Commission II Group II.4

The ISP SAR Processing Working Group Activities

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Abstract:

The activites of the ISP SAR Processing Working Group are presented with emphasis on the topics addressed during the two-day session held at Frascati in December 1979.

1. Introduction

During the ISP International Symposium held in Paris on 12-14 September, 1978, it has been decided to create a subgroup of the group II.4 (Instruments for processing and analysis of Remote Sensing data). The specific purpose of the subgroup was to deal with the instrumentation required for processing and analysis of SAR (Synthetic Aperture Radar) data. The meeting on this subject held during this symposium arrived at the conclusion that although SAR processing exhibits some commonalities with the processing of remote sensing data in general (e.g. with respect to storage, archiving, etc.) its unique featuresdeserve a particular attention. Moreover it has been recognized that other aspects namely acquisition, algorithms and interpretation would possibly affect the required instrumentation. Therefore contacts with other ISP commissions were thought desirable but unfortunately this link has not been established yet.

A two-day session of the ISP SAR processing working has been held at Frascati in December 1979. The Earthnet Frascati centre of the European Space Agency acted as the host and this allowed for the participation of some 80 persons. Needless to say how much the ISP correspondents are grateful to ESA for having made this meeting possible.

About twenty contributions have been presented, encompassing

System Aspects and instrumentation.

Participants were from Europe, USA, Canada and Japan and fortunately most of the leading bodies in the area of SAR processing were represented.

Proceedings of these meetings are under publication by the European Space Agency.

This paper is aimed at reviewing the papers forming part of the proceedings and at summing up some conclusions this working group arrived at.

1. Systems Aspects

1.1 Seasat SAR Digital Processor Configurations (ref. 3)

The US spacecraft Seasat-A did offer the first opportunity to develop configurations aiming at processing data gathered by a spaceborne radar.

Without entering any algorithm related discussion, it is worth bearing in mind that processing data from spaceborne radar happens to be much more difficult than processing data from airborne radar. This is mainly due to the difference of geometry and above all due to the Earth rotation occuring during the radar measurement.

The processors under consideration are listed as follows:

MDA	Richmond	Canada
CRC	Ottawa	Canada
RAE	Farnborough	United Kingdom
DFVLR-GSOC	Oberpfaffenhofen	Germany
JPL	Pasadena	USA
Bendix	Ann Arbor	USA

Although this presentation is concerned with the hardware aspect only, it is worth mentioning that various processing algorithms have been eventually implemented. For instance:

MDA	range doppler approach
CRC	two-dimensional approach
RAE	Time-domain approach
JPL	frequency domain approach

The MDA Configuration (January 1979):

The hardware configuration exhibits the following features:

host Computer	Interdata 8/32
Computer memory	512 K bytes
mass storage	two 80 M bytes discs
peripherals	CRT/keyboard OPTRONICS film recorder COMTAL image analysis

All basic processing steps are performed (e.g. auxiliary data processing, range and azimuth correlation, geometric corrections), to produce a 36 x 40 km image with Seasat typical characteristics (25 m resolution, 4 looks). The initial throughput was rather modest (38 hours) but an array processor (AP-120B) is under implementation to speed it up (see also DFVLR-MDA processor).

The CRC Processor (Communication Research Centre):

The hardware is as follows:

host computer	Interdata 8/32 (two buses configuration)
computer memory	768 K bytes
mass storage	two 80 M byte discs
array processor	AP-120B (64 K words) by FPS
peripherals	Norpak 512 x 512 raster graphics imaging system CRT console/Tektronics 4014

To minimize disc input/output operations, simultaneous computing occurs in Interdata and array processor. All hardware components run asynchronously.

A typical product features 21 x 47 km, 4 looks, 25 m resolution (process throughput: 8.5 hours). One look, full azimuth resolution (7m) images are also produced.

RAE Processor:

Under RAE contract, System Designers Limited has developed an experimental SAR processing facility (ESPF), now installed at Farnborough. Its main characteristics are:

host computer	Prime 400
computer memory	224 K words
mass storage	three 80 M byte discs one 300 M byte disc
peripherals	four VDU's Tektronic graphic display Linescan Image writing machine

A typical product is 50 x 50 km, 1 look, 25 m resolution at a very low throughput (time domain correlation).

DFVLR-GSOC Processor:

The software processor as developed by MDA has been purchased by the ESA to run on an Interdata facility existing at Oberpfaffenhofen (DFVLR-GSOC).

Such configuration is as follows:

host computer	Interdata 8/32
computer memory	768 K words
mass storage	one 300 M byte disc one 80 M byte disc
array processor	AP120B (16 K words) by FPS

peripherals	various displays VP-8 Image Analysis System (via AMDAHL Computer) Mulby 3135 Linescan

A typical product (40 km x 40 km, 4 looks, 25 m resolution) is produced in 20 hours. A faster version (7-9 hours) will run from January 1980 on.

The JPL Processor (ref. 2)

The interface between the HDDR and the computer is consisting of a piece of custom design hardware converting a 1-bit serial line (fibre optics plus coaxial as backup) into a 32-bit parallel stream. The playback ratio is 1/32. The processor itself is consisting of:

host computer	SEL 32/55
computer memory	one 80 M byte disc one 300 M byte disc
array processor	AP120B (26 K words) by FPS
peripherals	Dicomed Image Recorder

A 100 km x 100 km frame (4 looks, 25m resolution) is produced in 9.5 hours.

The BendiR SAR processor:
It is consisting of an interface (SDP, SAR Data Preprocessor) and of the processor itself (SARP, SAR Preprocessor). The SDP (digital hardware in TTL and ECL) transfers data from the HDDR to a mass disc via an array processor AP-120 B. Various other functions are performed: frame synchronisation, presummation of adjacent returns, test pattern generation etc.). It interfaces the SARP by means of an I/O processor IOP38 (to the AP-120 B) or by DMA (host to SDP).

The SARP features are:

host computer	Data General NOVA
mass storage	300 M byte disc
array processor	AP-120B (64 K words) by FPS

The image characteristics of a 100 km x 100 km are not specified. The processor throughput is qualified as "low".

It is of interest to notice that all above hardware configurations exhibit many commonalities in spite of a great diversity at algorithm level. They are all based on powerful mini computers either 16 bits or 32 bit (SEL, Interdata). All require at least one 300 M byte disc.

The array processor AP-120 B developed by Floating Point Systems is extensively used in particular to perform Fast Fourier Transforms.

Another interesting point is the need for various graphic displays and the access to an image analysis system.

So far, the announced improvements are all based on making more benefit from the array processor either by using it for data transfers as well or by considering multi-array configurations (Bendix, JPL).

After implementation, those configurations improvements are expected to give a throughput of 7 hours for the MDA-DFVLR processor and 2 hours for the JPL processor.

1.2 An Example of Real Time Airborne SAR Processor (Ref. 7)

Compared with the task of processing SAR data from spaceborne radar such as on Seasat, the processing of airborne SAR data can take advantage of many simplifications. In the airborne radar, aircraft angular motion errors and yaw offsets are removed mechanically by steering the antenna so as to always point broadside to the direction of motion. Furthermore, the PRF is slaved to the aircraft along track velocity to ensure constant azimuth sample spacing on the ground. Across-track motion errors in the slant range plane are removed by phase compensation circuits in the radar receiver. As a result of these elaborate motion compensation systems, the processor requirements are considerably simplified. Because the antenna boresight always points perpendicular to the aircraft line of flight, the portion of the Doppler spectrum illuminated is fixed and symmetrical about zero Doppler. Also, the fixed sample spacing on the ground and the removal of motion phase errors in the receiver, all result in simplifications in the design of the azimuth correlator.

With the ERIM X-band radar, the processor produces nominally 3 m resolution imagery in both slant range and azimuth, over a slant range subswath of 6 km which can be selected anywhere within a 3 to 15 km slant range full swath. However, several combinations of resolution and swath width can be fitted and be handled by the processor.

The processor is contained in the 10½" high rack-mount unit, and consists of 47 6" x 8" circuit boards. Low power Schottky TTL logic is used with 20 KB of PROM for coefficient and code storage and 125 KB of RAM for data storage.

Arithmetic rates are typically 5 MHz with several associated functions paralleled and pipelined. This allows an input line rate of up to 75 Hz with 2048 point lines.

The MDA real-time airborne SAR processor has now been in continuous operation for over a year. Many experiments have been conducted using the produced images. Some of them explored new avenues opened up by the real-time availability of the images. An experiment in the polar regions consisted of relaying ice condition information visible on the SAR image directly to the crew of vessels operating in the area.

An additional function of the real-time processor has been developed by the operators on the aircraft. The real-time images allow an exact monitoring of the entire SAR system's performance during imaging missions.

1.3 Future spaceborne SAR processors

1.3.1 Future on-ground processing of spaceborne SAR data

From the discussion, two main (and compementary) approachs are pursued.
The first one consist of speeding up SEASAT-like processors, i.e. improving the throughput without any compromise as far as image quality is concerned.
Benefit is made for appearing computer architectures (e.g. array processors, multiprocessors, bit-serial parallel processing) In particular the bit-serial parallel processing has been considered as very promising and will be discussed more in depth within the second part (intrumentation) of this presentation.
The second one is aimed at putting emphasis on throughput, at the expense of performance. The interesting concept of quicklook SAR processors as presented by CCRS can be considered as typical (REF 9) It is therefore here after introduced.

The SEASAT satellite carried an imaging L-band radar, which covered a swath width of 100 Km. at a ground resolution of 25 metres. In order to achieve the long-track resolution from its orbiting altitude of 805 Km., an aperture of about 5 KM. must be synthesized. For the 4-look SEASAT image, the synthetic aperture is approximately 20 Km. The extent and duration of this aperture and the earth's rotation causes the path length between a particular earth point and the orbiting radar to vary by up to 800 metres. Since the slant range resolution is 8 metres (ground range resolution 25m), the target 'walks' through many range resolution cells. This range migration is the major problem in processing SEASAT data. For digital processors the amount of computation and volume of data needed to produce each image point are also signigicant difficulties.

Fortunately all these problems are mitigated when the resolution of the images is reduced to 100 metres. The range migration can now be approximated by linear skewing of the raw data, and the data processing work-load is reduced by a factor of 16. The images obviously lack the detail available in fully processed 25 metre image but are useful for screening the data and can be used for certain applications. The loss of resolution is partly offset by the increase in number of looks available (potentially 64), which reduces the speckle in the image.

The processor has been inplemented on a DEC 10/90 computer. A block of area 20 Km. x 17 Km. takes two (2) hours and 20 minutes to produce a 7 look image. It is now being transferred to DEC-10

computer equipped with the CSPI MAP-300 array processor.
A feasibility study is also underway to determine the speed at which images of this kind can be procuced using direct convolution hardware.

1.3.2. Future on-board SAR processors.

The trend towards on-board processing proved a controversial issue. The discussion has been substantiated by addressing 3 projects:

- the microwave remote sensing experiment (MRSE, ref 10)
- the technological studies in view of SAR processors on-board shuttle and/or Spacelab (ref 11)
- the technological studies in view of future free-flyer remote sensing spacecrafts. (REF 12)

The experimental aims of the MRSE instrument (on-board Spacelab) are:

- to measure the directional wave height spectrum of the sea surface by the two frequency scatterometer method
- to generate high reslution radar images of land surfaces by application of the synthetic aperture principle (SAR mode).

The spatial resolution is in order of 25 x 25 m^2. Due to limitations in antenna size, in data rate, (down link from SL) and absence of an on-board processing facility the imaged swathwidth is only 8,5 km.

The SAR mode of MRSE is based in the pulsed radar principle. In order to obtain the required range resolution a pulse compression by linear chirp modulation is implemented. The transmitted chirp pulse with an instantaneous frequency varying linearly is generated in a sufrace acoustic wave expander. In the receiver a complementary device performs the compression to the required range resolution. The dynamic range will be controlled accurately within the processed swathwidth by an Automat. Gain Control (AGC). The actual AGC adjustment is transmitted together with the data stream. Thus the compression of dynamic may be removed during the final processing on ground. The data are sampled in a burstmode. In order to reduce the transfer rate, "first in first out" memory organization is used to average the data samples in time. After coherent detection the inphase and quadrature phase signals are digitized in very fast A/D-converters with 4 bit encoding.

In a multiplexer subsystem this buffering the combination with housekeeping and auxiliary data, and the formatting is performed The data are then routed to the Spacelab high rate multiplexer via the direct access channel.

In all modes the data streams are transmitted to ground via TDRSS The processing of the scientific data for use by the different experimenters will be done after the mission by DFVLR which will obtain the magnetic tapes from NASA.

For processing SAR data DFVLR is just implementing a processor software package in the main computer facility.

It can therefore be stressed that the on-board processing is limited to the necessary signal conditionning in order to be compabible with the data down-link capabilities.

Further missions will require a more sophisticated on-board processing and various on-going technologie studies are aimed at fulfilling this requirement by using either analog or digital devices.
In particular for SAR azimuth processing an analog Correlator would be a suitable tool. Since the performance of such devices is mostly not predictable, investigations have been initiated with a breadboard study (ref 11)

A result of the analysis of available components, performed during the first phase of that breadboard study, has been that the analog CCD correlator R5403 is a favoured candidate for that application. For analysis and tests, two special SAR-simulators have been built to provide the azimuth-correlator with specific radar-signals.

The RETICON R 5403 is a true analog integrated circuit performing a 32 words real correlation. It consists of two analog shift registers built up with bucket brigade technology (BBD). The contents of eacht two opposite register elements are multiplied by means of 32 parallel analog multipliers, the outputs of which must be summed externally. Furthermore, the information travelling along the reference register can be stored on 32 internal capacitors, thus allowing the correlation process between a fixed reference function and a moving signal function, respectively.

A 64 words correlation could be performed by cascading the BDD's of two R 5403's. However, the signal quality at the output of each shift register at high clock frequencies if fairly poor. Therefore, the two BBD's are cascaded indirectly.
Four 64 words real correlators have been implemented in printed circuit boards. Two 32 words correlators (on one board) are using the same peripheral circuits. Therefore, the power consumption of the board is considerable below twice the consumption of a 32 words correlator.

At a frequency of 2.1 MHz, each of the four boards which were measured needs a power of somewhat above 2 Watt. The supply voltages are +15 VDC, ± 6 VDC.

Each board has a weight of 138 grams.

The thermal noise at the output of the correlator is 0.001V. With respect to a 1 V_{rms} maximum output voltage, the dynamic range can be calculated to be 60 dB.

For this kind of board, the noise level can be expected to be at least one order of magnitude lower than in case of a multilayer printed circuit board. It could be shown that the clock peaks are generated mainly from direct coupling between the clock lines and the current sources.

The results of these breadboarding activities show good performance with respect to signal quality, linearity and noise.
It seems that nearly all SAR specifications probably could be met.

The high efficiency allows real time processing of a swatchwidth of about 50 km.

To process complete swath of 100 km results in a total power consumption of about 104 watts.

The penalty in doing so of cause is a higher sensitivity to noise or crosstalk within the system than corresponding digital solutions. The problem of the need of adjustment and inflight calibration is still under investigations.

Further problems may arise due to qualification requirements, which are not yet known. It seems such device fits fairly well the realtime azimuth processing requirements.

A complete 64 words complex correlator consists of four real correlator boards, eight DAC's, a simple passive summing network and two ADC's. A complex correlator, therefore, consumes 8 watts without the 8 DAC's and 2 ADC's. If each DAC is estimated to need 0,4 watt and moreover, 1,8 watts total allowed for the ADC's we arrive at 13 watts for am complete complex correlator with a mean speed (in case of 128 words batch processing) of 1,5 x 10 correlations/sec. at a clock frequency of 2 MHz. Because of a data rate of 2.8M Samples/sec at the input of each subaperture branch two such correlators can perform a real time subaperture correlation at a swathwidth of 100 km. With four looks in parallel the complex azimuth correlation can be performed at a power consumption of

2 x 13 x 4 watts = 104 watts, total.

A parallel approach, as reported in reference 1, is based on optimizing the algorithm by making maximum benefit from the linear frequency variation of the radar signal (spectral analysis approach) and identifying analog and/or digital devices, fast enough as to cope with the required number of operations.

The raw radar signal (range compressed) is obtained directly from the satellite ground receiver via a formatting interface or from a high density digital tape on which it has been archived. One subaperture of data is stored in a corner turning memory prior to azimuth processing. The data is read out in a skewed fashion with an address scheme following the point reflector delay history. Interpolation in range may be necessary and is performed by the range migration compensation unit (RMC). The memory capacity is given by the product of the number of range gates (R) with the time-bandwidth product per sub-aperture (TB). A 4 points complex interpolation is believed to be adequate.

The data is then mixed with the reference chirp obtained by Fourier analysis of the raw data itself and from orbit prediction and satellite on-board attitude mesaurements. The sub aperture image or look is obtained after a direct Fourier transform of the mixer output. The lenght of the transform is equal to the time bandwidth product per subaperture (TB). The number of complex multiplications per output image point in the FFT is $\frac{1}{2}$ log2 TB_L. The data is then oversampled before the non-linear detection. Simultaneously, two dimensional deskewing is performed to produce an image with one axis parallel to the satellite ground track and the other perpendicular. Assuming four point interpolation is adequate, one 4 x 4 complex matrices multiplication is performed per output pixel. A delay store is required to accumulate the looks: for N looks the capaciy of the store is K_1 x R x TB_L (real 8 bits words) where K_1 is a factor taking into account the FFT inefficiency (n.b. of valid output points) and the oversampling ratio.

Finally, pixel averaging and, optionally, slant range to ground range conversion is performed to produce a final image product. Radiometric and geometric corrections can be merged with the processing operations described before without additional load and the output product is compatible with a level II (precision preprocessed) image.

After looking into the computational requirement, the author of the above mentioned study, believes that real time processing of the radar data, as gathered by the future remote sensing satellites, is feasible but must be implemented with special purpose hardware.

As a matter of fact NMOS dynamic random access memories are able to handle input and output data rates in the range of 2 to 4 Mbytes/sec. The data rate through the processor can be decreased by processing fractions of the swath in parallel. Eight units processing each one eighth of the swath would be sufficient. Total memory requirement does not constitute a problem. Multiplication rate is marginally higher than what is achievable with today's fastest bipolar 8 bits multiplier (100 nsec multiplication time) but parallel subwath processing brings the required performance within well achievable limits.

1.4 Optical Processing (ref 12)

In spite of the trend towards digital processing, optical processing exhibits attractive features (e.g. throughput, proven technology etc...) and some thoughts have been given to its future.

In the program performed for the European Space Agency, 53 (100 km swath width) SAR data collection passes received at the Oakhanger Station from the SEASAT were transferred to film recordings and then optically processed. A total of approximately 150,000 km of strip map image data were generated at ERIM at a processing cost of about one cent per square kilometer as part of this program.

Processing of SAR data by optical methods can be characterized by the operations required to compress the extended point target histories to points or spots of light at the processor output, and, additional operations associated with data handling and output image data extraction.

A variety of optical processor configuration are available; we discuss here the tilted plane processor system used for SEASAT-A SAR data processing at ERIM. The SAR data is entered as a recorded film strip at the input plane of the processor. It is illuminated with a collimated coherent light beam which passes through the film over a film area encompassing the full range interval of recorded data and slightly more than a full azimuth length of a point target history.

The tilted plane processor makes use of two telescopic lens sets in cascade, one is spherical and the second a cylindrical telescope.
Briefly stated, the spherical telescope simply re-images, in the range dimension, the light focused by the zone plates of the input radar data to the processor output plane. The cylindrical telescope modifies the imaging process in one dimension, the azimuth dimension, to remove the anamorphic property and adjust relative scale factors.

The provisions for radar data film entry and output image data extraction in the optical processor are quite important to realizing high quality imagery. In the ERIM system a precision film transport is used to move the signal film through the processor input plane at a selectable constant speed or in indexed increments. Output imagery is provided in several forms: as a film recording of the output image light distribution either in a conventional or a holographic sense; as a directly viewable projection display; or as a photo-detector scan which is digitized and tape recorded.

Processing is performed with the input film moving and the output film speed set to equal the image data motion which occurs in the azimuth or film length direction.

The output film is exposed through an output aperture which covers an extended range interval (swath width) and an azimuth interval several resolution cells wide. The position of an image point on the output film is maintained over the output aperture by proper setting of the output film speed, i.e., image tracking is maintained. This has the benefit of noise smoothing and of reducing the power required of the laser illumination source in the processor.

The phase perturbation of the SAR signal caused by azimuth wander, range walk and range curvature is corrected in the processor. Azimuth wander is corrected by directing the processor input illuminating beam to an angle which shifts the azimuth signal specturm to prescribed fixed frequency location. The desired spectrum location is judged at the signal frequency spectrum plane available in the processor optical channel. Range walk is corrected by cancellation. This is accomplished in the signal frequency plane by insertion of a phase function which is equal but opposite in sign to that caused by range walk in the signal frequency spectrum. Range curvature correction is also accomplished by using a compensating phase function in the signal frequency plane.

The adjustments to the corrector element in the processor can be made on an automated continuous basis or they can be made as fixed settings which are maintained for portions of the length of the input SAR data. The latter approach is used in the ERIM optical processor system as it was found that fixed corrector settings allow full resolution high quality imagery for image strip lengths of about 500 km. Imagery of reduced resolution (20 m slant range 20 m azimuth) can be produced with fixed corrector settings for image strip lengths of about 4000 km. The proper settings of the corrector elements are made by operator observation of the signal frequency spectrum position in the processor frequency plane and image quality judged at the processor output image plane.

The processor output light intensity distribution or aerial image is made available in the present ERIM processor configuration, nominally at a scale factor of 690,000:1 in ground distance coordinates and a cross-track to alongtrack aspect ratio of 1:1. Imagery is generated in 28 km swath segments and an extended along track or azimuth length.

Conversion from the normal slant range coordinate of the SAR to ground range is done to first order with higher order conversion terms not included. This leaves a residual scale factor variation in the image cross-track dimension of about plus and minus five percent relative to the center of the 100 km swath.

The processor system itself has a peak signal to noise ratio of 80 dB or more and will readily accommodate the large dynamic range of the SAR imagery.

Image recording is done on a 70 mm wide film transparency with 4000 km of image length placed on film about 6 m long.
The storage capacity of film is quite favorable.

Approximately 12.000 km of 100 km swath width strip map imagery can be generated in one day given the SAR signal film and using a dedicated optical processor and film development facility. With the present ERIM processing configuration this assumes SAR data is provided in the form of strips each representing a quarter swath width 4000 km long.

The optical processing of SEASAT-A SAR data accomplished at ERIM, though not performed in a dedicated production mode, has proven to be an effective and moderate cost dataprocessing approach having a high throughput computing capacity. Optical processing of SAR data if implemented and dedicated to the specific needs of a system such as the SEASAT-A SAR, will provide a very effective data processing capability well suited to complementing a digital processing facility.

2. Instrumentation

2.1 Future requirements (ref 4)

The processing requirements we will have to meet once the next generation of RS SAR systems will come into operations will be considerably more demanding than today's ones.

However some general considerations are worth introducing:

- The performance of a digital SAR processor of a L-Band radar like the one of Seasat, can allow for one scene 100 x 100 km 25 m resolution in 4 looks to be generated in 10 to 20 hrs.
  Improvements by factor 4 are possible and planned with presently available technology.
- Even the next mission flying a SAR will probably be experimental in nature (it will not operate in L-Band) and therefore it does not require, on sustained basis, large production of data.
- The present trend towards higher frequencies (i.e. C and X) will simplify to some extent the processing task.
- The present trend in technology indicates that computers, array processor, fast memories, parallel processors etc. with improved performance will become available in the near future at competitive prices.

- Some similarities appear when locating those requirements within the area of image processing in general.

When analysing the future requirements for image preprocessing of optical multispectral sensors, we can identify trends in the following directions:

- increase ground resolution (from 80m of MSS to 30m of TM and OII of LASS, to 10-20m of SPOT)
- increase number of spectral bands (from 4 of MSS to 7 of TM and OII)
- increase requirements in the geometrical and radiometrical accuracy (from bulk processing to precision processing)
- increase volume of data to be generated and made available due to the near operational nature of the service.

The throughput of presently developped systems, operating for instance for Landsat, tends to be adequate for MSS where dedicated pipelined systems are available (i.e. MDP at Goddard) but will soon become critical in the Landsat D TM area.

The plans Earthnet have elaborated from the mid 80's in this field show that the precision processing of a standard TM scene will require processing power and elapsed time comparable to the one expected for a SAR scene of 100 x 100 km in C or better X band.

Furthermore the system architecture, based upon minicomputers with large memories, large disk stores and fast array processors are practically identical to the one selected for experimental SAR processing today.

The parallelism of requirements is further shown by the similarity in the bit rates required for the two types sensors.

Experience has shown that:

- Interface between archive and pre-processing system
- labelling of raw data with auxilliary information (i.e. orbit/attitude etc.)
- checking input raw data

represent a workload which has been underestimated initially and should be accounted for in the evaluation of overall system throughput.

Another key area is input/output of data with the processing system: if much larger Direct Access memories could be made available on standard systems, their performance could be improved considerably.

Finally the output media and format is a topic still to be completely evaluated: it is clear that photographic support offer a dynamic range inadequate to SAR requirements.

In the case of digital products, the dynamic range can be selected to match the characteristics of the sensor but in such case most of standard utilities in image analysis systems would not be usable any longer.

From a technological standpoint, the requirements of SAR processing are certainly stringent but not unique. The many similarities of the SAR processing task with the task of precision correction of high resolution multispectral optical sensors will probably mean a parallel, and to some extent interrelated development of the two type of activities.

As a matter of fact, the rest of the workshop discustions has been devoted to 2 topics namely the image storage and archiving system and the possibilities of parallel processing.

2.1 Archiving systems: the meteosat example (ref 8)

Processing SAR signals, SAR images or other types of remote sensing data involve a very large amount of data. Typically one image will be of 25Mbytes of data and only few of these images can be stored on-line with to day's technology.

The term archiving is therefore introduced describing a facility where the basic data material is put away and only a label is stored on-line.

The Archiving Subsystem for Meteosat is part of the Ground Computer System based on a dual ICL 2980 main frame computer. The Archiving Subsystem establishes a digital archive based on high density digital tapes and a photoarchive based on high resolution hard copies on film. Furthermore the system performs retrieval and generates various products to the users. The Subsystem is based on two minicomputers which are linked to the main frames. A number of standard peripherals like disks and CCT's are connected to the minicomputers but the special devices which include 3 high density tape recorders (HDTR's)and one Film Recorder are connected via special designed intelligent formatters. These formatters are based on the CR80 system which is a modular 16 bit processor system based on a multibus architecture.

The digital archive is based on 3 high density tape recorders and special formatters. It should be noticed that the data rates are determined by the minicomputer and its disk rather than by the HDTR and formatters.

The system was installed in December 1977 and has been in operational use since then, and some conclusions can already be drawn:

1. It was possible to develop the overall system and the application software in parallel by two different organisations and integrate these items at a reasonably small effort
2. The application software is written in a high level language only
3. It has not been necessary to modify the intelligent peripheral controllers except on a few points
4. It has been possible to almost double the system without changing application software
5. It has been possible to introduce new HDTR products without application software changes.

We therefore find that the concept of intelligent device formatters, which interface on a high level to the control computer, will be a viable solution to to day's image processing systems.

Although the overall performance of the system has been good, some operational problems occured due to the use of high density tape recorders in a computer milieu.

The following appeared:

1. The high density tape recorders are a kind of "An Ugly Duckling" in the computer milieu in the way that thet need special operational care, i.e. in cleaning tape path and mounting tape
2. The performance of HDTR's depends heavily on the adjustments which makes it difficult to maintain compatability from time to time, i.e. a typical HDTR has 80 adjustment points which all should be adjusted carefully
3. Burst errors are much more determining for the performance than expected probably due to 1) and 2) above

We have performed a bit error rate analysis of almost 10^{10} bits on two high density recorders in the system based on 86 individual tests. Comparing the calculated bit error rate, including and excluding bit slippage it is found that bit slippage is the most important error source. We know that for a good adjusted tape recorder using screened tape, bit slippage does not occur but in an operational milieu, data may be recorded on one recorder and reproduced on another, adjustment may not always be optimum and the cleaning not always perfect.

However, these problems can be solved if the following points are considered:

1. Operational and maintenance procedures are made with special attention to these problems
2. The high density tape recorders are improved with error correcting electronics and record/reproduce electronics with fewer adjustment points.

2.2 Instrumentation for Image Data Storage

The main applications for storing data are as follows:

1) Storing raw (unprocessed) data.
2) Storage of data during processing.
3) Storage for dissemination.
4) Storage for archives.

The important parameters so far as the user is concerned are:

1) Total capacity (as a single module).
2) Data rate of reading and writing.
3) Access time (time to retrieve specific data).
4) Whether the data can be readily changed.
5) Integrity of the data (error rate).
6) Reliability.
7) Cost.

Size and weight may also influence the final choice, however, like cost these are fairly well determined when an initial choice has been made.

The important technologies are those of:

1) Magnetic tape.
2) Magnetic disk.
3) Optical storage methods.
4) Storage devices (components).

Although magnetic tape systems (e.g. video tape recorders, instrumentation tape recorders, computer compatible magnetic recording, and magnetic disk systems have been discussed in depth, this summary will be concerned only by optical storage and emerging memory devices.

Optical storage is the obvious method of photographic or hard copy storage in which an image, or raw data, is recorded on film or some other suitable material. This is capable of very high definition, implying a large capacity. The dynamic range of photographic materials limits the dynamic range.
However, the image is ideally suited for examination by the user. Although film and photographs can be scanned to produce analogue or digital waveforms for further processing, this degrades the image further in both dynamic range and resolution. In general, this method is most likely to be restricted to archive processed or raw data and for the dissemination of pictorial information.

A second optical method of storage is that of holography. This approach received considerable publicity in the early days, promising very high density storage. Although some work has been done on its use for image storage, there appears to be no viable commercial product available to enable an assessment to be made. The equipment to store and retrieve the image is both bulky and complex and the image, in common with photographic methods, cannot be easily changed or re-converted to electrical signals.

The third optical system to be described is that of the video disk. This is a relatively new technology and deserves its own section since optical techniques are used to record and (mostly) to replay, the resulting output is an analogue or digital waveform and not a directly viewable picture.

A typical specification is shown in Table 1.
Although random access may result in a time of several seconds it is possible to change tracks locally much faster by moving the tracking mirror.

The video disks provide permanent and stable storage of data. They would not be regarded as systems which permit ready alteration of data.
They provide high capacity at a fairly high data rate. As an emerging technology it looks very promising within the limitations discussed.

Its application is likely to be for raw data and processed image archive, possibly as an interchangeable record for dissemination if standards can be agreed.

Storage devices under discussion are magnetic bubble memories and semi-conductor devices.

Table 1

Main parameters of a video disk store

Spiral track pitch	2 μm
No. of turns	54.000
Usable disk diameter	10 to 30 cm
Rotation rate	25 rev/sec
Data rate	10-20 M points/sec
Playing time	>30 minutes
Capacity	>10^4 bits
Average access	5 secs
Local access	60μs
Bit Error rate	1 in 10 (corrected)

Bubble memories are currently undergoing rapid development in both data rate and capacity.

Typical parameters for a device are shown in Table 2
These devices are slow at present but faster shifting rates are already being reported (1MHz). It is expected that early applications will be to replace small magnetic disk storage systems. This will remove the mechanical drive and moving head mechanism with consequent improvement in reliability and reduction in maintenance. The bubble devices match this kind of store in almost every respect, the most notable exception being that of data rate. The applications of these devices are therefore expected to follow those of magnetic disk stores.

Semiconductor Devices

The first demarcation for this technology is that of CCD verus RAM. Much development has occurred in semiconductor memories over the past decade. This work has been further increased by the recent emphasis on micro processors. However in the struggle between digital CCD and RAM, the latter is emerging as the current leader. The apparent simplicity and potential density of the CCD having been set back by difficulties in producing devices.

Table 2

Magnetic Bubble Memory, typical parameters

Capacity	250 k bits
Data rate	100 kHz
Average access time	7 ms
Bit Error rate	1 in 10^9
Non volatile storage	

Table 3

Semiconductor storage, typical parameters

RAM

Capacity	64 k bits
Data rate	3-4 M bits/sec
Access time	300-500 ns

Analogue CCD

Capacity	2000 samples
Data rate	5-10 MHz
Average access time	100-200 μs
Transfer inefficiency	10^{-4} - 10^{-5}
Dynamic range	40-50 dB

The development of analogue CCD storage devices has not progressed as fast, nor as far as that of RAM's, mainly because of the much lager market for the latter. Analogue CCD's are limited by their transfer inefficiency to about 1000 - 2000 element devices. As analogue devices they are difficult to multiplex and thereby to build up larger capacities by parallelling devices. The analogue CCD also requires much greater care on its design and setting up in order te maintain the accuracy of its information. It is not expected that these will become serious contenders for image storage in the near future. Parameters of typical semiconductor stores are shown in Table 6.

In this paragraph, an attempt is made to provide a summary of the main technologies.
Magnetic tape is in a strong position for most applications for image storage. Techniques are well established and the future promises useful extensions to the specifications of instrumentation tape recorders, however access time is long.

Magnetic disks have a secure niche at present, in particular for storage while processing. However, it is likely that this position will be eroded by the advent of bubble memory systems entering first the low capacity systems. This change is not expected to be felt for at least five years.

Optical disks show great promise for relatively fixed data storage, providing a source of data for display, dissemination and for processing as well as for archives. Semiconductor storage devices, while making some progress, will probably develop along slower lines than recently since the component count and the number of applications requiring higher capacities will reduce the market of higher capacity devices. Memory speed will be more likely linked to micro processor speeds where their main application is expected to lie.

2.3. Parallel processing

Array processors are machines oriented towards pipelined processing of arrays of data ("vector-oriented machines"). The integration of such machines in all SEASAT SAR processors has already been pointed out. However among the emerging architecture, once seems promising with regard to image and/or SAR processing. It consists of an one or two-dimensional array of simple processors. All processing elements perform the same task in parallel under the control of a master unit. The discussion has been concentraded on two european machines (Propal II by CIMSA and DAP by ICL) which are networks of one-bit processing elements (bit-wise parallel processing). Both hardware and software aspects have been reviewed.

The PROPAL II processor has a single-instruction/multiple data stream (SIMD) type organization..

The main elements of PROPAL II are:

- a Control Unit, derived from the MITRA 15 mini-computer
- Elementary Processors, varying in number from 8 up to 2084, arranged in a parallel structure.

The Control Unit consists of:

- a Microcomputer and its Control Memory,

It executes, as standard, PROPAL II and MITRA 15 instruction sets in a basic 150 ns cycle, and has 8 interrupt levels;

- a 16-bit word Local Memory containing:

  . Service tasks (supervisory functions)
  . Application tasks (jobs containing PROPAL instructions which will have to be executed with the parallel processors)
  . Data buffers

- an Interface with the elementary processors.

The Parallel Processors uses serial bit type operators; as a result, logical and arithmetic computational operations can be performed on variable length data. These processors concurrently execute the same instruction (under the control of the Control Unit) on the data stored in each of their own memories.
Further, each processor contains :

- logical and arithmetic operators, executing a basic instruction in 150 ns

- a 16-bit register, included in the "Ascenseur"

- a work memory, having a bit addressing capacity now extended up to 16K bits.

The "Ascenseur" serves both as a work register for each Elementary Processor and as interchange box for interprocessor communication.

Data to be processed in parallel can be transferred:

- either from the Local Memory to the Elementary Processors via the Control Unit ;

- or from the Host Memory directly to the Elementary Processors.

In many cases, the first step in application programming normally entails selection of the algorithms and then verification by running them under a simulator. This method is very useful when a processor structure does not readily lend itself to a usual sequential type analysis.
This simulation is performed on the host computer and constitutes a branch of the program production system.

An example of PROPAL-MITRA Configuration, aimed at processing SEASAT-SAR imaged in about 8 hours has been presented.
It sequentially executes the following phases:

- duplicates the raw image on an intermediate high density data tape
- transfers an image onto a magnetic disk
- computes the parameters using auxiliary data
- carries out radiometric corrections and range compression (Fourier transform, Filtering, Frequency shift, Inverse Fourier transform)
- performs azimuth processing and data reduction (processing in frequency or direct convolution)
- executes multi-look processing and geometric corrections in azimuth (earth rotation and correction)
- executes geometric corrections in range, followed by output on computer type magnetic tape

The second machine (DAP by ICL) which is developed as part of a mainframe computer has been taken as an example to discuss the influence of instrumentation on the algorithm itself (ref 13)
An obvious influence is related to the possibility of adapling the word length at each step of the processing. But the speaker put emphasis an a more subtle effect:
bit-wise machines require a rethinking of all basic routines to make maximum benefit from their architecture. Conventional routines written for sequential processing do not fit parallel architectures. Therefore the performance prediction if highly questionnable; The eventual efficiency largely depends on the time devoted to rethink and optimize the implemented code.

From an historical viewpoint, PROPAL II and DAP are understood as concepts originated with STARAN while the next generation already appears (eg. MPP) in particular in terms of integration level (VLSI). Discussion about the capabilities of the DAP-Fortran (Fortran extention for parallel processing) has shown how difficult it is to estimate the ultimate throughput of such a machine, when performing SAR processing.

Conclusions

3. It is obviously not intended to sum up the discussions which followed each presentation. However it is worth mentioning some general trends which result form the general spirit of the discussions:
Spaceborne SAR processors as configured for SEASAT-A have shown that hardware is the limiting factor. Various algorithms exist and can be improved but all SEASAT configurations suffer from severe throughput limitations.
Array processors, in particular the AP-120 B, become a standard but they do not appear promising enough in view of real time SAR Processing.
Airborne real time SAR processors exist and an inprovement of the algorithm efficiency is to be expected to improve the image quality.
Various avenues toward real time SAR processors of spaceborne data have been highlighted.
On ground two ways are pursued either towards quiklook processors or towards full precision processing by using promising parallel architectures.
For on board application the controversy still exist with regard to suitable devices (analog or digital). Various breadboards are under implementation and some concrete results will soon be reported.
Flexible optical processors still prove of interest in view of operational processing.
Future instrumentation for SAR processing has to be considered and identified within the context of multi-sensor and multi-platform missions. This approach offers the advantage of clearly separating the commonalities experienced and the unique features and requirements of SAR processing.
Another advantage offered is to put emphasis on the system aspects (e.g. archivign system) rather than on particular devices (e.g. bubble memories or digital optical disks).
Parallel processing is understood as a suitbale tool for alleviating image processing tasks, provided enough attention is paid to develop suitable (and drastically new) algorithms for this kind of architecture.

It turns out that ISP Group II.4 has been appreciated as an appropriate forum for exchanging experiences in the challenging area of SAR processing. However, it is felt desirable to consider how to implement efficient links with the groups I.5 (data a quisition and image processing in Remote Sensing) and VII.7 (interpretation of radar imagery) as the required instrumentation is heavily depending on both data acquisition and processing algorithm. In turn, the instrumentation used for processing directly affects the resulting image quality parameters and therefore impacts the interpretation capabilities.

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