-left matching. Since the algorithm was originally designed for optical imagery, parameter tuning had to be carried out in order to adapt it to SAR imagery.

4. ANALYSIS AND RESULTS

Match points can be visually inspected in Figs.1 and 2. In the reference (left) image, a regular set of grid points was chosen, and the algorithm searches for the corresponding match points in the right image. Missing grid points mean that based on the internally computed confidence value the corresponding match was classified as bad, and therefore discarded. Fig.3 shows the gray-level encoded range disparity image corresponding to Fig.1.

A lack of texture was found to be the main reason for inaccurate or missing match points. Steep slopes in the terrain, which lead to extreme foreshortening or even layover situations, pose special problems in stereo matching, due to the different geometric appearance associated with the different viewing angles. On the other hand, foreshortening and layover areas can provide particularly useful features for real-simulated matching, since they provide highly textured regions with good contrast.

A quantitative analysis of the matching accuracy was carried out for the Magellan data by comparing the automatically determined match points with manual matches acquired by an experienced human stereo operator. The manual measurements we use as reference exhibit an uncertainty of +/- 0.6 pixels. This was determined by repeat measurements, as described in [8]. Table 1 shows the differences between manual and automated match points in range (r) and azimuth (a) direction, expressed as mean value and standard deviation σ. The percentage of matches which exhibit an error Δ in the disparity measurement of less than two pixels is also given.

Table 1 Analysis of Magellan stereo match points

Algorithm	number of matches	$\overline{r}$ pixel	σ_r pixel	$\overline{a}$ pixel	σ_a pixel	$\Delta < 2$ %
ALG1	272	0.4	2.2	0.4	0.6	57
ALG2	302	0.2	1.2	0.1	1.3	76

When examining the real-simulated match points visually, no clearly discernible mismatches were found. Since for this data set no manually acquired reference matches of sufficient accuracy were available, a first comparison between the two matching algorithms was carried out by analyzing the differences between the matches produced by ALG1 and ALG2. Mean value and standard deviation σ of the differences in range and azimuth direction are listed in Table 2. When applying ALG2 to X-SAR data, 71 % of the match points were classified as bad, as opposed to 26 % rejected by ALG1. In a practical application, such a high percentage of outliers may cause problems, since valid match points are too sparse. The determination of the absolute accuracy of the two algorithms with respect to suitable refence values remains the subject of further investigations.

Table 2 Analysis of ERS-1 and X-SAR real-simulated match points

Data	$\overline{r}$ pixel	σ_r pixel	$\overline{a}$ pixel	σ_a pixel
ERS-1	0.3	3.0	1.5	2.0
X-SAR	0.7	2.2	2.2	3.5

5. SUMMARY AND OUTLOOK

Tests on Magellan stereo pairs have shown that up to 76 % of the automatically acquired match points differed from the corresponding manual reference matches by less than two pixels. The immediate next step will be to employ the real-simulated match points for a refinement of the corresponding sensor flight path. Then, match points between stereo image pairs will be used together with the improved sensor parameters to compute a DEM of the Oetztal test site. Our investigations aim at studying the potential accuracy and limitations of a completely automated approach of DEM generation from SAR stereo images in a practical application.

6. ACKNOWLEDGMENTS

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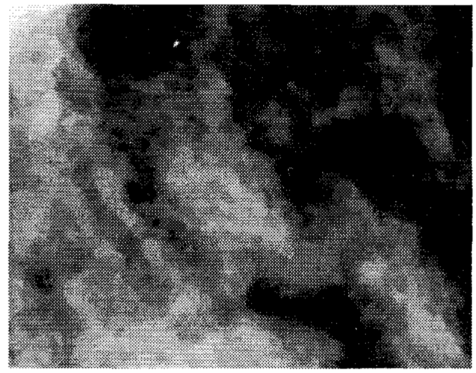

Figure 3: Range disparity map corresponding to Fig.1, produced by ALG2.

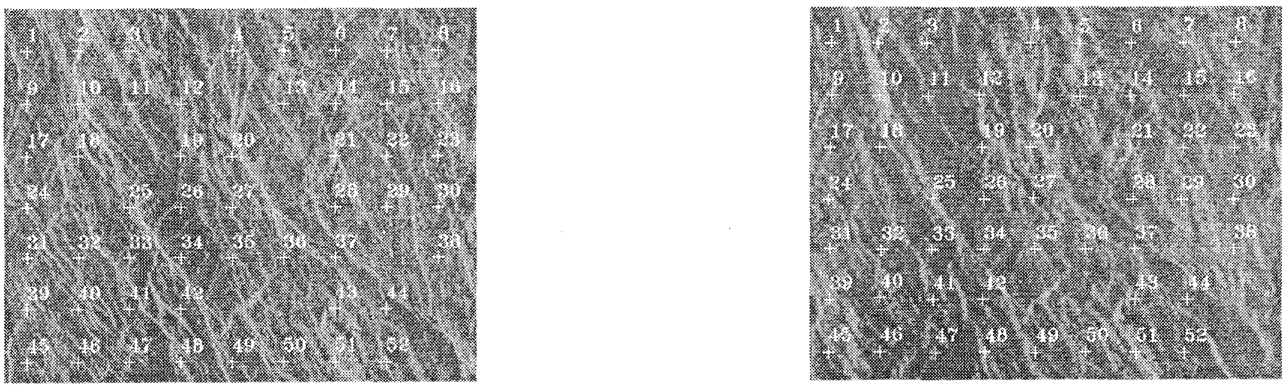

Figure 1: Subscene of a Magellan stereo pair with superimposed match points produced automatically by ALG1. The scene was illuminated from the left, with a look angle of 40 deg (left) and 21 deg (right). The area shown is located on Venus at about 8 deg S, 74 deg E. Image size is 460 x 360 pixels.

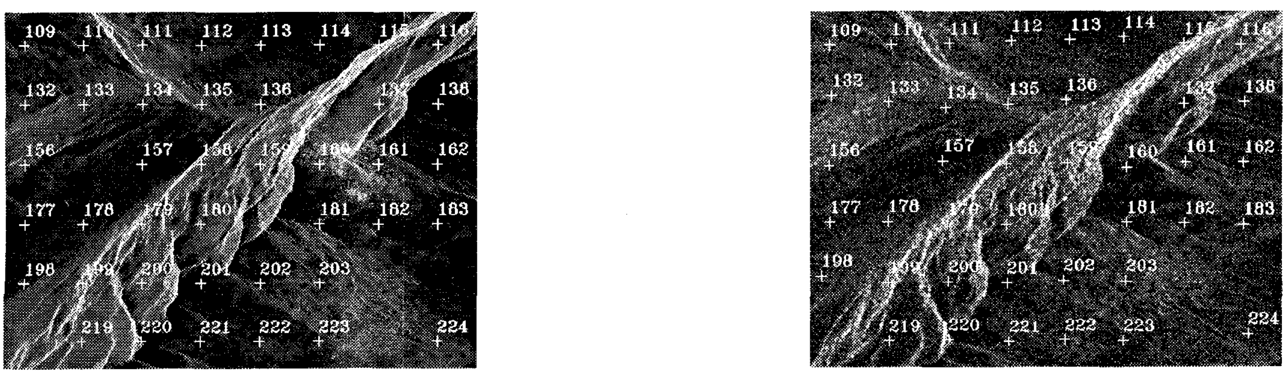

Figure 2: Simulated (left) and corresponding real (right) ERS-1 detail of the Oetztal, Austria, with automated match points from ALG2 overlaid. The scene was acquired from ascending orbit with a nominal sensor look angle of 23 deg. Image size is 512 x 387 pixels.