Processing Of The Danish C-band SAR Data

Madsen, Søren Nørvang; Dall, Jørgen

Published in:
10th International Geoscience and Remote Sensing Symposium

Publication date:
1990

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
ABSTRACT

A new Danish C-band SAR was tested in the fall of 1989. As part of the system a very flexible software processor has been developed. The processor is designed to serve several purposes such as experimental test and analysis processor, real-time processor development tool, and operational off-line processor. The processor also holds substantial motion compensation features, and they are described too. In the initial test a 2 by 2 m resolution was verified by analysis of echoes from corner reflectors.

Keywords: C-band SAR, software processor, motion compensation.

INTRODUCTION

In January 1986 a new remote sensing activity was initiated at the Electromagnetics Institute of the Technical University of Denmark (TUD). The Institute started the construction of an airborne Synthetic Aperture Radar, SAR, operating at C-band. The project is denoted Coherent Radar and Advanced Signal processing (KRAS) and it is primarily sponsored by the Thomas B. Thriges Foundation. The main objective is to design a very flexible radar that can be set up for many different applications including ERS-1 underflights.

The antenna is a 1.2 m long vertically polarized slotted waveguide array with a 30° elevation beamwidth, which resembles a cosec-square pattern. It is installed in a modified external fuel tank on a Gulfstream G-3 jet aircraft of the Royal Danish Air Force. The antenna is three-axis stabilised and the antenna look-angle can be controlled, to enable the imaging of all incidence angles from 20° to 90°. The 2 kW transmitter peak power gives a system range of 80 km. The aircraft operates nominally at an airspeed of 465 knt, at altitudes up to 45,000 ft, and it has a range of more than 7000 km.

THE TUD SOFTWARE PROCESSOR

The SAR processing software is based on the range-Doppler algorithm [3], which corrects for the range curvature by means of interpolated range shifts in the range-Doppler domain. Other algorithms including the non-separable algorithm [4] and the step transform [5] have also been considered. However, the nonseparable algorithm is very inefficient in the KRAS case where the depth of focus is much smaller than the pulse length, and
the step transform does not meet the requirements set up for the integrated side lobe ratio and the geometric distortion. Therefore the range-Doppler algorithm was adopted. As illustrated in Fig. 1a, fast convolution with the FFT plays an important role in this algorithm. Potential advantages of using an alternative fast transform or convolution algorithm have been studied, [6], but the FFT proved the most suitable, one reason being that some of its alternatives call for special-purpose hardware.

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At given by:
\[ \Delta \theta = \frac{\Delta h}{R \cdot \sin \theta_{LOS}} \]  
(2)
where \( \theta_{LOS} \) is equal to the expected angle = \( \arccos (h/R) \). It is seen that for satellite simulation under-flights, where the angle of incidence is small (20° - 30°) it is extremely difficult to determine the LOS angle accurately. At 20° incidence angle and 10 km altitude even 50 m height uncertainty will give 1° uncertainty on the LOS angle. This corresponds to a residual error of 1.5% on the motion to be compensated. The philosophy is obviously: "Use a stable platform".

The implementation of a computationally efficient system is also difficult. In principle all received echoes should be range compressed to obtain an accurate slant range measurement before motion compensation. However, the KRAS radar operates at higher PRFs than needed to achieve the desired azimuth resolution, as this improves the signal-to-noise ratio. The data rate is reduced (usually by a factor of 4 or 8) with an azimuth pre-filter which filters and subsamples the data in the along track dimension. By performing the range compression after the azimuth pre-filtering the computational load, which is particularly important in a real-time implementation, can be significantly reduced.

Since the azimuth pre-filter is a Doppler lowpass filter, or one could say a short first order beam-forming filter, data should be motion compensated before the pre-filter. However, it has been found, [8], that the apertures formed by the pre-filter are so short, that it is sufficient to phase compensate the data before the pre-filter; range migration correction can be performed afterwards. Furthermore, it has been found that the signal will not be significantly attenuated (< 0.3 dB) in the pre-filter even if the same phase correction is used for all ranges. The processing sequence is therefore as shown in Fig. 1b where "1st order mocomp." is a common phase shift of an entire range line and "2nd order mocomp." performs a phase correction and a range migration correction as a function of range (the range shift already performed must be subtracted).

A major problem in the present system is that the INU velocities drift with time. Since the antenna pointing is controlled by the INU this results in a mispointing of the antenna relative to true cross track. Also it gives rise to errors in the along track velocity estimate, which in turn causes focusing problems, especially at long range. To enable updates to the INU velocities a Doppler tracker has been included in the KRAS radar. The Doppler tracker is implemented using the "sign-Doppler" algorithm, [9], and it estimates the Doppler centroid as a function of slant range (or the corresponding incidence angle, \( \theta_{LOS} \)). According to the geometry in Fig. 2 the Doppler shift is given by:
\[ f_{DOP} = \left( v_y \sin \theta_{LOS} - v_x \cos \theta_{LOS} \right) \frac{1}{\lambda} \]  
(3)
From this equation the cross track velocities can be estimated by inserting the Doppler estimates and the corresponding incidence angles.

The \( v_x \) velocity is actually the most critical parameter for long range high resolution mapping. The tolerance on \( v_x \) corresponding to 45° quadratic phase error is:
\[ \Delta v_x = \frac{v_x}{\sqrt{\lambda R}} \]  
(4)
where \( \lambda R \) is the azimuth resolution. To achieve a 1 m resolution at 80 km range requires an accuracy of 0.06 m/s on the along track velocity! One-way to update \( v_x \) is from autofocus estimates.

PRELIMINARY RESULTS

The first tests of the system where conducted in the fall 1989. Motion compensation was not applied during the first mission, and an 8 m resolution was obtained. Copenhagen and the TUD were mapped in the second mission. Data were recorded from an altitude of 41,000 ft (=12,500 m) at slant ranges from 22,000 m to 34,000 m. Motion compensation was applied, and three corner reflector were deployed on a low backscatter background (a soccer field) at the TUD. Fig. 3 shows the test site. STC (sensitivity time control) was not used during recording. The equalization of the radiometric response across the swath is entirely due to the antenna shaping. It is noted that there are no interference fringes indicating reflections from the wing, and there is no "banding" effect in the along track direction indicating motion compensation problems.
The Danish SAR has now successfully completed the initial tests. A series of test flights and updates will take place in the spring and summer of 1990. During this period the performance of the motion compensation facilities, and the built-in calibration facilities [10] will be analyzed. A number of operational features such as the in-flight velocity update and the real-time pre-filters for both range and azimuth will be tested. The design of the real-time processor will be accelerated, and the recently funded development of a prototype dual-polarized microstrip antenna will commence. This work is aiming at a later update of the system to full polarimetric capability.

REFERENCES


