Automated terrain corrected SAR geocoding

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ABSTRACT

A technique for automated terrain corrected SAR geocoding is presented. Instead of operator selected control points the presented method uses cross-correlation with a SAR intensity image simulated from the Digital Elevation Model to refine the geocoding transformation.

INTRODUCTION

Geocoding is the transformation between the coordinates of an imaging system, in our case the range-Doppler coordinates of the SAR, and orthonormal map coordinates. Geocoding is necessary to combine the information derived from the SAR data with in-situ data or information of other sensors. In addition, it is used for 2-pass differential SAR interferometry and for the terrain slope corrected normalization of the SAR backscattering coefficient.

The most tedious and time consuming step in SAR geocoding is the search for ground control points because of the difficulties associated with the precise identification of corresponding points in the SAR image and map. The very different appearance of the SAR image and the map as well as the speckle noise present in the SAR image are the causes for this. In addition, many of the targets which can be identified should not be used because of the effect of the target height on the target position in the SAR image. Examples for this are houses, bridges, and trees.

In this paper a way to automate this step is presented. After an overview of the technique key steps as the parametric geocoding transformation, the SAR image simulation based on a DEM, and the automated fine registration between the simulated and the real SAR images will be discussed. Finally, the accuracy and robustness of the presented geocoding technique will be discussed.

AUTOMATED SAR GEOCODING METHODOLOGY

The two main steps of the presented geocoding technique are the calculation of the transformation lookup table and the resampling of data files using this lookup table. The lookup table contains for each pixel of the map (i.e. the geocoded images in the desired map projection) the corresponding coordinate in the SAR range-Doppler geometry.

The calculation of the lookup table is done in several steps. In a first step a parametric description of the orbit, the SAR imaging geometry, and the map projection, considering the local terrain height, is used to calculate an initial geocoding lookup table. Errors in the available orbit data, the SAR system parameters, and uncertainties in the map projection definition usually result in slight geocoding errors, which are corrected, in a refinement step. Traditionally, this refinement was done based on operator selected ground control points. The key idea of the presented automation of the geocoding is the simulation of a SAR image based on a Digital Elevation Model (DEM). The requirement of a DEM is not very restrictive as it is used for terrain corrected geocoding anyway. An automated cross correlation analysis between the simulated and real SAR images is used to determine the geocoding refinement. The refinement applied to the initial lookup table leads to the refined lookup table which allows to do the actual data resampling in a single step.

For a flow chart of the geocoding sequence see Figure 1.

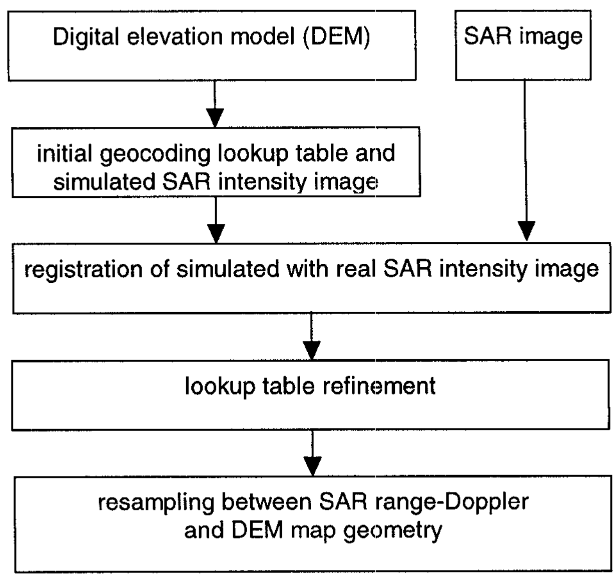

Figure 1: Flow chart of automated terrain corrected SAR geocoding.

PARAMETRIC GEOCODING STEP

In the parametric geocoding step the DEM map geometry and the SAR range-Doppler imaging geometry are used to determine the initial transformation lookup table. For each pixel of the DEM the DEM coordinate is first transformed from the map coordinates to Cartesian coordinates . Next the Datum shift between the Datum of the reference ellipsoid used for the DEM map projection and the reference ellipsoid used for the description of the sensor orbit geometry, are corrected for. Then the acquisition time and position

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corresponding to the selected map coordinate are determined. Finally, the look vector to the selected map coordinate is calculated leading to the desired azimuth and slant range position. Image skew (for non-deskewed images) and the local terrain height are taken into account in these transformations.

A variety of map projections are supported. The modular concept easily allows to include additional map projections given the corresponding equations. The map projection, reference ellipsoid, and Datum shift parameters are defined in the DEM/MAP parameter file.

SAR IMAGE SIMULATION FROM DEM

After the above transformations the SAR look vector and the terrain surface coordinates are available in the same Cartesian coordinate system, allowing to directly calculate geometric parameters such a the SAR look vector, the image plane normal and the surface normal, the local incidence angle, and the projection angle. For a detailed discussion of the imaging geometry it is referred to [1]. The true local SAR pixel size A [m^2] for a tilted surface is calculated by

$$A = \frac{az \cdot r}{cos\,\psi} \qquad (1)$$

with

az : azimuth pixel spacing [m]
r : slant range pixel spacing [m]
ψ : projection angle, defined as the angle between the surface normal and the image plane normal (see Fig. 2).

The backscattering of the simulated SAR image is found by multiplication of the calculated pixel area with an empirical function of the local incidence angle which is used to account for the incidence angle dependence of the backscattering coefficient. The image simulation does not consider the dependence of the backscattering on the surface type. As a result an almost constant value is obtained for flat areas. Figure 3 shows an example of a simulated SAR image for a part of Death Valley, USA. The valley floor, in the center of the image, is flat. The simulated backscattering is almost constant. The real SAR image (Figure 4) shows a lot of backscatter variation for the same area because of the different surface types found (see [2]). For the sloped areas, on the other hand, the local topography has a strong influence on the backscatter.

FINE REGISTRATION STEP

The purpose of the fine registration step is the improvement of the geocoding geometry over what was calculated with the parametric transformation equations. As fine registration function a bi-linear function (range and azimuth offsets are linear functions of range and azimuth) is used. The registration function is determined in a cross-correlation analysis between the simulated and the real SAR image, with the simulated SAR image representing the map geometry. For a large number of small image chips the corresponding location in the other image is searched for. Apart from the local offset estimates a quality measure is determined for each estimate. Based on the reliable estimates, i.e. the estimates with a quality measure above a certain threshold, the fine registration function is calculated using a least squares fit.

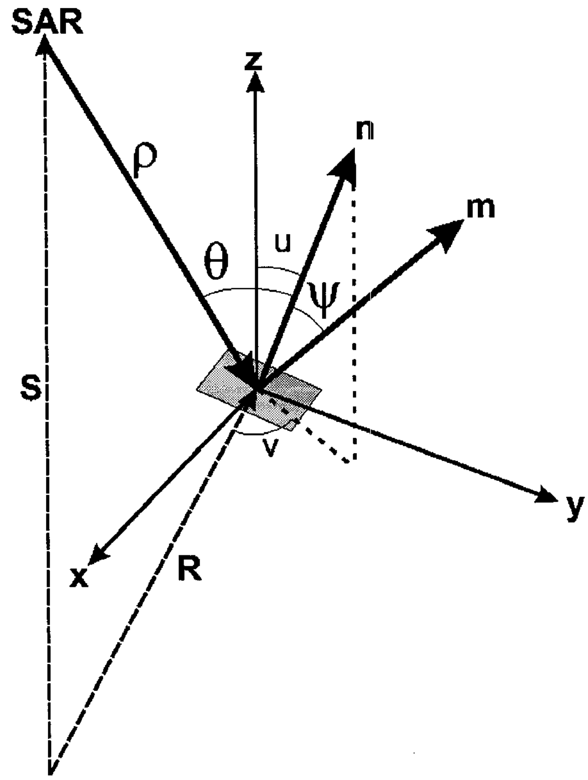

Figure 2: SAR imaging geometry with **vectors**: x (azimuth), z (vertical), r (radar look vector), R (Earth center to pixel), S (Earth center to SAR), n (surface normal), and m (image plane normal) and **angles**: θ (local incidence angle), ψ (projection angle), and u,v (spherical angles of n).

In the case of the Death Valley example (Figures 3,4), no reliable estimates are found for the image center where the surface type clearly dominates the backscattering variations. A sufficient number of reliable offset estimates was found, nevertheless, for the more rugged areas, allowing to determine the fine registration function.

The fine registration function is used to modify the geocoding lookup table resulting in what we call the refined lookup table. The values of the refined lookup table indicate for each pixel the corresponding location in the SAR image. The reasons to apply the refinement to the lookup-table are the intention to conduct the SAR geocoding in one single resampling step to minimize the effects of data interpolation and for efficiency reasons.

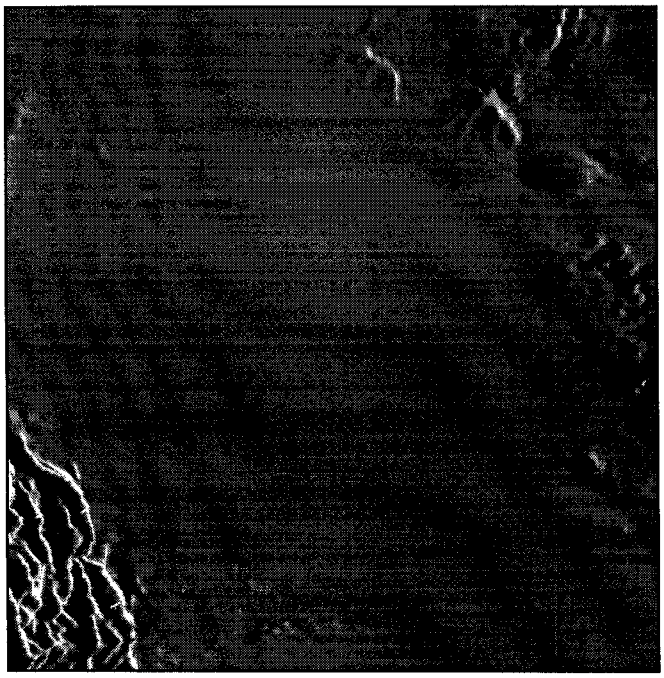

Figure 3: Simulated SAR intensity image corresponding to SAR intensity image shown in Figure 4.

Figure 4: ERS-1 SAR intensity image (5-look) over Death Valley, USA.

ROBUSTNESS AND REGISTRATION ACCURACY

The presented method was successfully applied to the geocoding of ERS and JERS SAR data. Not only high resolution DEMs but also DEMs with moderate resolutions between 100m and 250m were used.

For ERS the automated geocoding worked even in relatively flat terrain with a maximum scene height variation below $100m$. For JERS the robustness of the technique in rather flat terrain is not as good as for ERS because of the much stronger influence of the surface class on the backscattering.

In most cases the geocoding accuracy achieved was higher than the pixel spacing of the DEM used. The standard deviation of the local offset estimates from the fine registration function serves as a measure for the reliability and accuracy of the fine registration.

CONCLUSIONS

A method to automate the fine registration step required in SAR geocoding was presented. Based on a DEM a SAR intensity image is simulated. For a large number of locations the registration offset between the simulated and real SAR images is determined using intensity cross-correlation. Reliable estimates are used to determine the fine registration function.

In most cases the geocoding accuracy achieved with the presented method is high because of the high number of locations used to determine the fine registration function. Once the refined geocoding lookup table is determined the geocoding is done in a single resampling step.

The presented method is efficient as no operator selected control points are required. The technique is robust in the sense that quality measures for the success of the automatic fine registration are determined, indicating that the fine registration was not successful if no reliable offsets could be determined, as it may be the case for flat terrain.

REFERENCES

[1] Ulander L., Radiometric slope correction of synthetic-aperture radar images, IEEE TGRS Vol. 34, No. 5, 1996.

[2] Wegmüller U., T. Strozzi, T. Farr, and C. Werner, Arid land surface characterization with repeat-pass SAR interferometry, Proc. 2nd int. workshop on Retrieval of Bio- and Geo-physical parameters from SAR data for land applications, 21-23 Oct., ESTEC, Noordwijk, The Netherlands, ESA SP-441, pp. 565-570, 1998.