INTEGRATED MULTI-FREQUENCY POLARIMETRIC AND INTERFEROMETRIC SAR PROCESSING TECHNIQUES

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ABSTRACT

The algorithms and implementation of an integrated SAR processor designed to process multi-frequency SAR data from either polarimetric, interferometric or mixed mode (a combination of polarimetric and interferometric modes) SAR systems is described. The processor is designed to automatically produce co-registered multi-frequency images regardless of the data collection mode at different frequencies. If at least one frequency interferometric DEM is available, all images are resampled and terrain corrected using the DEM. Examples are provided and discussed.

1.0 INTRODUCTION

Research on the utility of Synthetic Aperture Radar (SAR) data in many diverse applications has seen great activity in the past decade. In particular, two powerful SAR techniques emerged during this time. Polarimetric SARS were first demonstrated during the 1980's and are described by van Zyl et al. [van Zyl, 1987] and Zebker et al. [Zebker , 1987]. Since then polarimetric SAR data have been applied to most disciplines of Earth Science. A recent summary of these investigations can be found in [van Zyl, 1996]. The second powerful SAR technique that has emerged and has received much attention lately is SAR interferometry. While first published by Graham [Graham, 1974] in the late 1970's, interest in this technique has steadily increased since the demonstration of SAR interferometry using digital processing [Zebker, 1986]. A summary of the different applications of SAR interferometry is given in [Allen, 1995]

To really derive the maximum information content from SAR data, it is desirable to combine polarimetric and interferometric techniques, preferabl y at multiple frequencies, as more information about the scattering surface can be derived [Evans, 1996]. The NASA/JPL AIRSAR/TOPSAR system [Lou, 1996] is capable of simultaneously acquiring interferometric (C- and/or L-band) and polarimetric data (C-, L-, and P-band). In this paper, we describe a processing approach that is used to process data acquired in any of these modes. This approach is different from that described in Madsen et al. [Madsen, 1993] for the TOPSAR processor in both the motion compensation approach, as well as in the sense that data are deskewed before interferograms are formed. Using this approach, the same basic SAR processor is used to process data acquired in any of the modes supported by the AIRSAR/TOPSAR system. In addition, the radar images are all radiometrically calibrated.

2.0 THE AIRSAIU'I'OPSAR SYSTEM

The NASA/JPL AIRSAR system is a three-frequency airborne SAR system that was developed to be a general test-bed for developing various advanced SAR techniques. The SAR system is flown on a NASA DC-8 passenger jet, modified for research applications, operated by NASA's Ames Research Center in Mountainview, California. The earliest mode implemented in the AIRSAR system (operational since 1988) was the three-frequency polarimetric mode, where fully polarimetric data are acquired simultaneously at C-band, L-band, and P-band. This mode was used to provide prototype data for the SIR-C/X-SAR science team [Stofan, 1995] and many of the algorithms implemented for SIR-C data calibration and analysis were developed using AIRSAR data. The addition of L-band and C-band antennas in front of the left wing, separated from the aft antennas by 20 m, made it possible to acquire along-track interferometric data at L-band and C-band, while simultaneously acquiring polarimetric data at P-band.

In 1990 NASA, in collaboration with an Italian consortium (CORISTA), approved the addition of another set of C-band antennas to implement a single-pass and fixed baseline cross-track interferometer (XTI) for topographic mapping. The C-band antennas were provided by CORISTA, while NASA sponsored the system modifications and processor development described by Madsen et al, [Madsen, 1993]. This mode of the AIRSAR system became known as TOPSAR [Zebker, 1992] and data have been acquired since 1991. The original TOPSAR processing software has been updated several times since the original publication in [Madsen, 1993]. One version of this updated software was delivered to the Environmental Research Institute of Michigan (ERIM) under a contract with the Defence Advanced Research Projects Agency (DARPA), and is currently being used to process the data from the ERIM IFSARE system. It should also be mentioned that the TOPSAR antennas were placed on the DC-8 in such a way that one of the TOPSAR antennas and the regular polarimetric C-band antenna could be used to form an along-track interferometer with a baseline of 1.2 m, resulting in vastly improved performance in the ATI mode.

In 1995 TOPSAR was extended to acquire XTI data simultaneously at C-band and L-band, All TOPSAR interferometers can be operated in single or dual baseline modes. For single baseline operation signals are transmitted out of one antenna only, and the received signals are measured simultaneously through two antennas. In the dual baseline mode, signals are alternately transmitted out of the antennas at either end of the baseline, while the received signals are measured simultaneously through both antennas.

3.0 PROCESSING APPROACH

The aim of this Integrated AIRSAR Processor is to implement a processing strategy capable of processing all the modes described above with the same basic processor. Therefore, the processor must automatically produce co-registered multi-frequency images, whether or not at least one frequency was acquired in the interferometric mode. Madsen et al. [Madsen, 1993] describe a way to process single frequency cross-track interferometry data. In their approach, the individual images are never explicitly deskewed. Rather, the deskew is implicitly included in the location algorithm; the along-track offset given by Madsen at al. [Madsen, 1993] is identical to the deskew used in the traditional range-Doppler processor.

When processing multi-frequency data, one has two options to ensure that the output images automatically co-register. In the first approach, the sub-patch size is chosen such that the same number of output lines are kept for all frequencies, (This assumes that the radars operate at the same pulse repetition frequency, which is the case for the AIRSAR system.) All frequencies can then be processed with properly scaled Doppler parameters, meaning that the along-track shift for all frequencies will be the same, regardless of the aircraft motion. Therefore, the location parameters derived at any frequency can directly be applied to all the other frequencies. In this case, the size of the sub-patch used, as well as the amount of overlap between adjacent sub-patches are determined by the length of the azimuth reference functions at the lowest frequency.

There are two main disadvantages to the approach described in the previous paragraph. First, the fixed number of output lines for all frequencies means that the processor becomes quite inefficient in the case of the high frequencies for which the azimuth reference functions are much shorter than at the low frequencies, since large parts of the overlap areas between successive sub-patches are unnecessarily recalculated. Secondly, since the size of the patch at the high frequencies is large compared to the synthetic aperture size, the motion compensation may be less than optimum.

These disadvantages can be overcome by processing each frequency separately into the zero squint geometry before utilizing any interferometric information. After the deskew is applied, the multi-frequency images automatically co-register. This now means that each frequency can be processed with a sub-patch size optimally chosen for that particular frequency. In a sense this follows the same processing paradigm usually employed in repeat-pass interferometry, The disadvantage, at least in our implementation, is that the bookkeeping of the phases during motion compensation is slightly more complicated.

4.0 PROCESSOR IMPLEMENTATION

The Integrated Processor is implemented as a collection of stand-alone programs. Which programs are used, and in which order, depends on the AIRSAR/TOPSAR mode that the data were acquired in. First we process all the channels of a particular frequency into multi-looked images in the zero squint geometry. We implemented two versions of the processor to do this. In the first each channel is processed separately and the single-look images are stored on disk. Multi-looking is performed on the various cross-products of the individual channels. The advantage of this approach is that less memory is required for the SAR processor since only one channel is processed at a time, but this advantage is offset by the fact that the large single-look files need to be stored on disk. In the second implementation, we process all channels for each frequency simultaneously, and the cross-product formation and multi-looking are performed in the SAR processor. In this case significantly more memory is used in the SAR processor, but no intermediate single-look files need to be stored.

We utilize the first approach on Hewlett Packard HP 735 workstations to process AIRSAR/TOPSAR images of up to 20 km in the along-track direction (limited by disk size). These workstations have 512 Mbytes of memory, and P-band images are typically processed to reduced resolution (4.5 m) to fit inside the available memory. The second approach is utilized on a Silicon Graphics Power challenge computer with 2 GBytes of memory to process images up to 80 km long in the along-track direction. As in the case of the HP workstations, P-band data are processed to reduced resolution to fit in the memory. In both cases we use a range-Doppler algorithm as described by Madsen *et al.* [12]. This algorithm was chosen to accommodate a Doppler centroid that varies rapidly as a function of range.

The post processing steps applied after the SAR processing depends on the mode in which the data were acquired. For the three-frequency polarimetric mode the various cross-products are combined into the standard AIRSAR compressed Stokes Matrix format and then radiometrically calibrated.

In the case where interferometric data were acquired, the interferogram phase is first unwrapped and the slant range digital elevation model is formed, The location parameters for each slant range pixel is now calculated using the elevation model just derived. Since all the images acquired at the different frequencies now are co-registered, the same set of locations parameters can be used to geometrically resample all images. These location parameters are then used to resample the calibrated polarimetric SAR images. In addition to the calibrated and geometrically corrected SAR images and the digital elevation model, images of the local incidence angle and the interferometric correlation coefficient are also provided. These images are also geometrical y corrected using the location parameters previously calculated.

5.0 SUMMARY

In this paper we described the implementation of an integrated SAR processor designed to process data from either polarimetric, interferometric or mixed mode (a combination of polarimetric and interferometric modes) SAR systems, This processor is now used operationally to produce data acquired with the AIRS AR/TOPSAR system for NASA investigators, and it is anticipated that the simultaneous use of digital topographic information and multi-frequency polarimetric SAR data will significantly improve our scientific understanding of scattering from different types of Earth terrain, Several examples will be given during this presentation.

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