THREE DIMENSIONAL DATA FROM SAR IMAGES

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ABSTRACT

The utility of SAR data, now becoming widely available, for mapping, is restricted because in the areas where it is most useful, that is areas where cloud cover is very high, there is also a lack of digital elevation models (DEMs) to use for terrain geocoding. A solution to this problem is to derive the DEM from stereoscopic SAR images.

A mathematical model is first needed which will allow three dimensional co-ordinates to be computed from image co-ordinates measured in at least two SAR images. Provision must be made for various configurations of data such as parallel track, same side data, or cross track data, and the possible use of SAR images with optical images such as SPOT. The second requirement is to determine a sufficient number of conjugate points to form the DEM and work done in stereo matching SAR data is described. A data pyramid is used to select seed points for the Otto-Chau adaptive least squares method of stereo matching by region growing.

Results are available from SIR-B and Seasat data and it is hoped that results from ERS-1 data will also be presented.

KEYWORDS: SAR, ERS-1, Seasat, Digital elevation models, Stereo-matching.

1. INTRODUCTION

Digital elevation models (DEMs) may be derived from a number of sources. For geocoding SAR data a grid spacing of about 25m with a height accuracy of 1m is ideal but accuracies betwen 5 and 10m may be adequate in many cases., This type of DEM should idealy be derived directly from small scale aerial photography by photogrammetric means. In practice this is an expensive and time consuming operation and in the case of operational geocoding systems, for example at the German Processing and Archiving Facility (PAF) at DLR, Oberpfaffenhofen (Schreier et al, 1990), data is collected from existing sources, including maps, of variable quality. DEM data does exist in classified data bases but this is not generally available. DEMs may be obtained from stereoscopic SPOT data . Automatic image matching can provide a DEM of a full SPOT scene (60 x 60 km) on a 30m grid with an accuracy of 10 - 15m. (Day and Muller, 1989). The computation for this can take as little as 4 hours using parallel processing (Zemerly et al, 1991). There are at present problems in obtaining such data because the coverage of stereoscopic SPOT data is limited and in many areas of the world cloud cover prevents the rapid acquisition of suitable data. Some work has been done to collect data from satellite altimeters (Berry et al, 1992) but this is of much poorer quality than is required for accurate terrain geocoding.

In view of the problems in obtaining DEMs from other sources it is desirable to look at the possibility of obtaining height from the SAR itself. This possibility has been discussed by Leberl (1990) by using stereoscopic SAR data, interferometric SAR or shape from shading. The two latter methods are being investiagted in a number of places (Rocca and Prati, 1992; Thomas et al, 1991) but at present are at a very early stage of development. The use of stereoscopic SAR, using methods similar to those used for SPOT, has been investigated at University College London by Denos. She has shown that by using speckle reduction filters, combined with the automatic selection of seed points and an image pyramid, a high percentage of points in a Seasat image can be matched. Work is in progress to determine the accuracy with which heights can be calculated from this matched data.

Clark, also at UCL, has investigated the geometry of stereoscopic SAR and, using SIR-B data has shown that root mean square errors of about 10m can be obtained although the method is very sensitive to errors in analysing the SAR image. Clark's approach was to solve the range and Doppler equations (discussed below) for two images simultaneously to give the position vector of the common ground point. Clark has also shown that SAR can be combined with optical data such as SPOT to derive heights.

2. A MATHEMATICAL MODEL FOR 3D DATA FROM SAR

There has been much discussion about the best configuration of SAR for stereoscopic measurement. Work at present is concentrated on ERS-1 data, from which overlapping images are available by two methods. Same side viewing may be obtained where adjacent orbits overlap. In the 35 day orbit cycle the overlap varies from 20km at the equator to 50km at 50^0 north or south, as the repeat cycle lengthens greater coverage may be obtined by the intersection angles decrease. During the roll-tilt mode full overlap may be obtained with good intersections. Opposite side stereo may be obtained from ascending and descending passes which can extend to full coverage during the 35 day cycle. The use of opposite side methods cause problems in identifying points and although Fullerton et al (1986) have looked at ways of overcoming this, the emphasis has been on developing same side stereo methods. Leberl (1990) has reported height accuracies of 28m for Seasat data of Los Angeles and a range of accuracies for SIR-A and SIR-B data. Leberl and his co-workers use a photogrammetric approach to stereo SAR using hard copy data, however the method proposed at UCL makes use of the range and Doppler equations used for geocoding. With this method accurate orbit information is required together with the Doppler information derived in the SAR processor. The equations for a single image are:

$$f_D = \frac{2}{\lambda R} (\dot{\underline{S}} - \dot{\underline{P}}) \cdot (\underline{S} - \underline{P}) \qquad (1)$$

$$R = (|\underline{S} - \underline{P}|) \qquad (2)$$

where:
- f_D is the Doppler shift frequency
- R is the sensor target slant range
- $\underline{S}$ is the sensor position $(X_S\ Y_S\ Z_S)$
- $\underline{P}$ is the position of a point on the ground $(X_P\ Y_P\ Z_P)$
- $\dot{\underline{S}}$ is the sensor velocity $(\dot{X}_S\ \dot{Y}_S\ \dot{Z}_S)$
- $\dot{\underline{P}}$ is the target velocity $(\dot{X}_P\ \dot{Y}_P\ \dot{Z}_P)$
- λ is the radar wavelength

A pair of images yield four equations which can be solved, using an iterative method which required the evaluation of the derivatives of the equations (Clark 1991), to give the common position $\underline{P}$. It is clear that the two sets of equations must be in the same co-ordinate system.

The method was tested on SIR-B images of Mount Shasta. Since the method requires accurate orbit, which was not available, an accurate orbit was constructed and individual range pixel spacings were calculated for each pair of points, thus removing orbit errors from the calculation. Using this data with 12 ground control points, a root mean square error of ±8.1m in Z was obtained. However the method is very sensitive to errors in the input data.

3. AUTOMATED MATCHING OF SAR DATA

Automated matching of stereoscopic data from space has been successfully carried out with SPOT data, and also with other optical data. At UCL a variation of the adaptive least squares matching technique has been developed by Otto and Chau (1989). The method adopts the area based matcher with a region growing mechanism which is a powerful means of dealing with discontinuities and areas which are difficult to match. In order to work effectively around discontinuities the Otto-Chau matcher requires a sufficient number of seed points to cover the whole image.

SAR data has a number of features which differ from optical data. Speckle is one of these and gross differences due to different incidence angles and orbit configurations is another. In order to apply a suitable methodology to matching SAR data the Otto-Chau matcher has been incorporated into a system which includes automatic seed point generation using an image pyramid. The technique is described in full by Denos (1991) but is outlined here.

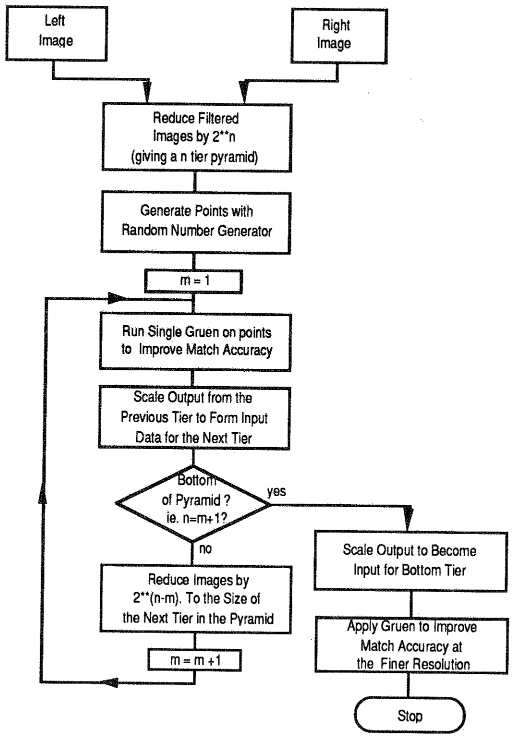

Figure 1. Flow chart for Cascade stereo matching scheme.

Figure 1 shows a flowchart of the cascade stereo matching scheme. The principle behind the automated seed point generation is that if stereo images are reduced in size by a large enough factor, then randomly generated points can be transformed into accurate conjugate points in the original image by applying adaptive least squares matching at each tier of the resolution image pyramid. The matcher is able to pull in the correlation at each new tier of the pyramid and by applying the sheet growing mechanism of the Otto-Chau matcher near the top of the pyramid it is possible to produce a dense stereo matched set of data at the bottom of the pyramid.

The method has been applied on the SIR-B data of Mount Shasta where a rather sparse, unevenly spaced set of points were matched, and on Seasat data of Death Valley. The results from Death valley are given in table 1.

		No Speckle Reduction		Speckle Reduction		
Tier Number	Image Size	Points Matched	Percentage Coverage	Points Matched	Percentage Coverage	
1	4x4	3000	N/A	3000	N/A	
2	8x8	1053	N/A	1866	N/A	Point at which sheet growing commences
3	16x16	247	N/A	453	N/A	
4	32x32	392	38.5%	312	30.5%	
5	64x64	2160	52.7%	2198	53.7%	
6	128x128	10911	66.6%	9655	58.9%	
7	256x256	44974	68.8%	46353	70.7%	
8	512x512	161893	61.8%	205020	78.2%	
9 *	1024x1024	153222	58.5%	212330	81.0%	

N/A = Not Applicable
* = 2 pixel grid used

Table 1. Results of matching SAR data of Death Valley.

4. IMPLEMENTATION ISSUES

The work described above indicates that DEMscan be derived from overlapping SAR data using a mathematical model of the stereo geometry and matching techniques developed from successful methods used with SPOT data. Questions do however remain as to whether such a system can be economically applied in practice and whether it can compete with other methods of obtaining DEMs.

The problem

The problem to be addressed is 'how to obtain DEMs for geocoding SAR data'. The primary concern is to geocode the data from ERS-1 SAR although this may be supplemented in the future by SAR from JERS-1 and Radarsat.

Coverage

The repeat cycle for ERS-1 during the first two and a half years of of the mission will not exceed 35 days. This means complete side overlay is available north and south of 50° but full coverage will not be available A few scenes giving greater coverage will be obtained during the roll-tilt mode and full coverage may be obtained from crossing tracks during the 35 day cycle although there are constraints on the use of the SAR during darkness. It would thus appear that the only way in which full coverage can be obtained is either by the full operational use of a roll-tilt mode or by making use of opposite side stereo. At present neither of these options is fully available.

Accuracy

The limited studies of accuracy indicate that although high accuracy is possible, it can not be guaranteed and much more experience is required to assess the performance. If accuracies in the range of 10-20m are attainable, as Clark has indicated, then stereo SAR could provide data of sufficient accuracy for geocoding.

Alternatives

Although there is considerable interest in interferometric SAR, and there is a much higher probability of obtaining good data than from stereo, there have as yet been no quantitative results published. The same applies to shape from shading. The accuracy which may be obtained is therefore unknown. Other sources of data such as maps are available but the task of digitising contours to form DEMs on a wide scale is daunting and the collection of data from different countries and different mapping organisations is fraught with administrative and political problems .

Implementation

The problems of collecting DEM data are clearly large and the sensible approach is to make provision to use data from all possible sources. This implies the use of an integrated approach in which the user is provided with a database, a tool box with which to operate on the data and a user interface such as a workstation. Such a workstation is being developed at UCL, Dowman and Upton (1991).

The main processes required prior to display (although the data may have already been operated on during previous processing) are as follows:

SAR geocoding;
Merging two data sets;
Overlaying raster data with vector data.

The interactive processes required are:

Read image co-ordinates (mono or stereo);
Image enhancement;
Ground control point identification;
Feature extraction.

After some of these operations the data may be sent back to be added to the data base or to replace existing data. Other data will then be subject to further off line processing:

Calculate orientation or orbit data;
Calculate object space co-ordinates (stereo mode);
Image matching.

The display is a crucial part of the workstation. It is the point at which the operator interacts with the data and it is essential that this is done quickly and efficiently. The display may show a single image or it may show two images. If two images are required then parallax free stereo viewing must be available; this means moving both images independently, under control of their respective camera model, and providing a stereo viewing system. The following operations must be possible:

Overview whole images;
Measure ground control points;
Revise and compile map data.

Such a system allows great flexibility in processing the data and merging it with other data.

5. CONCLUSIONS

The full exploitation of SAR data through geocoding is still at an early stage. DEMs are crucial to a realisation of the full potential of SAR and if these DEMs can be produced from the SAR data itself then the use of SAR can become extremely effective. It has been shown that a number of techniques are available and that each has a potential, it is therefore important that development and testing continue and that all techniques become available in a user friendly environment.

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