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OFF-LINE PROCESSING OF ERS-1 SYNTHETIC APERTURE RADAR DATA WITH HIGH PRECISION AND HIGH THROUGHPUT

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I. INTRODUCTION

The first European remote sensing satellite ERS-1 will be launched by the European Space Agency (ESA) in 1989. The expected lifetime is two to three years. The spacecraft sensors will primarily support ocean investigations and to a limited extent also land applications. Prime sensor is the Active Microwave Instrumentation (AMI) operating in C-Band either as Synthetic Aperture Radar (SAR) or as Wave-Scatterometer and simultaneously as Wind-Scatterometer.

In its SAR mode the AMI will cover a 100 km wide swath with a 23° incidence angle at midswath. The satellite orbit will be sun-synchronous, with a nominal altitude of 777 km. The ground repeat pattern will be 3-days during the initial stages, but will be changed up to twice a year to give variable repeat patterns of up to 30 days.
ERS-1 will perform 5256 orbital revolutions per year. Assuming an average of 8 minutes SAR acquisition time per orbit - corresponding to 32 scenes (100 km x 100 km) - a total of 168,000 scenes per year will be acquired. The raw data wil be transmitted in real time with 105 Mbps via an X-Band link to a worldwide network of acquisition stations where all data will be reported on High Density Digital Tapes (HDDT). A significant amount of this data volume will be received with European ground stations.

In Europe there will be two distinct types of processing for ERS-1 SAR data, Fast Delivery Processing and Precision Processing.
Fast Delivery Processing will be carried out at the ground stations and up to three Fast Delivery products per pass will be delivered to end users via satellite within three hours after data acquisition.
Precision Processing will be carried out in delayed time and products will not be generated until several days or weeks after data acquisition. However, a wide range of products will be generated by several Processing and Archiving Facilities (PAF) in a joint effort coordinated by ESA.

The German Remote Sensing Data Center (Deutsches Fernerkundungsdatenzentrum DFD) will develop and operate one of these facilities. DFD has been implemented by DFVLR to promote and support the utilization of remote sensing data in the Federal Republic of Germany (FRG). The related activities include the acquisition, processing and evaluation of such data for scientific, public and commercial users.
Since many years DFD is involved in processing of SAR data including data from the SEASAT L-Band SAR, the Canadian airborne X/C/L-Band SAR and the Shuttle Imaging Radar SIR-B. For SEASAT several hundred scenes acquired over Europe were processed under ESA contract with a processor that was developed by the Canadian firm MDA [Bennett, 1981] under a joint contract from the Canadian Center for Remote Sensing and DFVLR.

Based on this experience the German Remote Sensing Data Center is presently performing a phase-B study regarding the development of a SAR processor for ERS-1. The conceptual design of this processing facility is briefly outlined in the following chapters.

II. SYSTEM DESCRIPTION AND PRODUCT DEFINITION

The SAR Processing and Archiving Facility is functionally divided into several subsystems executing processing tasks and performing monitor and control functions as outlined in Figure 1. The major processing tasks are Preprocessing, Geocoding and Data Management.

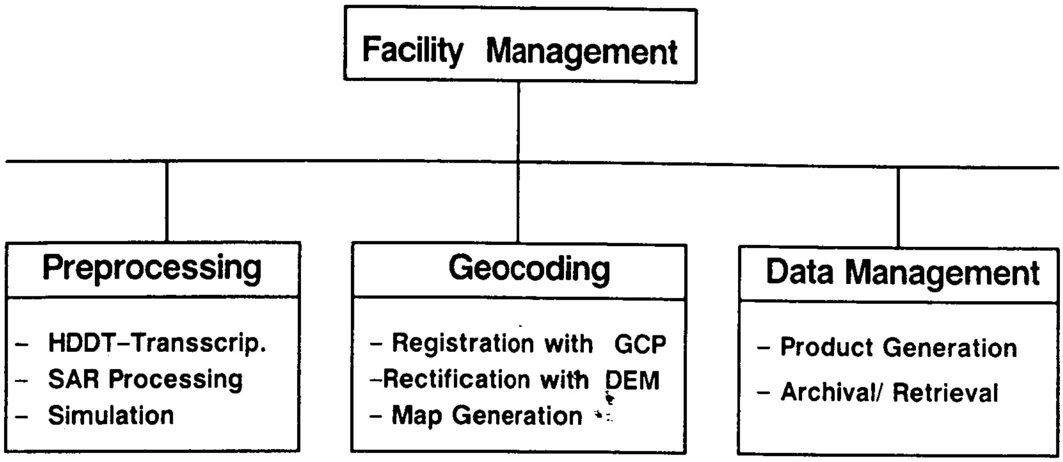

Figure 1. The SAR data processing chain

The <u>Preprocessing</u> task comprises several functions such as the transcription of HDDT's, the SAR processing and the simulation of raw SAR data. The major of these tasks is the SAR processing. Depending on the selected processing parameters, image data sets with different characteristics will be generated and passed to the other subsystems for further processing and handling. The Preprocessing subsystem in itself is complex enough to require operations control support using an expert system. Accordingly the subsystem is called <u>Intelligent SAR Processor ISAR</u>.

The <u>Geocoding</u> task accepts the earth located preprocessed data sets as input and performs geometric manipulations. The major subtasks are the optional rectification of SAR data with Ground Control Points (GCP) and/or Digital Elevation Models (DEM) - and the subsequent resampling to a geocoded grid in different map projections.

The <u>Data Management</u> task finally comprises product generation and all related archival and retrieval functions. The Product Generation step converts the annotated data sets which are generated during Preprocessing and Geocoding into physical products that can either be archived or distributed to the user who has requested it. Products are either digital products such as Computer Compatible Tapes (CCT) or different kinds of optical disks or photographic images on film or paper in various formats.

The above described processing subsystems for Preprocessing, Geocoding and Data Management form the SAR Data Processing Chain. This chain represents a distributed processing system with the subsystems executing their tasks in parallel, often in a pipeline configuration. All subsystems are attached to a high performance Local Area Network (LAN) which enables

- the exchange of large data sets among the different subsystems and
- the operations control of the integrated system.

The data flow through the system and the operations and quality control is performed by software tools for data and facility management which are implemented on workstations that have access to all subsystems via the LAN. These functions might again be supported by an expert system.

A variety of SAR Products will be derived with the SAR Data Processing Chain. Starting with Raw Spacecraft Telemetry Data (level 0), recorded on HDDT, plus orbit and attitude data, the ISAR transcription task generates Annotated Raw Data Sets (level 1), which can be extracted on request. The subsequent SAR processing task generates a variety of Bulk Products while the Geocoding task finally generates Geocoded Products from Bulk Products.
Bulk Products (level 1.5) are digital images which are earth located. The image data sets consist of pixel arrays ordered in range and azimuth, representing a segment of the ground swath. The radiometric information is as accurate as possible. The earth location is derived from a precise orbit and the best attainable attitude information. Geometric manipulations are restricted to an optional slant range to ground range conversion.
Geocoded Products comprise Corrected Products, Precision Products and Map Products. Corrected Products (level 2A) are derived from Bulk Products in ground range. Such products are of use for scenes taken over the open ocean, coastal areas and flat terrain. Depending on the area, none to many GCP's are used for the rectification resulting in quite different absolute and relative geometric accuracies. Several map projections such as UTM, stereographic and others can be selected. Precision Products (level 2B) and Map Products (level 2C) are both derived from Bulk Products in slant range. Such products will be generated for areas with moderate to strong variations of terrain elevation. The rectification makes use of Digital Elevation Models to avoid severe geometric distortions and shall achieve absolute and relative geometric accuracies in the order of the pixel sizes (30 m for ERS-1). However, the accuracy finally achieved depends very much on the accuracy of the DEM used. While a precision product would be derived from a single scene, a map product could originate from several scenes applying mosaicking techniques. The Map Product in a proposed scale of 1:200,000 can directly be compared with existing topographic or thematic maps.

III. THE PREPROCESSING SYSTEM

According to the system description given in chapter 2 Preprocessing is the first step in the production procedure of SAR imagery. The term Preprocessing designates the task that converts raw data sets plus auxiliary information to annotated raw data sets and to digital image data sets. The ERS-1 satellite will carry the first SAR sensor which is designed to work operationally for several years. This is the most significant difference to all spaceborne SAR systems flown up to now. From that it is clear that existing Preprocessing systems like GSAR [Bennett, 1981] with an average throughput figure of one product per day will not be adequate to process a reasonable amount of data. Therefore a high throughput capability represents a hard requirement for the processor. Because the output product of the Preprocessor can be used as an input to the Geocoding system this latter task can best be performed if the Preprocessor products are of best possible quality. Therefore both requirements - high precision and high throughput - are very important to the Preprocessor.

The term high precision will be applied in a many layered way. First of all it shall be a requirement which is closely related to product quality. In this context pixel location accuracy in cross-track and along-track direction shall be a key issue. These parameters are effected essentially by the accuracy of the earth model, the state vector of the satellite and the attitude measurements.
It is required to achieve a location accuracy of 20 m in cross-track and 150 m in along-track for all level 1.5 products (acquired over slow varying terrain slope). In the case of ERS-1 the GEM-6 earth model [Klinkrad, 1985] will be the standard model which is characterized by the earth oblateness coefficient and the semimajor axes. The state vector gives all necessary information about the position of the satellite in all three axes as well as the velocity vector. The Mission Management and Control Center of ESA delivers the predicted orbit with an accuracy of 36 m, 51 m and 1300 m (radial, cross-track, along-track). The restituted orbit values are 25 m, 25 m, and 100 m. However, one product offered by the German PAF will be a refined state vector using primarily laser tracking data which have an accuracy of less than 1 meter in the position and less than 10 cm/s in the velocity and it will be available a few weeks after acquisition. Therefore it is one of the main differences between the Fast Delivery Processor and the Off-line Processing Facility that high precision orbit data are used which are not available shortly after data acquisition.
The refinement of the satellite attitude measurements in its three axis, roll, pitch and yaw as well as the related acceleration figures will be done by a cross-correlation of a replica of the theoretical antenna pattern positioned according to the attitude data with several ensembles of the real azimuth spectral data. This operation can be done randomly and repeatedly across the swath and along the whole 100 km in azimuth supported by the fact that the data are accessible in both image directions without delay and that the host will be a very fast machine with a floating point performance of 2 megaflops.
Another topic of accuracy will be the calibration of the range chirp and the compensation of the antenna gain. High precision will also be applied to the calculation of all parameters relevant to the latter items. Moreover each complex sample will be represented with 32 bits throughout the processing.
In order to give the user a full flexibility for his choice of product, a whole family of intermediate products (level 1.5) will be available which comprise the Fast Delivery Product, Bulk Products in slant- or ground-range and even products with complex pixel representation preserving phase information.
The system is designed to achieve a throughput in the order of 6000 products per year. This requirement has several consequences in terms of hardware and software design which will be described in the next chapters. The software related aspects will be given comprehensively in a separate paper [Noack, 1986].

The requirements high precision and high throughput have been the main driving factors for the hardware selection. It has already been mentioned that the processor shall be capable of processing 6000 products per year. Assuming standard operation times this results in a processing time of 1/2 hour per level-1.5-product. Moreover the system shall be flexible to be adapted to other spaceborne sensors like the German XSAR.

There has been chosen a distributed, parallel architecture arranged as a lattice whose nodes are single purpose CPUs and the branches represent computer-computer links. Figure 2 gives an overview of the ISAR hardware configuration.

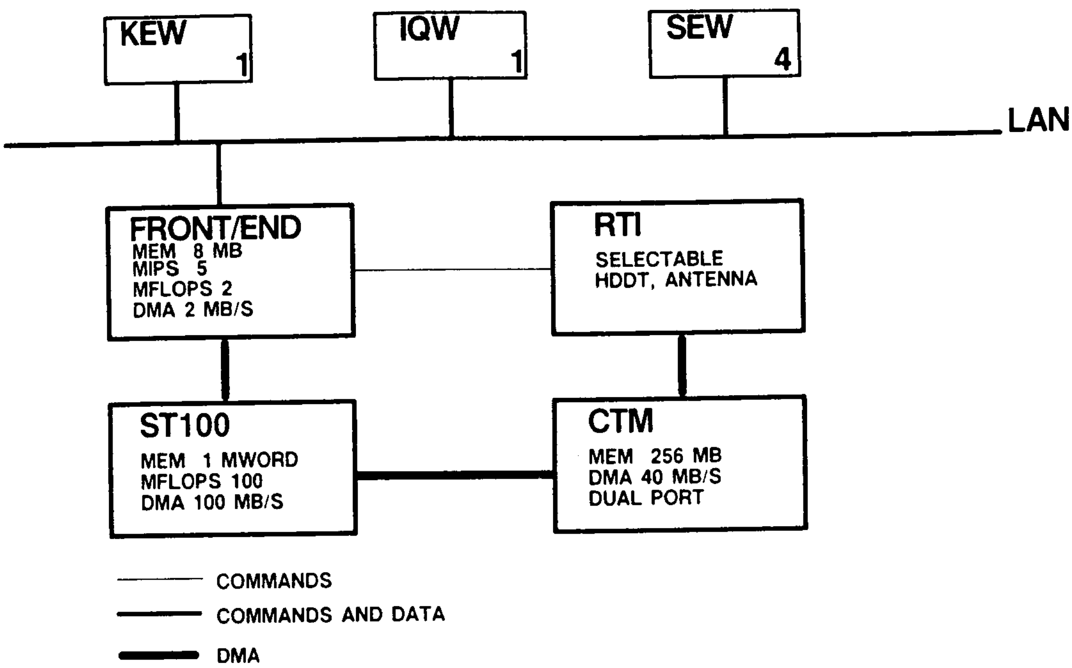

Figure 2. ISAR hardware configuration

The particular subsystems are the Knowledge Engineering Workstation (KEW), the Image Quality Analysis Workstation (IQW), the Software Engineering Workstation (SEW), the Front/End Hostcomputer (FEH), the ST-100 Arrayprocessor (ST-100), the Corner Turn Memory (CTM) and the Real Time Input Facility (RTI).

The Local Area Network connects all systems with interactive tasks like software development, process configuration, image quality analysis etc. with the high throughput computers FEM, ST-100 or RTI. As a special device the CTM will be used as a data buffer between HDDT, the regular input medium to the processing system, and the ST-100 Arrayprocessor. It will be loaded directly from HDDT with a full reproduce speed of 105 Mbit/sec. From this point the SAR data are accessible randomly in range and azimuth with a DMA speed of 40 Mbyte/sec.

The data flow (see Figure 3) is organized as follows: First of all the Data Management System sends a processing request to the KEW. There the order will be worked out to a full scene configuration. After the HDDT has been mounted and automatically positioned the data transfer will take place for a full ERS-1 scene in about 15 seconds. Now the ST-100 can start the required correlation task up to the final processing level. At the end the data are stored on a disk of the Front/End Computer ready for being transferred to the Image Quality Workstation or to the Data Management Computer.

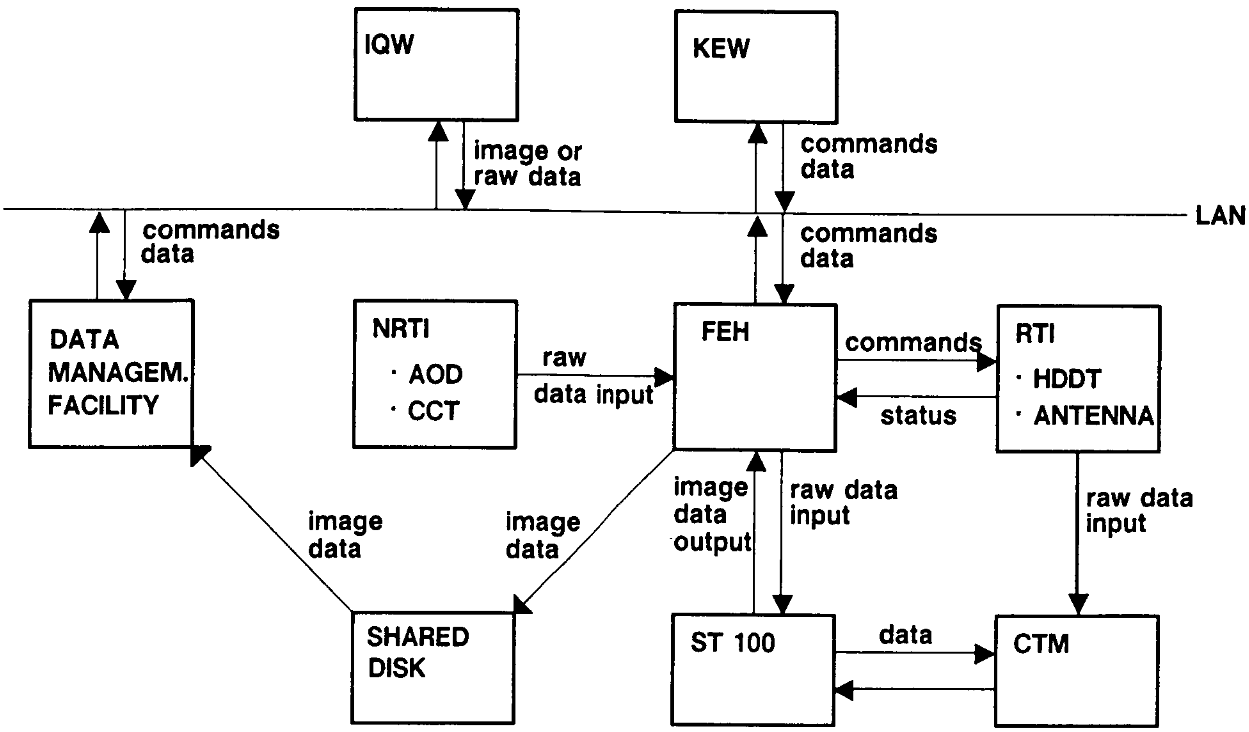

Figure 3. ISAR data flow

Basically SAR imaging and processing is a two-dimensional operation whose coordinate axes are designated across track and along track respectively. The Range-Doppler-Algorithm uses a separate matched filter operation implemented in the Fourier frequency domain and turns out very advantageously in terms of quality and speed. It is a very well known and documented procedure and has therefore been chosen as the standard processing algorithm for ISAR.

The term Range-Doppler designates the timely ordered subsequence of processing steps of which the most important are

- Range Compression,
- Azimuth Compression and
- Interpolation

The penalty for breaking up the two-dimensional nature of the imaging process into two one-dimensional procedures comprises in two additional processing steps which take care for earth rotation and for effects due to varying across track distance to a target during integration time.

There is a requirement that the software shall be implemented in a high-level language. Additionally there shall be an integrated software development system covering all phases of the software lifecycle. An analysis of all development systems on the market showed a large variety of products all of which had some deficiencies. From that point of view ADA has been chosen as implementation language, because it includes its own development environment.

All central parts of the software system will be managed by the expert system running on the KEW which controls the whole production process by

- receiving production orders from the PAF,
- configuring the production process,
- supervising the correlation sequence and
- supporting the operator in all decision processes.

Up to that point all processing is related to products of level 1.5. The generation of all higher level SAR products of the German PAF will be described in the subsequent chapter.

IV. THE GEOCODING WORKSTATIONS

The term Geocoding describes the task, which accepts digital SAR image data sets from the Preprocessing System and generates geometrically corrected and precisely located Geocoded Products in different map projections. The high accuracy shall be achieved using precise orbit/attitude data, Ground Control Points and Digital Elevation Models. The achieved accuracy shall be within the range of the pixel size. The throughput design goal for the Geocoding System is to produce an average of 8 Geocoded Products per day or 2000 products per year.
The precision Geocoding of SAR images is a task which requires both an image display system for the interactive subtasks such as registration and quality control and a high performance processor for the rectification tasks which are required for the rotation and resampling of large data matrices with high throughput. The hardware to be selected shall be compatible with other systems presently used at the German Remote Sensing Data Center.

The DFD has started to implement a network of UNIX-workstations, all interfaced to a Local Area Network, with some of these workstations performing image processing tasks. The UNIX-workstation concept was chosen deliberately to become as far as possible independent of the selected hardware configuration for future software developments. In addition to that, such workstations are cheap compared to minicomputers and the use of several identical workstations increases the throughput capability and the operational reliability.
Present plans are to implement three workstations for the SAR Geocoding task. Though the final decision for the manufacturer has not been made, a state of the art workstation SUN-3/160 from SUN Microsystems, Inc. is being used as model configuration (see Figure 4).

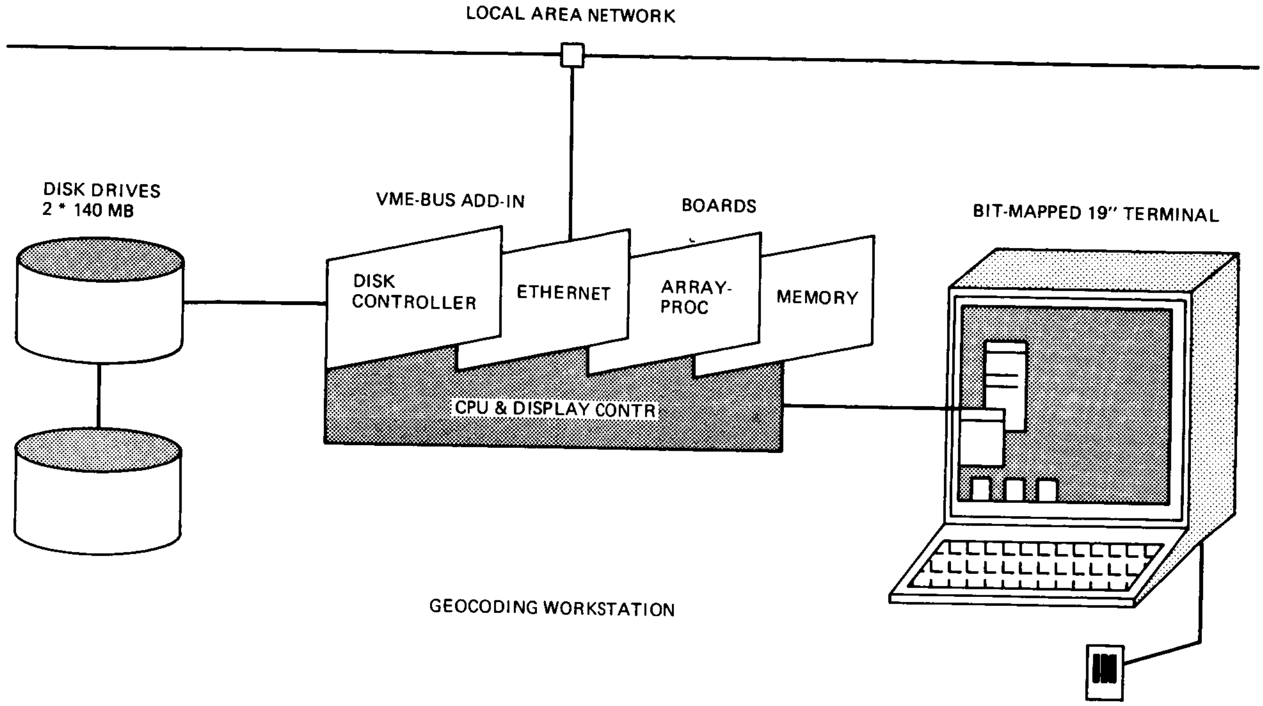

Figure 4. Workstation for Geocoding of ERS-1 SAR data

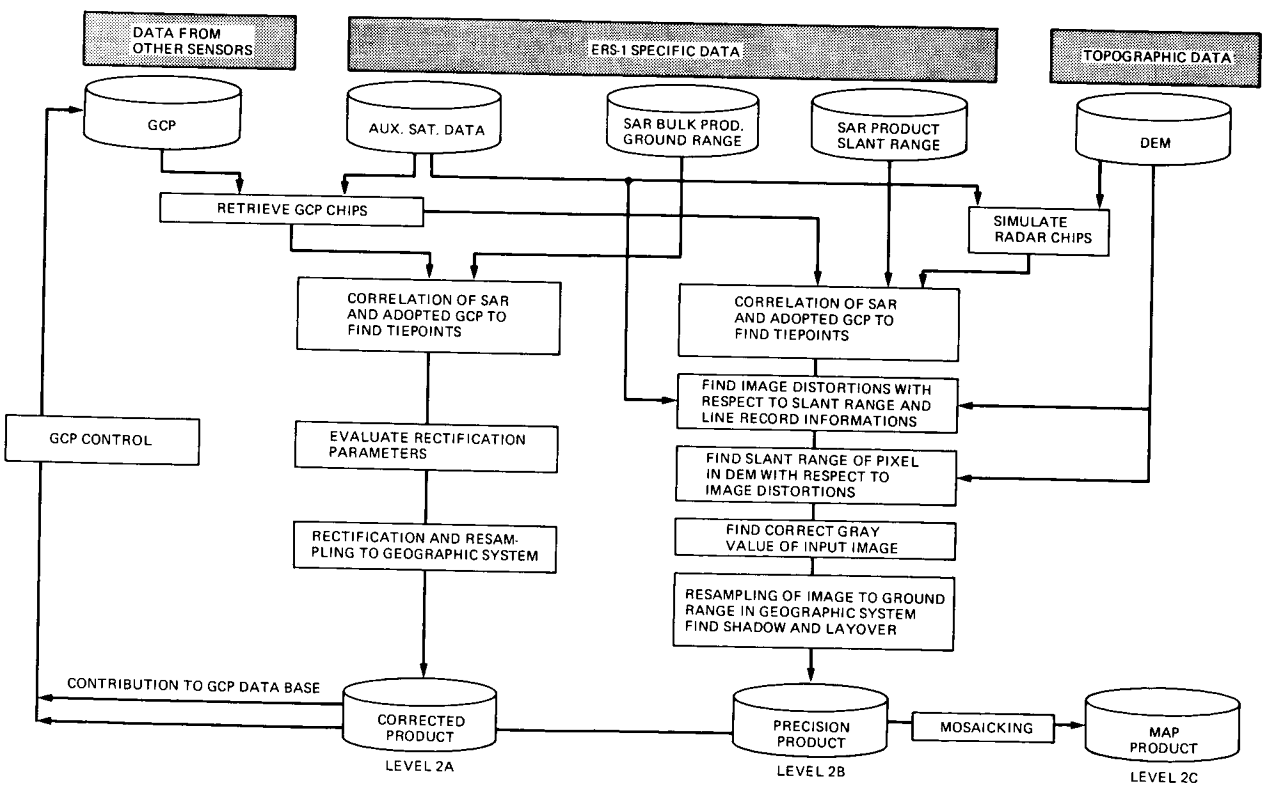

Figure 5. Data flow and processing steps for the generation of Geocoded products

The Geocoding algorithms will be part of the UPSTAIRS image processing software. UPSTAIRS - installed in 1985 at the German Remote Sensing Data Center - is designed to fulfill the requirements of remote sensing users and is open to incorporate future developments due to its modular structure and programming interface. Figure 5 depicts a flowchart for the generation of Geocoded products.

Coming from five data bases, two main data streams can be distinguished. The first describes the generation of a Corrected Product, using only geographic coordinate information from the satellite auxiliary data and, if required and available, Ground Control Points. When the GCPs are detected in the radar image by automatic algorithms, standard rectification and resampling procedures will generate the Corrected Product.

The second data stream uses GCPs to compute the internal distortions of the SAR image especially in azimuth with respect to slant range distance. Coming from exact located DEM points, the slant range is computed involving the distortions found above and thus giving a reference to a point in the slant range input image. Therefore pixel coordinates will be found even in regions of typical radar distortions. Notice that the process of generating Corrected and Precision products will enhance the GCP library, thus contributing "boot-strapping" information for following radar images. Map Products will be generated by mosaicking methods from the Precision Product.

To meet the requirements of the Geocoding System, approaches and algorithms are modified for restituting the radar geometric distortions and producing level precision and map products. (More detailed information can be found in Domik, 1984; Ehlers, 1983; and Maier, 1985.)

To cope with the huge amount of GCP and DEM data, a GCP library and a DEM data base will be installed, both able to accept data from different sources and in different formats. The design of these data bases fulfills the requirements of SAR data Geocoding, but will also serve as a data pool for mapping applications using data of other satellites.

The GCP data base will consist of small image chips containing features such as water boundaries, road crossings and other outstanding points on the earth surface, which can be found in satellite images. The effort to fill the data base with suitable Ground Control Point chips will be supported by automatic pattern recognition algorithms, which could be used to extract features from Landsat MSS/TM and SPOT images. In addition to that, the GCP data base can also be filled with chips from SAR images processed earlier and topographic map information. A special problem will arise from the fundamental difference between optical satellite data and radar images. Therefore algorithms are now under investigation, to increase the correlation between image chips of different sources.
The implementation of a GCP data base will be a dynamic process, which will start before ERS-1 is in orbit. The data needs maintenance and update and efforts will be done to cover all regions of interest with Ground Control Point chips.

The second necessary information, to rectify radar images and to restitute radar specific distortions like layover, foreshortening and shadow, is the digital elevation data of the terrain, which will be stored in a DEM

data base. The storage of DEM data needs no sophisticated data format design, if a regular grid of values is used and the location is referenced with geographical coordinates. For example, the area of the Federal Republic of Germany is covered by approx. 500 megabytes of 16-bit elevation data using a grid of 30 m x 30 m. Transformation and resampling to other geographic coordinate systems can be performed with standard map and image transformation algorithms.
The severe problem is the availability of DEM data in the required accuracy. Even for countries covered with small scale maps, digital elevation information is available only for selected regions. Huge data sets of terrain information of the Federal Republic of Germany will be compiled for governmental planning purposes until 1987. Besides, few data are existent for Middle Europe. All of them come with different format and accuracy and need thorough compilation before they can contribute to a DEM data base.

However, the use of DEM data to be derived from the new generation of satellites such as SPOT is being investigated as a serious alternative.

V. THE DATA MANAGEMENT FACILITIES

The results of Preprocessing and Geocoding are annotated SAR data sets in digital form, primarily image data at different processing levels. At this stage the Precision Processing task is completed. However, further processing steps are required to finally provide products to users in a coordinated way. The major tasks are Digital Product Generation, Image Recording and Archival and Retrieval. These tasks will be performed by a central facility which will operate all necessary peripheral devices.

Digital Product Generation comprises two processing steps that transfer the annotated and processed SAR data sets to an archival medium for subsequent storage in the digital archive for at least 10 years and that copies such data sets on media suited for distribution to users.
For both tasks it is planned to make use of the evolving Optical Disk Storage Technology. Since the requirements for the archival product and for the user product are quite different it makes sense to distinguish

- Archival Optical Disk (AOD) and
- User Optical Disk (UOD).

The Archival Optical Disk shall hold many complete data sets storing in the order of 1 to 10 Gbytes of data with preferences for higher storage capacities. The AOD may be a WORM device, which shall have nearly error free access guaranteed for at least 10 years.
The User Optical Disk shall hold a minimum of one complete data set, since this concept shall also be used for the distribution of other remote sensing data sets, such as LANDSAT Thematic Mapper data. The required storage capacity per UOD is in the order of 300 Mbytes of data.

Image Recording is the task that produces master transparencies for the image archive. This is generally performed in two consecutive steps by generating latent images using special film recorders interfaced to data processing systems and subsequent development processing in a photo laboratory.
It is assumed that an existing image recorder will be used to record the

various SAR image products on 240 mm black and white roll film. The recorder is presently used on a routine basis in a batch operating mode requiring manual operator interaction for each single image being generated. The standard interface is via CCT in a specific data format. To cope with the image recording requirements of the ERS-1 era, it is necessary to enhance the recording capabilities to enable automatic operation.

Archival and Retrieval covers the remaining data handling tasks including implementation and maintenance of data archives, implementation and maintenance of catalogues, order handling for ESA and national users, distribution and dissemination of products and user service.
Cataloguing and order handling shall be performed with computer assistance using a relational data base management software system.

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