# Design Aspects of a System for Geocoding Satellite SAR Images

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## 1. Abstract

The concepts in algorithmic design and operational use of the German Processing and Archiving Facility Geocoding System for ERS-1 are presented. The System will produce non-terrain corrected and terrain corrected products. The latter require complex algorithms in terrain height consideration and ground control pointing.

The Geocoding System will be implemented on UNIX workstations and programmed within an image processing system. To guarantee operational throughput and flexibility, new software tools will be implemented.

## 2. Introduction

In 1990, the first European Remote Sensing Satellite (ERS-1) will be the first step towards a scenario of satellites carrying a Synthetic Aperture Radar (SAR) as a prime sensor (SIR-C, RADARSAT, J-ERS-1). For the 90's and beyond, SAR-sensors - then upgraded in terms of wavelength and polarization - will be the basic source of image information besides optical sampling techniques.

To cope with the large amount of data and to benefit from its intrinsic information, the data processing and data evalutation techniques must keep pace with the development of space-segment hardware.

Especially for SAR-data processing, powerful hardware and sophisticated software concepts will be realised, to generate digital raster image data out of the holographic information gathered by the sensor (Noack, 1987).

The microwave image information is now basically interpretable by digital or visual means, but suffers from the lack of geographic context. Therefore, scientists, engaged in remote sensing, first try to rectify or geocode the satellite images (for optical images as well) to ease the interpretaton and to utilize further existant geocoded information for data synergism, covering several aspects (spectral wavelength, time, polarization, look-angle) of the investigation area.

Rectification and geocoding algorithms are more or less a standard feature of many remote sensing image processing systems, but are time-consumming (by manual tiepoint search and raster data resampling) and produce often unsatisfactory and uncomparable (with other systems) results.

This is one reason, why many potential commercial and governmental users hesitate from using satellite borne images due to the complex procedures, which must be performed, before getting useful information.

For optical scanner images, a few national remote sensing organisations and commercial distributors are already offering geocoded satellite images. For the future microwave satellite scenarios mentioned above, such geocoded products should become a standard user service and is therefore planned by several facilities (JPL, CCRS, ESA).

The German Aerospace Research Establishment (DFVLR) is currently building up - in contract with ESA - a Processing and Archiving Facility (PAF) for ERS-1 SAR images.

One major sub-system besides the processing of the radar raw data by the new Intelligent SAR processor ISAR is the SAR Geocoding System GEOS. The major design aspects of the Geocoding sub-systems will be described in the following chapters.

## 3. Algorithmic Needs for Future Satellite SAR Image Data Geocoding Systems

The future remote sensing satellite scenario can be characterized by the amount and variety of data. The SAR processing systems must cope with this data by increasing the processing speed up to near real time. The variety of the data for different satellites and sensors must be properly obeyed in the SAR cases, where orbit, wavelength and satellite technical parameters determine the SAR image generation process and its quality. Thus, the input data needs a flexible structure in hardware and software of the SAR processing system.

The target, where all SAR and also optical sensors can be referred to, is the imaged body itself - the earth. All sensor views of the same physical ground element and all sensor data can be geometrically re-ordered to a pre-defined cartographic presentation. The latter task is subject of Geocoding Systems.

Satellite image Geocoding Systems can be characterized by the following attributes:

- kind of sensor and its imaging physics
- parametric or tiepoint rectification (or intermediate)
- consideration of terrain height displacements
- support of different cartographic projections
- data throughput capabilities

The imaging physics (which intentionally substitutes "geometry" in this case) of Synthetic Aperture Radar sensors determines the geocoding algorithm to compute the proper geo-location of each output pixel. The orientation of one image pixel in a SAR image and its correspondence to an earth location can be established by solving three equations (Curlander, 1982):

- The range timing (the absolute travel time between sensor to target)
- The azimuth Doppler reference (depending on the SAR Processing algorithm applied)
- The actual terrain shape (ellipsoid or Digital Elevation Model if terrain height is considered).

In remarkable contrast to optical sensors, the pointing accuracy of SAR systems do not depend on angle measurements, but on time and frequency analysis of the radar echo. These parameters can be extracted with better accuracy than satellite angle control.

Having the necessary parameters at hand, a geocoding approach with parametric rectification using the sensor/processor entities is obvious for SAR systems and gives sufficient results for many application areas.

Unfortunately, SAR images and its geometry are affected by the local earth surface elevation more heavily, than it is the case for optical sensors. For ERS-1 (look angle 23 degrees at mid swath) 1000 m elevation come along with mis-registration of about 425 m. For areas with moderate to hilly terrain, these mis-registrations can cause pixel geocoding errors which are considerably higher than the possible system pointing accuracy mentioned above. The most common way to tackle with this problem is to introduce the terrain height of each earth point target by using a Digital Elevation Model (DEM).

In principle, an absolute mapping accuracy could then be achieved within the bonds of the system parameter accuracy. However, the introducing of a "foreign" data set like DEM, which has no direct relationship to the SAR mission data or even to remote sensing geometry, can cause "scaling" problems. These problems will come from:

- the remaining uncertainity of the SAR pixel location.
- shifts and scalings in reference to the common ellipsoid.
- errors and uncertainty in DEM generation.

Having this in mind, it is obvious, that some ground control must be incorporated in the geocoding process, when precision mapping is aspired. In any case, the quality control of geocoded SAR products must use ground control to verify the achieved accuracy.

Following the principles of geocoding stated so far, SAR geocoded products can roughly be divided into two categories:

- Geocoded without terrain correction, using an ellipsoid as reference earth surface and referenced to the system initial geometric accuracy. These products are abbreviated here GEC (Geocoded with Ellipsoid Correction).
- Geocoded with terrain correction, using a DEM as reference earth surface with more precise accuracy introduced by ground control points. These products are abbreviated GTC (Geocoded with Terrain Correction).

The algorithms for generating these two basic products at the German-PAF are described in the following chapters.

## 4. Geocoding without Terrain Correction

Due to the spare availability of DEM data, the GEC-data are considered to represent the major throughput of the Geocoding System. As already mentioned above, the SAR systems inherent pointing accuracy can be used to rectify SAR images without any foreign control or tiepoint information. Using this scheme, the geodetic location of each SAR image pixel could be estimated and resampled to the desired map projection. Of course, this approach would be rather time consuming and ineffective. Instead, the correct SAR image pixel to ground correspondence of four corner pixels of an appropriate rectangular frame is calculated precisely. The area and pixels in between the rectangle are transferred using a lower degree polynominal, estimated from the four corner pixels mapping function.

The deviation of the geocoded pixel location using polynominal interpolations instead of the correct transformation formula depends on the mesh-size and the used interpolation formula. For SEASAT images this approach, with a 500 pixel mesh size gives only deviations of one pixel with respect to correct mapping. Due to the increased data throughput without considerable loss of accuracy, this rectification scheme is used in many geocoding algorithms.

Considering that geocoding of satellite borne imagery consists mainly of a rotation towards grid north and some rectification of internal distortions of the image, the rotation of points within the mesh frames can be written:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

In re-arranging the transformation matrix and splitting in two steps, the formula reads (Curlander, 1987a).

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -\tan\theta & \sec\theta \end{pmatrix} \begin{pmatrix} \cos\theta & \sin\theta \\ 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

A further initial step can be involved to avoid aliasing when rotating and resampling the image. This step oversamples the image in y-direction. The oversampling factor nf is derived from the rotation angle (Friedmann, 1981).

$$nf = 1 + \tan\theta$$

Although the initial 1-step formula seems to be more convenient than the derived 3-step formulas, the re-aranged resampling scheme has important advantages. The step-by-step rectification touches only one coordinate direction per step and needs only 1-dimensional resampling kernels. Considering a 4 x 4 cubic convolution 2-dimensional kernel, 16 points must be touched, whereas only 8 in the modified 1-dimensional scheme (plus 4 additional in the initial oversampling step). This remarkably increases data throughput. The line/column access scheme fits to the data needs of array-processors and simplifies address calculation. Figure 1 shows a schematic sketch of the geocoding process.

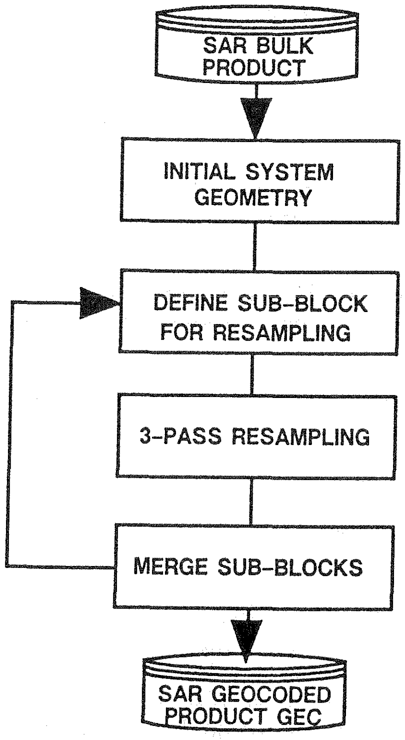


**Figure 1. Geocoding Process without DEM Correction**

Because no ground control information or control and merging of DEM data is required for this geocoding process, it can run without operators interaction.

Therefore, the flexible architecture of the D-PAF Intelligent SAR Processor (ISAR), consisting of a huge hardware memory, a powerful 100 MFlop array processor and a UNIX workstation host, is used as an implementation target for generating the SAR geocoded GEC product in one standard map projection (e.g.: UTM).

The direct coupling of SAR image generation and SAR geocoding within one process will make it possible to use the complex intermediate data for geocoding input rather than the look summed and detected slant range image.

## 5. Geocoding with Terrain Correction

When terrain correction is involved in the geocoding process, the computing algorithm becomes more complicated, due to additional raster data sets needed (DEM), which requires data handling and geometric model adjustment.

Together with contracted institutes, DFVLR has performed a phase-B study to identify the required algorithms and to introduce and test new approaches. According to the gained results, the operational processing scheme for GTS-products will be as follows:

The terrain elevation data, which is necessary for GTS-product generation will be stored on-line in raster format in a large disk database. Before adding DEM data to this database, quality tests will be performed to ensure a minimum accuracy of the DEM data used. Although, it must be aspired that DEM generating organizations might perform a quality test, the results we have gained with different height data form different sources, unveiled a variety of errors - some severe and some neglectable for geocoding - which are partly derived from the generation process of the DEM data.

From the DEM database, the required part of the DEM is resampled to the cartographic projection demanded by the geocoding process. This resampling of DEM data will use a comparable fast algorithm as outlined for the SAR GEC-Geocoding mentioned in the previous chapter.

As stated earlier, the utilisation of the resampled DEM for terrain correction might give erronous results, because the estimated SAR point location accuracy (ERS-1 about 100 m) and the DEM accuracy

(FRG: approx. 25 m raster size) might not fit on a pixel by pixel basis. Hence, both geometry models need to be adjusted and refined. Due to the origin of most DEMs from maps, the height model itself will be used as a geometry adjusting reference.

This can be achieved by considering the strong influence of hilly topography to the backscatter of SAR images. Using the imaging geometry and simple backscatter assumptions, a simulated image can be generated out of hilly parts of the DEM, showing the backscatter behaviour of the SAR with an exact cartographic reference. After some pre-processing, the original SAR image can be correlated with the template, giving an "artificial" tiepoint. The phase-B study results (Wiggenhagen, 1988) showed that the process can work automatically and gives better results for considerably good DEMs than matching SAR with Landsat TM images.

The "artificial" tiepoint with DEM-derived information has several advantages:

- No other external data set (like Landsat or Spot) is needed, which might introduce inconsistant geometric adjustment. Instead, the DEM data itself, which is used for terrain correction is the geometric reference.
- The search for "candidate" hilly regions for simulation and matching can be done in advance. Using the pre-known geometry of ascending and descending ERS-1 orbit, candidate regions can be found and flagged in the DEM database. Operationally, it will only be necessary to simulate small regions, around the hilly areas, rather than simulating the whole image.
- Test show (Curlander, 1987b) that the DEM to SAR image geometry derivation is mainly driven by linear effects. Thus, only few tie-points (2-3) will be needed for the adjustment, which can be found even in moderate hilly terrain.

By introducing these few tie-points, an adjustment calculation will fit the geometry estimation of the processor to the needs of the DEM data and cartographic accuracy (Raggam, 1987). The number of necessary tie-points and the degree of adjustment will depend on the sensor behaviour. For ERS-1 the orbit will be known very accurately and the SAR processor will produce considerable loction estimates. Thus, only a few tiepoints might be necessary.

Having the adjusted imaging model and the resampled DEM data, a backward resampling to generate the GTS-product can start. There, each DEM point, corresponding to the pixel size in the final output image, is transferred to a common cartesic system, as well as the satellite orbit. A slant-range vector from DEM point to an estimated orbit position is defined, giving a relationship between slant-range length and Doppler-azimuth reference. The orbit point is now iterated to fulfill the range-Doppler relation given by the system geometry. The calculated range and orbit position gives the line and column location in the SAR slant range image which is used to resample the appropriate gray value of the output pixel of the GTS-product, located at the initial DEM point (Meier, 1985). Figure 2 shows a schematic flow chart of this process.

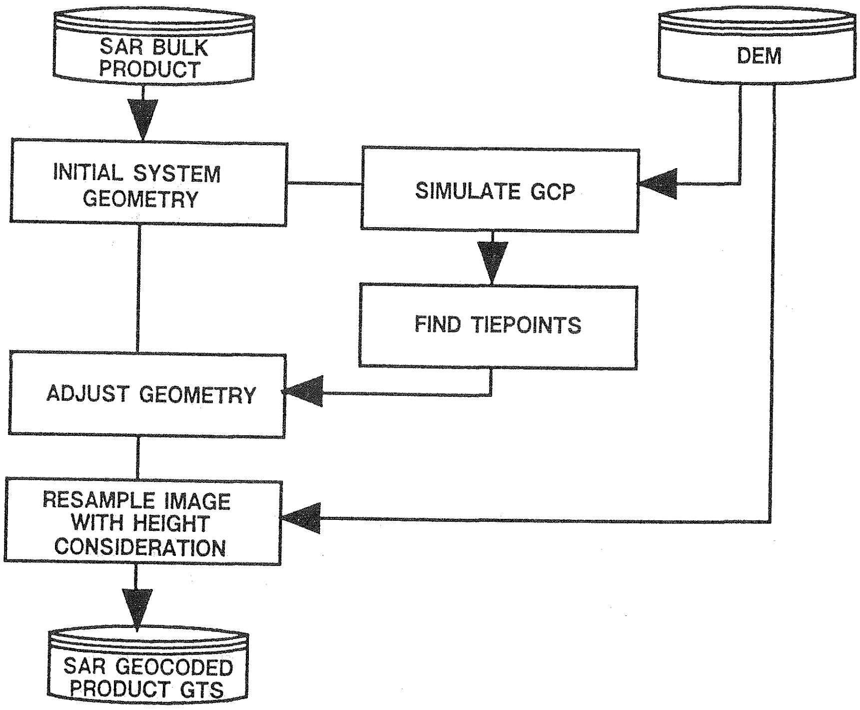


**Figure 2. Geocoding Process with DEM Correction**

In contrast to the GEC-product generation, the GTS-product generation must touch each DEM point for the exact location computation of the geocoded SAR pixel. Hence, the utilisation of fast geocoding algorithms, mentioned earlier, is more complicated to realise. A poly-nominal interpolation of the correct imaging geometry for small sub-frames must also treat the DEM geometry transfer and terrain height dependant adjustment. This resampling scheme will increase data throughput and is modified to meet the requirement of pixel location accuracy within the magnitude of the DEM raster size used.

## 6. The Software Environment of the Geocoding System

The sketch of the geocoding algorithms explained in the previous chapters reveals the diversification of the necessary data and input/output interfaces for this task.

Obviously, geocoding is tightly coupled to the output of the SAR processor and its computed parameters. As far as more accuracy in location is aspired, geocoding has also to tackle with digital elevation data, ground control points and precise map projections. Finally, all these data sets must be visualised, at least for quality control. For the D-PAF, geocoding is a set of modules to be integrated in a remote sensing image processing system, which is modified to the special needs of an operational production environment. Since several years, DFVLR, together with a software company, develops and uses the UPSTAIRS image processing software running on the VAX-VMS operating system. The UPSTAIRS software is dedicated to process remote sensing images and supports program development with predefined user/machine interface calls and simple access to a sophisticated image database. A magnitude of application programmes covers the area of radiometric and geometric processing of satellite borne raster images.

For the geocoding system, the UPSTAIRS kernel was ported to UNIX and partly rewritten in C (see Figure 3). Along with the software transfer, some important modifications, which enhances operationality of the Geocoding System have been integrated. These upgrades support operational data throughput, new data like DEM and GCP and a new user interface based on the bit-mapped screen of UNIX workstations. They are described in more detail as follows.

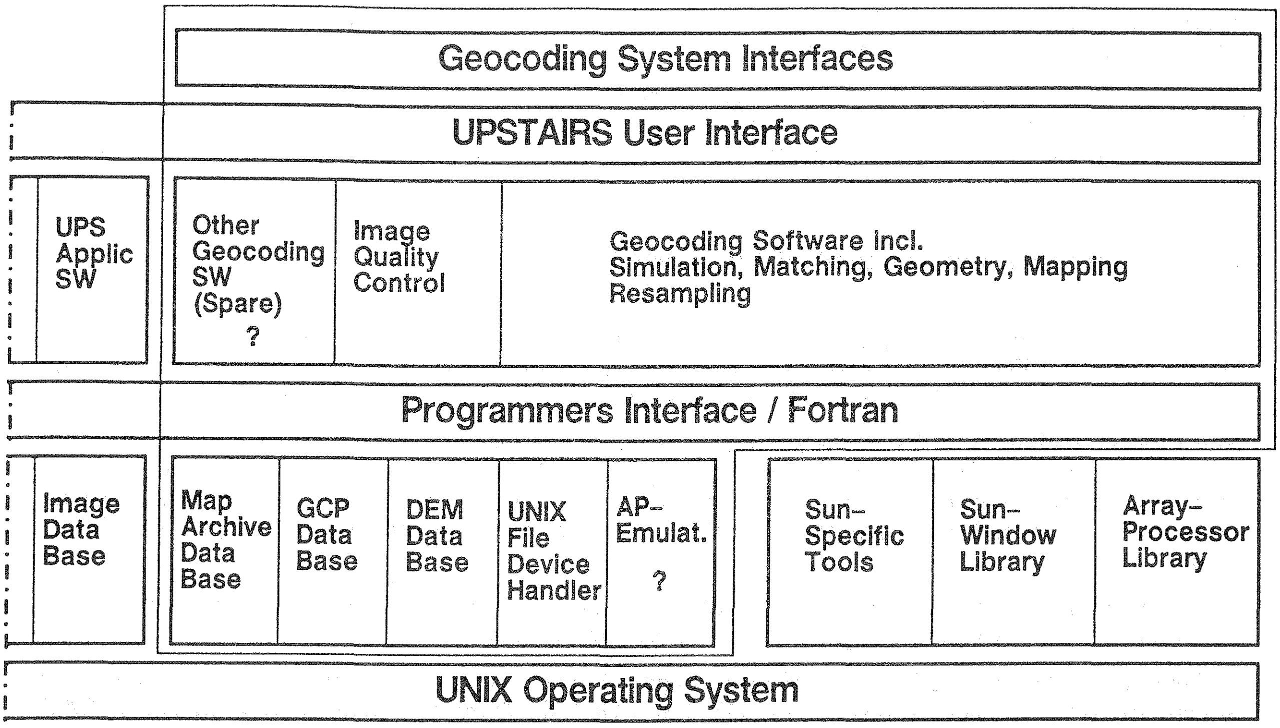


Figure 3. Geocoding Image Processing System Software Layers

### Data Throughput Upgrades and Upgrades for Operational Use

In contrast to an image processing systems as a "scientific tool", the operational Geocoding System has to store only the SAR input and the geocoded output image as a minimum. This data must be accessed and transferred as fast as possible. Therefore, software tools are integrated, which manage large pixel sets for fast data I/O by considering disk resources and HW/SW capabilities, especially the data transfer to the attached array processor.

To exchange data and parameters between different modules of the geocoding system, a "parameter pool" is integrated, which resides in the computer memory and delivers access via write and read functions. This feature will support the programming and the flexibility of the modules, rather than exchanging parameters by files.

### The Databases for DEM

Although the Digital Elevation Model raster data could be stored like image data, its handling within the Geocoding System is organised in a DEM database. The database is structured according to a geographic binary reference tree. Each branch in the tree defines a reference area. The final data-tile on the earth surface is able to store DEM raster sizes of about 10 m x 10 m resolution plus additional annotation data. These include flags for candidate simulation areas for artificial tie-points stated earlier. All DEM data will be stored on-line on magnetic disks. The capacity of the DEM database is only limited by disk capacity and - in principle - allows to store DEMs covering the whole globe. With subroutine calls, the DEM data can be accessed and resampled to the format required by the geocoding process.

### The Operators Interface for the Geocoding System

The geocoding system will run on a UNIX workstation with "bit-mapped" screen. This screen allows to display concurrently graphics, images (up to 256 different colours out of 16 million) and alphanumerics in different "windows" and utilizes a "mouse" as a fast and versatile user input device. Whereas the normal menu screen is managed in alphanumerics and gets its input via keyboard, the system will have some tasks, which directly benefit from the advanced user interface. Among these tools in the final image quality control, which will be performed using the normal colour screens, capable of displaying 900 x 1152 pixels in 256 shades of grey.

There, features in the goeocoded SAR image - displayed on the screen - will be compared with homologue points on map paper sheets on a digitizer table. Knowing the geocoded coordinates of the product the cursor on the screen will move, controlled by the movement of the digitizer pen.

## 7. The Hardware Environment of the Geocoding System

The revolutionary development in computer techniques gave smaller systems the capabilities of former mainframe hosts. Due to their reasonable costs, small workstations can be dedicated to one task and equipped with special hardware like bit-mapped screens, fast and large disks and array processors.

Nevertheless, such dedicated systems are not isolated as far as they are coupled via communication links to other workstations, building up a computing system with one (or even more) computing units for each task, but with the transparency of a large mainframe. Together with the UNIX operating system, supported by more and more manufactures, these computer networks can easily be adopted to different needs.

The Geocoding System is part of a larger workstation network with dedicated software and hardware for each function like SAR processing, data management and facility control.

A sketch of the Geocoding System is given in Figure 4. The server workstation controls the Geocoding System and is the physical storage for the DEM and GCP database, as well as the I/O interface to SAR data stored on optical disks.

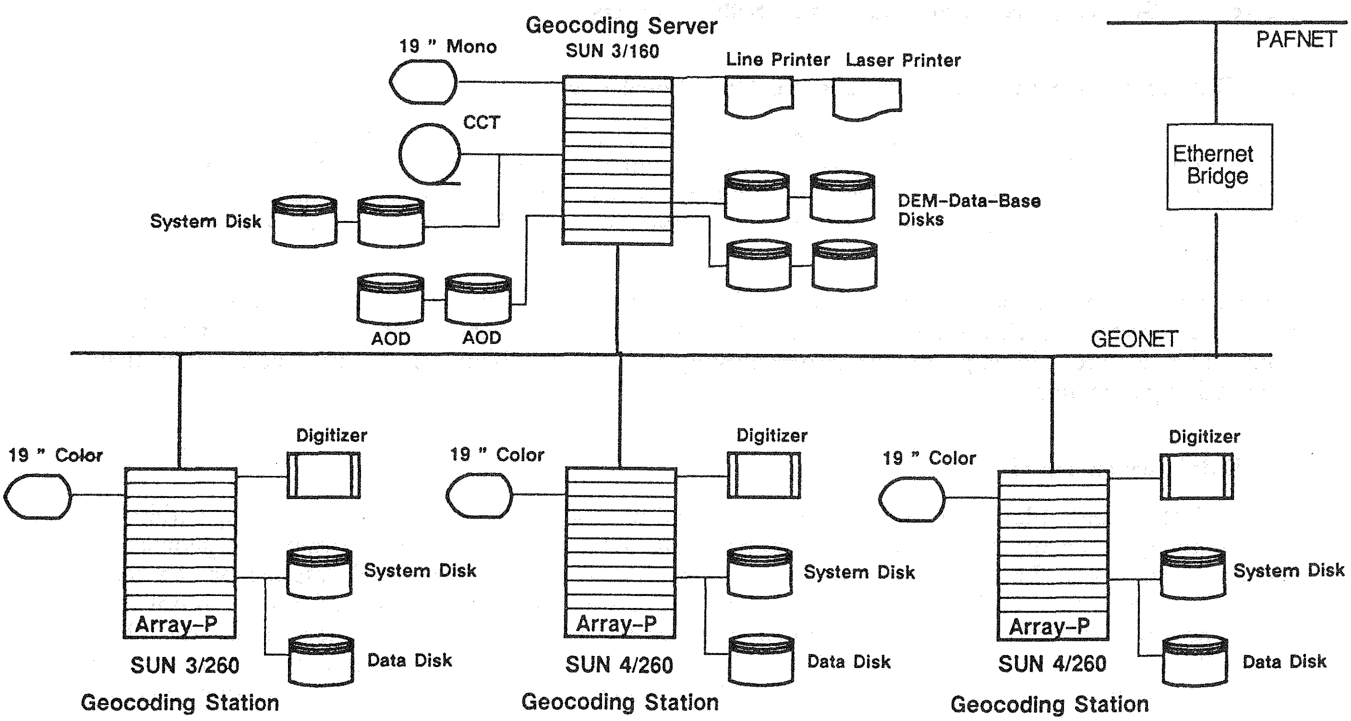


Figure 4. Hardware Configuration of the Geocoding System

To cope with the variety of products, the expected data throughput and to perform manual quality control and experimental processing without interferring the operational throughput, three indentically equipped workstations are foreseen for the system. As stated earlier, the geocoded product without terrain correction will mainly be produced by the SAR processor. This processor is also based on the workstation concept but equipped with special hardware like huge corner turn memory and a fast array processor (Noack, 1987). The Geocoding System mentioned above, will produce geocoded products without terrain correction for required special map projections and all geocoded products which need Digital Elevation Models for precise mapping.

## 8. Conclusions

Aspects for an operational system for geocoding SAR images with and without terrain rectification have been discussed and the design for the German Processing and Archiving Facility Geocoding System (D-PAF GEOS) for ERS-1 SAR images was presented. Though, this system is dedicated to ERS-1, it will also cope with SIR-C/X-SAR images and has the capability to process other satellite SAR images as well.

Further, our aim was not only to build up a mission dedicated number cruncher, but to define a basis in terms of concepts in software, hardware and methodology for advanced user needs to geocoded SAR products for the polar platform area.

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