JPL SAR PROCESSOR DEVELOPMENT IN SUPPORT OF FLIGHT MISSIONS

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Abstract

This paper presents an overview of Synthetic Aperture Radar (SAR) signal processor development activities at the Jet Propulsion Laboratory (JPL) in support of NASA sponsored airborne and spaceborne SAR flight missions. The processors being developed include both computer software oriented and special-purpose hardware systems. The contents of the paper include a summary of the anticipated missions, functional specifications and descriptions of the associated processors, and a few related issues.

I. Introduction

Synthetic Aperture Radar (SAR) signal processing for image formation is one of the key steps in operating an end-to-end SAR sensor and data system. Unlike an optical imaging device where the sensor acquired raw data may already be in image form, micro-wave imaging sensor like a SAR acquires raw data in a form resembling a holographic representation of the target scene. The raw data must go through an extensive amount of processing to form a product that is in a conventional and interpretable image format.

The arithmetic processsing to reduce SAR raw data into imagery can further be complicated by a number of factors that are peculiar in each SAR flight mission. These factors include the choice of radar frequencies, tolerance of sensor attitude and altitude uncertainties, experiment objectives, etc. The processor implementation on one hand must be an integrated part of the sensor system design such that the method to accommodate mission peculiarities would be handled from an overall system optimization point of view. It is equally important on the other hand that the processor's performance is compatible to real users' needs in terms of data quality and output speed.

JPL's on-going SAR processor development activities can be categorized into those that are supporting current missions, and those for future anticipated missions. Current missions include the CV-990 Aircraft flights and Shuttle Imaging Radar-B (SIR-B) Experiment. Functional requirements for the associated SAR processors are well defined. For some of the future missions, which include Venus Radar Mapper, SIR-C Experiment, etc., some assumptions on data parameters have to be made. One important objective for the research and development on the SAR processor is to also demonstrate the feasibility of SAR signal processing at a very high rate -- near real-time data acquisition speed. This processing throughput rate is required for the ultimate goal of real-time SAR applications in environment monitoring. It also serves a near term significance of further ensuring that users needs for image products can be met in a timely manner. A programmatic overview of those ongoing SAR processor development activities will be given in the next part of this paper.

II. Processor Development for Current Missions

The NASA CV-990 Aircraft SAR flight missions and the SIR-B mission are in this category. JPL is currently conducting about two aircraft missions per year. There are 10 to 16 flights in each mission and each flight acquires approximately one hour of data. The aircraft sensor parameters are listed in Table 1. One significant feature of the aircraft sensor is its capability of acquiring simultaneous quadruple polarization data, i.e., the vertical and horizontal polarizations plus their cross-polarizations upon reception.

Table 1. NASA CV-990 SAR Parameters.

Parameter	Value
Radar Frequency	1225 MHz, 5280 MHz
Pulse Length	4.9 μsec
Pulse Bandwidth	19.6 MHz
Nominal PRF	612 to 765 Hz
Nominal Altitude	10 km
Nominal Velocity	200 to 250 m/s
Antenna Beamwidth	18° (Az), 80° (Rg)
Polarization	HH, VV, HV, VH

The aircraft SAR sensor is equipped with both optical and digital recorders. The recorded raw data are processed by both optical and digital means. Optical processing is used for surveying and mapping of large areas. Digital processing is applied to selected sites where detailed quantitative data analysis is desired. The JPL optical SAR processor has been used extensively in the past to support both airborne and spaceborne SAR missions. The referenced paper provides a good description of the optical as well as digital processing methods used for SAR data reduction. Operational digital processing for aircraft SAR data began in the fall of 1983. The processing is done on a Digital Equipment Corporation (DEC) VAX 11/780 computer in the SAR system laboratory. It applies the frequency domain correlation technique for image formation. The algorithm is similar to the one used by the JPL digital SEASAT SAR processor, which is based on a Gould SEL computer with multiple array processors.

The software based system offers good flexibility and is producing digital 10 m resolution 4-look imagery that is especially important to study the radar multiple-polarization effect. The drawback of a software processing system is in its limited throughput. The current VAX 11/780 computer is equipped with a Floating Point Systems (FPS) AP-120B array processor. A plan is being made now to augment the VAX with an APTEC peripheral control unit to be able to efficiently utilize multiple array processors for a higher throughput rate.

A real-time digital processor for survey processing of aircraft SAR data is also desirable for the purpose of on-board verification of data quality and experiment site. Simulation has indicated that a 10 m resolution single-look image would be adequate for the survey purpose. A development project for the design and implementation of such an aircraft SAR on-board survey processor was initialized in the fall of 1983. Preliminary specifications include real-time production of single-look 10 m resolution image over 10 to 15 km swath width. For this on-board processing application, we propose to use a special-purpose hardware processor. At L-Band radar frequency, with a 16 point azimuth presum filter, the azimuth compression ratio for 10 m resolution is in the order of 20. Including the oversampling effect, the number of samples for azimuth correlation reference function is approximately 40. The range compression ratio is close to 100 which is obtained from the product of the length and bandwidth of the radar transmitted pulses. The processor throughput rate is approximately 50K pixels per second, i.e., 1K pixels per line and 50 lines per second. Assuming the time-domain correlation as the baseline, the computational rate required is approximately 7 million complex multiples and accumulations per second. This is not a demanding requirement compared to the capability of commercially available integrated circuits for signal processing. Provisions are also made that the processor can be reprogrammed for C-Band radar operation, which is expected to occur in 1985.

The SIR-B data will be processed both optically and digitally. The basic SIR-B SAR parameters and summary of the performance specifications of the optical and digital SAR processors are listed in Table 2. The SIR-B mission is designed to acquire a total of approximately 80 hours of raw data. The plan is to complete the optical survey type of processing in about 12 months after the completion of SIR-B data acquisition, and about one-tenth of the digital raw data -- 7.5 hours worth -- processed digitally over a two-year period. For optical processing, minor modifications were made to the existing JPL optical SAR processor to improve image geometric performance and to provide better film annotation. The software and hardware system for SIR-B digital processing is based on the SEASAT Interim Digital SAR Processor (IDP). The system equipment includes a Gould SEL 32/77 computer, four FPS AP-120B array processors and a number of data storage disk drive units. The digital data are input via a Thorn-EMI high-density-digital-recorder. The digital correlation algorithm for SIR-B resembles that for the SEASAT SAR data. Software modifications were made to: 1) provide greater amount of flexibility to handle different input quantization bits, different radar look angle and the associated swath width, etc.; and 2) improve the geometric and radiometric performance of SIR-B SAR imagery relative to that of SEASAT. The 7.5 hr. (approximately 2000 images) processing requirement of SIR-B necessitates a dedicated SAR processing facility fully utilizing the IDP thus requiring a shift of the aircraft processing to the VAX computer.

Table 2A. SIR-B Parameter Summary.

Parameter	Value
Radar Frequency	1282 MHz
Pulse Length	30.4 μsec
Pulse Bandwidth	12 MHz
PRF	1248 to 1824 Hz
Peak Power	1 Kw
Antenna Dimension	10.7 x 2.16 m
Orbit Altitude	225, 235, 340 km
Orbit Inclination	57°
Look Angles	15° - 60°
Swath Width	25 - 55 km
Resolution	25 m (Az), 17-58 m (Rg)

Table 2B. SIR-B Processor Specification Summary.

Parameter	Optical	Digital
Nominal Resolution	40 m	25 m
Number of Looks	4	4
Pixel Spacing	NA	12.5 m
Geometric Accuracy Over Image	<3% relative	<0.1% relative
Peak-Side-Lobe-Ratio	-	≤ -20 dB
Integrated Side-Lobe Ratio	-	≤ -15 dB
Dynamic Range	17 dB	48 dB
Image Radiometric Accuracy	-	< 3 dB

III. Processor Development for Future Missions

SAR flight missions beyond 1985 include the continuation of aircraft SAR flights, the 1987 Venus Radar Mapper (VRM) mission, the potential SIR-C, -D, and the Space Station imaging radars. The processor of interest, a near real-time high throughput and high precision processor, is the Advanced Digital SAR Processor (ADSP). A system design block diagram of the ADSP is shown in Figure 1. As shown in the figure, SAR raw data go through a series of computational hardware elements to form a SAR image. The computational hardware elements are custom hardware and are pipeline in nature. That is, continuous input and processed output are available with an output delay being the required processing time for that computational element. With currently available electronics logic and memory components, a pipe-lined throughput rate of 10 MHz complex SAR image samples is specified. This is approximately one-half of the real-time SEASAT SAR data acquisition rate, but is nearly real-time for the incoming SIR-B mission.

Frequency-domain correlation technique is used for the two critical range and azimuth processors in the ADSP system. To achieve the 10 MHz throughput rate, both the range and azimuth processors contain two Fast Fourier Transform (FFT) modules with arithmetic elements between them operating in the frequency transform domain. The range correlation processing is relatively straight forward; a fixed range transfer function is multiplied to the range spectral data. The azimuth correlation for data acquired from spaceborne SAR sensors is relatively more involved than range processing. It is required to handle a number of SAR data peculiarities, which include range migration, depth of focusing, clutterlock and autofocusing, etc. These required processing functions call for the incorporation of a closed-loop azimuth processing control which is handled by the control microprocessor and computer. Much of the azimuth processing control methodology is described in the Reference. Because of the high throughput rate and the complexity of having a number of computational elements, each is designed to handle a particular function, the challenge to the ADSP development will be very much in the system integration and verification phase which is scheduled in late 1985.

IV. Related Development Issues

Because of the relatively complex computational functions, the SAR correlator has been the focus of the SAR data handling and processing system in the past several years. Because the SAR processing functions are now very well developed, and the interests of SAR experiments is gradually shifting from exploration into exploitation, issues that are related to the quality of operation and flexibility to users, are increasingly important. The end-to-end ground data handling system, which includes the data recorder, SAR correlator, image processing computer, image data base management system, etc., must be treated as an integrated one. While the detailed engineering design parameters in a system must comply with the mission requirements, a number of the system design tradeoffs appear philosophical, and are more related to the general needs of users. Topics of this nature may include distributed versus centralized data processing subsystems, flexibility requirements, etc.

A survey of users' needs on the SAR data system was conducted recently. Approximately 20 SAR experimenters were polled. Fields of interest include agriculture, geology, oceanography, and radargrammetry. Survey results are briefly summarized as follows: On the data type needed: image data are needed

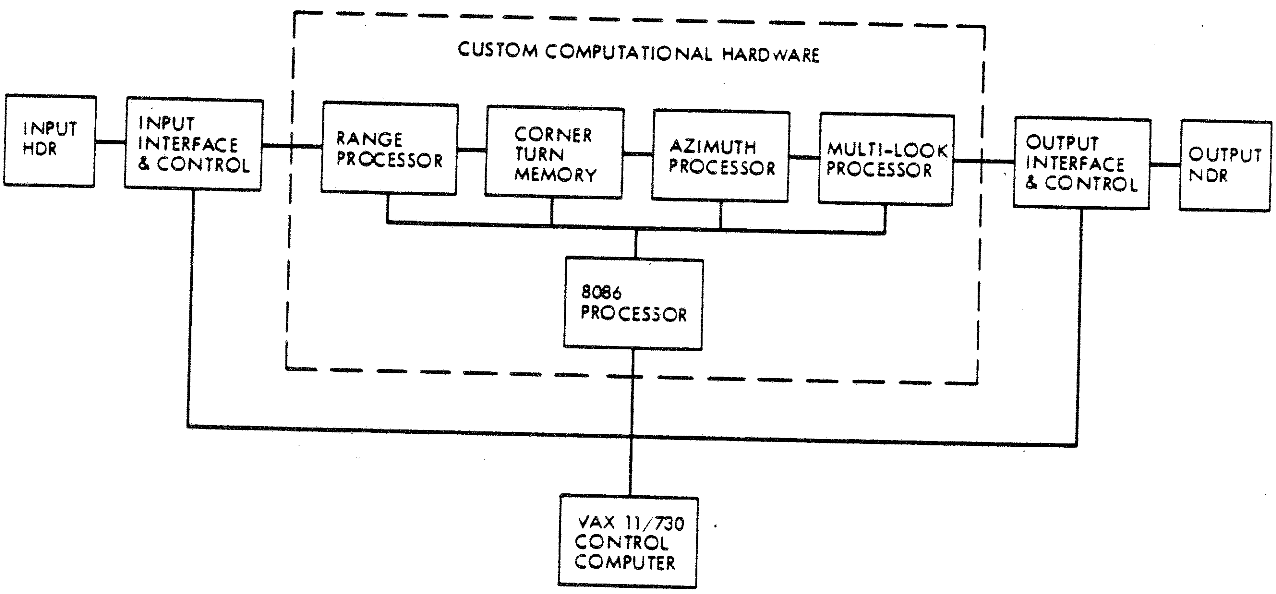

Fig. 1. ADSP (Advanced Digital SAR Processor) system diagram.

by all users, of course, a few users will also request SAR raw data; On radiometric calibration: accuracy to 1 dB variance is very much desired; On geometric correction: rectified image overlayable to Universal Transverse Mercator (UTM) scale with 100 meter location accuracy is desired; On processing turn-around time: one to three months for general experiment and application, near real-time to one day for those with field experiments; On user information system: needs user accessible computer based data management system with good documentation and an assigned staff function for user support.

Centralized data processing system is the current trend in JPL's development and planning for future missions. As commercial array processors are increasingly being used for computation, a number of SAR users now have their own capability for dedicated special processing with adequate throughput. The increased use of computer communication and networking is fostering the idea of a user information and data management network. It is feasible to combine the information network and available SAR correlation and image processing systems for a distributed SAR data system.

V. Summary

In the past several years, we have mainly depended on a computer based software processing system and on an optical SAR processor to provide image data products for airborne and spaceborne SAR missions. We hope a successful development of the Advanced Digital SAR Processor will provide a high quality digital SAR product in near real-time such that the SAR flight sensor can become more effective in supporting environment observation applications where rapid turn-around time is very important. We will certainly see continuous applications in software based systems, on which an individual user can perform customized processing to suit the special needs of an experiment. A high throughput SAR processor will certainly call for downstream high speed image processing and analysis machines. Existing software based SAR correlation systems can certainly be reprogrammed for this purpose. Future advancement of programmable array processors and the evolution of super-computers may ultimately provide the additional flexibility and computational efficiency necessary for SAR users to select a specific processing technique designed to meet their utilization requirement.

Acknowledgement

The author wishes to thank T. Bicknell and J. Curlander for their valuable inputs. The work described in this paper was performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Reference

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