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Published in:
Proceedings of the International Geoscience and Remote Sensing Symposium

Link to article, DOI:
10.1109/IGARSS.1993.322725

Publication date:
1993

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

THE DANISH REAL-TIME SAR PROCESSOR: FIRST RESULTS

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ABSTRACT

A real-time processor (RTP) for the Danish airborne Synthetic Aperture Radar (SAR) has been designed and constructed at the Electromagnetics Institute. The implementation was completed mid 1992, and since then the RTP has been operated successfully on several test and demonstration flights. The processor is capable of focusing the entire swath of the raw SAR data into full resolution, and depending on the choice made by the on-board operator, either a high resolution one-look zoom image or a spatially multilooked overview image is displayed. After a brief design review, the paper addresses various implementation and performance issues.

KEYWORDS: SAR, DSP, real-time processor, implementation, performance.

INTRODUCTION

Sponsored by the Thomas B. Thriges Foundation the project "Coherent Radar and Advanced Signal Processing" (KRAS) was launched in January 1986. The concrete goal was to develop an airborne strip-map SAR including a real-time processor. Late 1989 the SAR sensor was ready [1], and with the completion of the RTP in August 1992, the last phase of the project was completed.

Fig. 1 shows a 17 km long segment of a three hundred kilometre long scene mapped during the second flight test and processed by the RTP.

The SAR that has been developed within the KRAS project is a VV polarised C-band system carried by a Gulfstream G3 which is a twin engine jet typically cruising at 465 knots and 41000 ft altitude. The resolution of the system is 2 by 2 m in the narrow swath mode where a 12 km slant range is covered. When mapping at coarser resolution the swath width can be doubled or quadrupled. The three-axis antenna stabilisation allows the SAR to operate in a nominal zero-Doppler geometry. A first order motion compensation (range-independent phase shift) makes sure that the central part of the Doppler spectrum is shifted into the pass-band of the azimuth pre-filter.

Financed by the Joint Research Centre (JRC) and the Danish Technical Research Council (STVF) the Danish SAR is currently being upgraded to a polarimetric dual frequency system. Any of the eight channels simultaneously acquired by this C- and L-band SAR can be processed by the RTP.

The purpose of the RTP is to process SAR data into full resolution strip map imagery in real time, and by displaying the focused data, to assist the operator in using the SAR system [2]. The operator can choose among four different degrees of multilooking/resolution and he can freeze the scrolling image and pan. The processed image can be recorded digitally, so that the real-time processing may even substitute a subsequent off-line processing in the single channel system.

The RTP includes range compression, corner turning, azimuth compression, detection and grey scale transformation. An optional spatial multilooking has also been implemented, and a re-corner turning ensures that the imagery is displayed on a scrolling monitor rather than being updated on a screen basis.

Based on funds from the Danish Technical Research Council (STVF) an upgrade of the RTP is in progress. The full version will also feature second order motion compensation, range migration correction, auto focus as well as radiometric and geometric corrections [2]. These functions will be implemented with the same type of hardware as used so far, thus the enhancement mainly involves software development. Also a hard copy unit will be added to the processor.

This paper addressed the performance issues, but first the RTP design and implementation are reviewed.

DESIGN REVIEW

The RTP is based on the range-Doppler algorithm. Other algorithms have been considered, but either they do not provide satisfactory image quality (step transform), or they are computationally inefficient (nonseparable algorithms), or they are incompatible with the need for range dependent motion compensation (wave equation algorithms).

Table 1 lists some of the driving parameters in the RTP design. 1.5 m resolution (without spectral weighting) has been assumed.

Table 1. System parameters of relevance to the RTP

Frequency		C-band	L-band
Effective PRF	[Hz]	≤ 200	≤ 200
Maximum range	[m]	80 000	80 000
Swath width	[samples]	≤ 8192	≤ 8192
Pulse length	[samples]	≤ 2048	≤ 2048
Synthetic aperture	[samples]	≤ 1024	≤ 4096
Range curvature	[samples]	≤ 2.4	≤ 38
Depth of focus	[samples]	53	13

Due to the long matched filters required for both range and azimuth processing, FFT-based fast convolution is used. For simplicity, consecutive azimuth blocks are overlapped by 50 per cent, meaning that the block length must be at least twice the synthetic aperture length.

From Table 1 it is seen that even at C-band range curvature is significant, and in most cases correction is imperative. Also, the limited depth of focus calls for frequent updates of the azimuth matched filter.

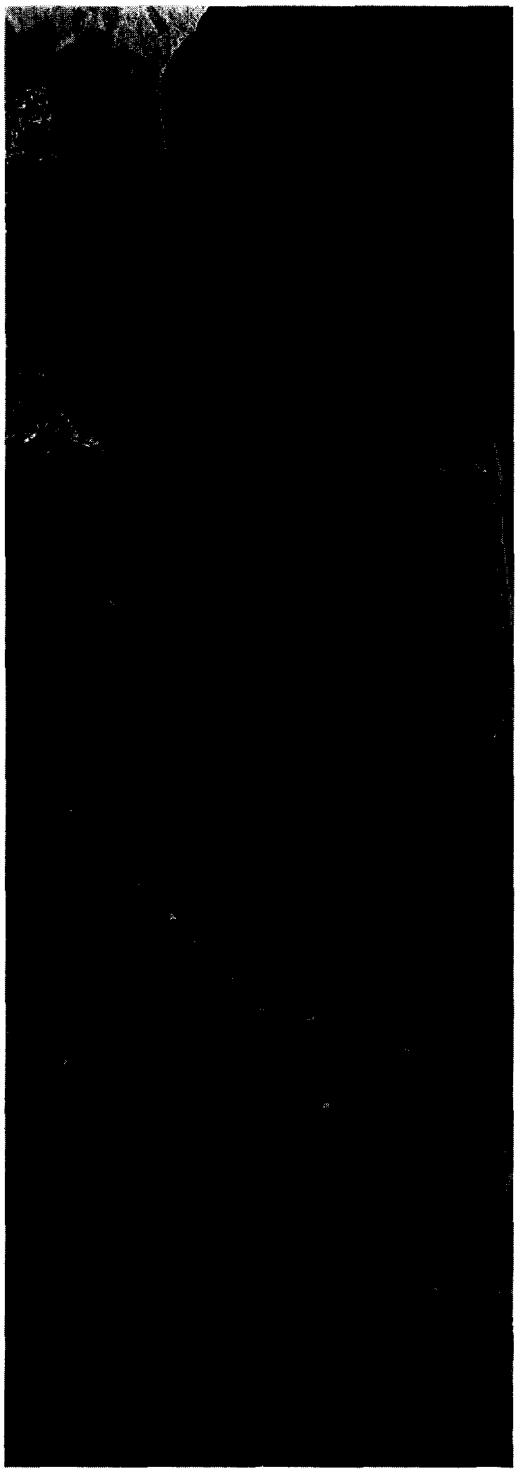

Fig. 1. The Danish strait Little Belt (4 x 4 looks).

IMPLEMENTATION

After azimuth pre-filtering the maximum PRF is 200 Hz, thus the 8K point complex range FFTs must be computed in less than 5 ms. In azimuth a typical requirement is 0.625 ms for a 2K FFT.

Also the frequent azimuth filter update and the interpolations associated with the second order motion compensation and the range curvature correction are very compute intensive, so the total requirement amounts to about 2 giga operations per second (GOPS). Therefore the RTP has been based on a pipeline architecture. Only three different types of hardware boards are involved: a programmable signal processing element (PSPE), a memory element (ME) and an interface element (IE). In the pipeline these elements are interconnected by a dedicated data path and a VME bus.

The hardware is implemented with 8 layer printed circuit boards (233.4 x 220 mm), and surface mounted components are used extensively. The RTP weighs less than 30 kg, and when operating it consumes about 0.5 kW of power.

From Fig. 2 it is seen that the RTP fits into a single 19" box. The 14 similarly looking boards are developed in-house. They constitute the pipeline, which is a direct mapping of the algorithm block diagram: interface to sensor (1 IE), range FFT, multiplication and inverse FFT (3 PSPEs), corner turning (2 MEs), azimuth FFT (2 PSPEs), matched filter generation and multiplication (1 PSPE), inverse azimuth FFT (2 PSPEs), re-corner turning (1 ME), detection, optional multilooking and grey scale transform (1 PSPE). The final PSPE currently serves as built-in test equipment (BITE). The boards to the left are commercially available standard boards: a CPU board for control, a display controller and a PROM board.

Since the RTP was originally designed for the KRAS system (C-band only), the current RTP version does not have enough memory to handle the large azimuth blocks and the severe range curvature associated with L-band data, see Table 1. Hence, these data will be focused to 4 m azimuth resolution. The range curvature and the depth of focus become the same at the two frequencies when the Doppler bandwidth and the effective PRF of the L-band RTP data are halved, and by adding an additional azimuth pre-filter, this can be done without affecting the raw data that are recorded for off-line processing.

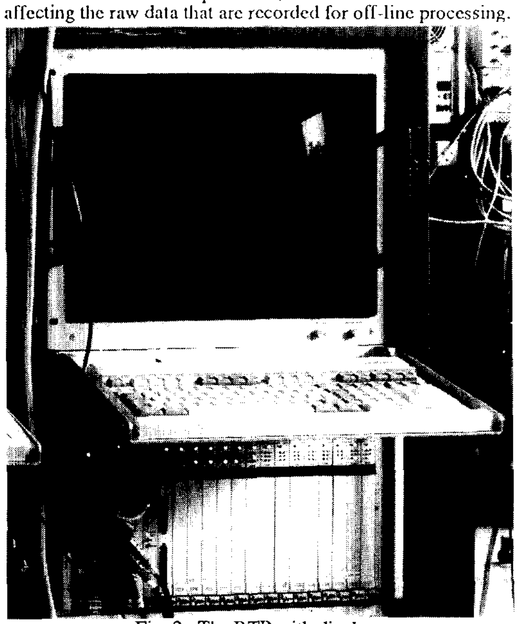

Fig. 2. The RTP with display.

PERFORMANCE EVALUATION

Denmark participated in an airborne SAR demonstration in Hungary, October 5 - 9 1992, with the purpose of testing the procedures laid out for SAR certification and demonstration in the Open Skies Treaty [3]. In an airfield a total of 40 trihedrals were deployed in three different patterns, see Fig. 3. The profile plots in Fig. 4 are associated with the 1.6 m reflector seen at the end of the runway. The complex RTP image was interpolated to provide the intensity profiles shown.

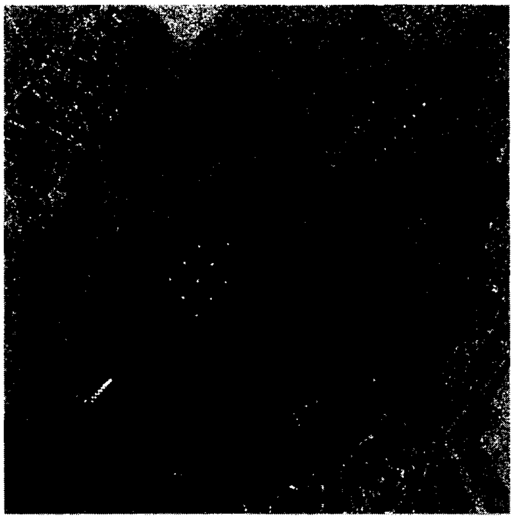

Fig. 3. Trihedrals deployed in an airfield (1-look). The flight track is to the right as in Fig. 1.

Hamming weighting was used for sidelobe suppression in range and azimuth, but the RTP was not yet able to correct for the weighting imposed by the azimuth pre-filter and the antenna pattern. Also, as mentioned in the introduction, range curvature correction was not yet implemented. (Range curvature is 0.6 sample at the 20 km range in question). On this background the 2.11 m and 2.16 m resolutions obtained in range and azimuth, respectively, are close to the 2 by 2 m goal.

The peak side lobe ratio (PSLR) appears directly from the figure, while the two-dimensional integrated sidelobe ratio (ISLR) has been calculated to -25 dB with a mainlobe width defined as three times the 3 dB width, and with sidelobes integrated out to ±10 times the 3 dB width.

The trihedral analysed above is the largest in a series of reflectors with radar cross sections ranging from 39.5 dB/m^2 to -15.5 dB/m^2 in 5 dB steps. The sensor-RTP combination proved to have a linear dynamic range exceeding 45 dB. The smallest reflector was not visible because it was masked by the background clutter, and the largest reflector was not able to saturate neither the sensor nor the RTP.

The dynamic range is interesting because the RTP works with fixed point arithmetic. Each PSPE is based on eight digital signal processors (DSPs) operating in 24 bits fixed point format. However, each stage of the RTP pipeline uses a scaling scheme that prevents the RTP from being saturated, even by a point target giving full scale RTP input. The 144 dB dynamic range offered by the 24 bits is sufficient to allow this very conservative approach.

After detection the 24 bits correspond to only 72 dB, but the dynamic range must be compressed anyway due to the 8 bit display. A logarithmic grey scale transform with operator adjustable saturation and dynamic range serves this purpose.

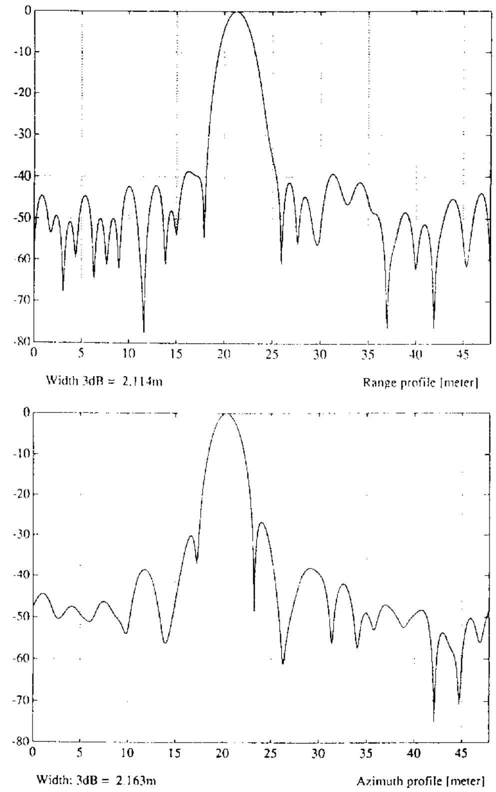

Fig. 4. Point target intensity profiles in dB.

CONCLUSIONS

In conclusion, the Danish real-time SAR processor has been completed and operated with great success. Capable of processing the entire swath into one-look full resolution imagery in real time, the processor meets its basic design specifications. An assessment of the processed imagery verified that the resolution is virtually 2 by 2 m, and the peak and integrated sidelobes are suppressed by more than 25 dB.

The RTP is currently being enhanced by second order motion compensation, range migration correction, auto focus as well as radiometric and geometric corrections.

Also an upgrade of the SAR sensor is in progress. The RTP will be able to process any of the eight channels acquired by the fully polarimetric C- and L-band system, but due to memory constraints, the azimuth resolution will be 4 m at L-band.

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