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AN ALGORITHM FOR RADIOMETRIC AND GEOMETRIC CORRECTION OF DIGITAL SLAR DATA.

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Abstract

In The Netherlands an accurate SLAR system with digital data recording is used for measurements within the framework of the national microwave Remote Sensing research program. However, the images are disturbed by unwanted platform motions due to e.g. turbulence at the low operating height (300 - 3000 m) of the SLAR system.

An algorithm is developed for the geometric and radiometric correction of the radar data by means of aircraft attitude and position measurements. These measurements can be obtained from an Inertial Navigation System (INS) onboard the plane. Some additional information like the aircraft height and the measurement distance is obtained from the radar signal. The correction model is implemented in a computer program.

The results clearly show an improvement of the image quality. Some specific problems that were encountered will be discussed and some results will be shown.

Keywords: SLAR, radar, preprocessing, calibration, image correction, radiometry, geometry.

Introduction

Airborne imaging techniques using microwaves have been available in The Netherlands since 1974, when an X-band analog Sideways Looking Airborne Radar (SLAR) system was obtained for research purposes. Several basic research programmes in Remote Sensing were conducted in this period to gain more understanding of the radar backscatter properties of natural targets in applications over land and sea. In 1979 requirements for a more accurate imaging tool led to the modification of a DECCA ships radar into an accurate SLAR system with digital recording, resulting in improved radiometric and geometric accuracy.

Some of the applications of radar remote sensing that are being investigated in The Netherlands require multitemporal images. Furthermore the demands on radiometric accuracy are high, in the range of 1 dB or better. Even with the improved digital SLAR this is difficult to achieve in airborne programmes due to variations in aircraft velocity and attitude.

A working group named PARES (Preprocessing of Airborne REmote Sensing data) was formed by the Netherlands Remote Sensing Board (BCRS) to solve these problems. The following institutes participate in this working group:

National Aerospace Laboratory NLR, Amsterdam
Physics Laboratory TNO, The Hague
Survey Department Rijkswaterstaat, Delft
Delft University of Technology

The working group will attack imaging problems for various existing systems. It commenced its work with SLAR data. Dynamic geometrical and radiometrical corrections are applied to the SLAR imagery on basis of aircraft position and attitude measurements. An algorithm was designed for this purpose. Digital radar data is fed into a computer together with simultaneously collected aircraft flight parameters (fig. 1). After the correction process an image file is formed. This image file is the final product of the PARES system, but at the same time it is the starting point for the various interpretation processes used in remote sensing.

The PARES system will be described in this paper. First an overview is given of the available data sources and the way in which some important parameters are determined. Then the geometric and radiometric aspects of the correction algorithm are discussed. A resampling procedure is necessary in this phase. After a short discussion on the implementation of PARES some results will be shown. Finally conclusions are given.

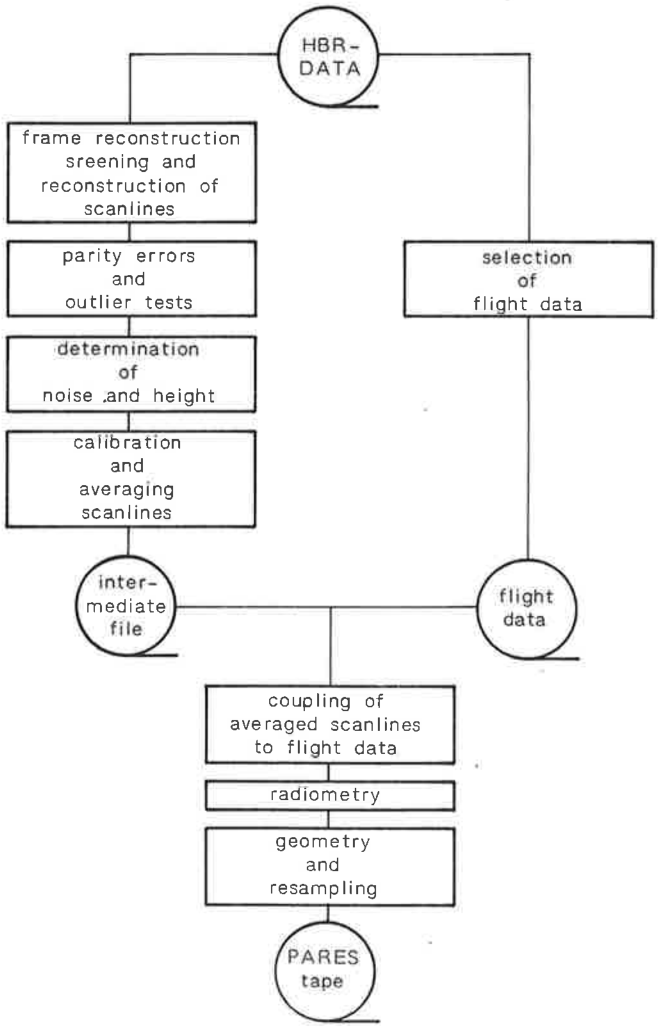

Figure 1: Flow diagram of the PARES system.

Data acquisition

The radar system

The radar system is built up around a transceiver unit of a DECCA ships radar, which was modified to upgrade the radiometric accuracy and the dynamic range. The antenna is a 2.5 m slotted waveguide antenna with horizontal polarisation. After video detection the signal is passed through a low pass presampling filter, followed by A-D conversion. Per scanline 2048 samples of 8 bit words are taken. The digital datastream of roughly 2 Mbits per second is stored on a high bitrate recorder, with high density writing. Some important parameters of the radar system are given in table 1.

frequency	: 9.4 GHz (X-band)
transmitted power	: 25 kW
pulselength	: 50/250 ns
polarisation	: HH
antenna beamwidth	: .9 deg.
P R F	: 100 Hz
recording	: 2048*8-bit samples
sample frequency	: 20 MHz (7.5 m)

Table 1: specification of SLAR system parameters.

The flight parameters

The NLR laboratory aircraft (Swearingen Metro II) is equipped with several modern navigation aids. An Inertial Navigation System LTN 58 provides the following important parameters:

angle of pitch
angle of roll
true heading
velocity (N-S and E-W)
latitude and longitude

This system can be updated with multiple DME measurements. An analysis of the indicated parameters showed that the accuracy is satisfactory for mapping purposes. Although the absolute position accuracy obtained is in the order of 100 - 200 m, the corrections for the unwanted aircraft motions are accurate to within the resolution of the SLAR system. So the images obtained after correction are geometrically spoken accurate.

Another important parameter is the height of the aircraft above the ground. Since the aircraft is not equipped with a suitable height measuring device, the SLAR system is used as a radar height meter. The time delay between the transmission of a radar pulse and the reception of the first echo from the ground is used to calculate the height. The obtained values are tested against the mean height to identify outliers due to obstacles and so on. The remaining values are passed through a filtering process to obtain an average height above the ground. The resulting values are suitable for the correction of imagery over sea and over flat terrain.

Data recording

An important aspect is the synchronization of the datastreams. Although the radar data and the flight data are recorded on the same tape simultaneously, this does not automatically imply an accurate synchronization between these signals because they are played back and processed in separate runs of the tape recorder. To facilitate synchronization in all steps of the correction process, an IRIG-B time code is added to the data acquisition. This time code is used for synchronization.

The two datastreams are recorded on separate channels of a HBR (High Bit rate) recording system. The data sampling occurs at different frequencies. Since the flight parameters vary slowly compared with the PRF of the radar system (which was optimized for this application), they are sampled at a lower frequency. The datastream from the radar has a high bitrate. Thus the recorder has to run at a high speed. The recording capacity is limited to 15 or 30 minutes (depending on the system mode) per tape.

The HBR tape is played back on the ground at NLR's Flight Data Conversion Station at a lower speed. The raw data are time tagged, calibrated to engineering units and stored as computer files. These files are now ready to serve as input data to the PARES correction algorithm.

Geometry

An uncorrected SLAR image shows geometric distortions due to several causes. The elimination of the slant range distortion has been reported before by Hoogeboom [6,9] for the Dutch Digital SLAR system. The correction of distortions due to velocity and attitude fluctuations of the aircraft will be treated here.

Each sample of the radar signal corresponds with a spot on the ground, called resolution cell. The ultimate aim is to express the locations of all resolution cells in one earth fixed 2-D coordinate system. This is achieved by three linear transformations. The motion correction is time dependent, the other two are supposed to be constant.

Squint

The main direction of the antenna lobe deviates from the aperture plane. This phenomenon is known as squint. One can derive from the measurements by Attema et al. [10] that a correction for squint may be accomplished by two rotations:

$$P_r = T_r P \qquad (1)$$

where P indicates the location of the resolution cells, T_r is the joint rotation matrix and P_r is the location expressed in the Radar coordinate System (RS).

Antenna postion

Before each flight the antenna pod with the radar antenna is mounted beneath the aircraft fuselage. The orientation of the pod and the origin of the RS with respect to the Gyro coordinate System (GS) of the Inertial Navigation System (INS) must be determined. The correction turns out to be:

$$P_g = S_{gr} + T_{gr} P_r \qquad (2)$$

where T_{gr} is the joint rotation matrix, S_{gr} is the shift between the origins of RS and GS, and P_g is the location of the resolution cell expressed in the GS.

Motion correction

An earth Fixed coordinate System (FS) with origin on the ground is defined at the time the

SLAR system produces its first scanline (beginning of image). The position of the origin of the GS is reconstructed by numerical integration of the N-S and E-W velocities delivered by the INS. The height above ground is available from the radar system, as previously explained. The rotation matrix is determined by the roll, pitch and heading of the aircraft. These parameters are directly available from the INS. Hence:

$$P_f = S_{fg} + T_{fg}\, P_g \qquad (3)$$

where the notation is similar to (2).

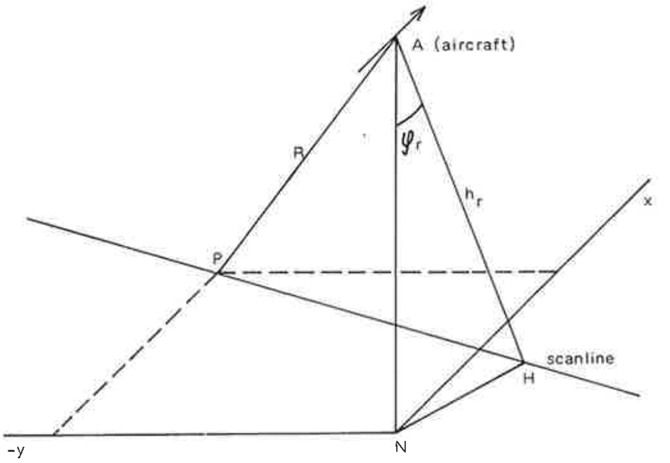

Figure 2: SLAR recording situation.

Two aspects have not yet been taken into account. First, the geometry is not influenced by the roll component. Secondly, the correction from slant range R to ground range must be performed in the triangle AHP (fig. 2) having an angle φ_r with the vertical. The total correction formula now becomes:

$$P_f = S_{fg} + T_{fg}\, S_{gr} + T_f\, P \qquad (4)$$

where T_f represents the resulting rotation matrix and $P' = (Ø, \; -\sqrt{R^2 - h_r^2}, \; h_r)$, where the prime denotes transpose.

An accuracy analysis showed that the one sigma values of the positioning errors of resolution cells projected in the FS are less than half the size of the resolution cells.

In a final step the database of backscatter coefficients and their coordinates must be processed in order to assign backscatter coefficients to the nodes (pixels) of a regular rectangular grid (resampling). The assignment is done by weighted averaging of the backscatter coefficients of the resolution cells. The weighting coefficients are determined by the amount of area overlap between the resolution cells and the resulting pixels.

Radiometry

The radar equation

The most important factors for the correction of pixel intensities in radar images are shown in the radar equation:

$$P_R = P_T \, \frac{G^2(\theta)\, \lambda^2}{(4\pi)^3\, R^4}\, \sigma$$

with: P_R = received power
P_T = transmitted power
G = antenna gain
θ = depression angle
R = distance to object (slant range)
σ = radar cross section
λ = radar wave length

P_T and λ are assumed to be constant in the Dutch digital SLAR system. Since this system cannot be absolutely calibrated yet, it is not necessary to introduce these parameters in the correction algorithm.

The distance R is known immediately, since the digital data acquisition starts slightly before the transmission of every pulse and the sampling of the signal takes place at a constant, well-known sample rate.

The other factors in the radar equation are not so easy to determine and will be discussed in the following sections.

The measurement of P_R (received power)

The SLAR system uses a transceiver unit which was originally designed for a ships radar. After some modifications the output voltage of this unit now varies linearly with the logarithm of the received power over a wide range of at least 6Ø dB. Therefore the transfer function of the system can be approximated by a straight line, except for very low input power levels, where the presence of noise disturbs the transfer function. This problem can be overcome by subtracting the average noise level from the received power in a resolution cell. (a resolution cell contains the average value of a number of samples). This method is favorable because it is not sensitive to drift, changes in the noise level, etc. The measurement and subtraction of the noise level is important because:

- it extends the dynamic range for accurate measurements of the received power,
- it enables the removal of resolution cells with a power level below a specified minimum value, which ensures that pixels containing only noise are not processed.

The antenna gain

The antenna gain function is often one of the most uncertain factors in the radiometric correction. There are several reasons for this:

- The gain function of the antenna mounted under an aircraft may differ from the gain function of the antenna in free space, because of the presence of obstacles in the near field of the antenna.
- The function of interest is not the antenna diagram in elevation for a fixed azimuth angle, but the function in elevation after integration of the azimuth diagrams (significant differences may occur for the type of antenna under consideration).
- An in-flight calibration of the system or measurement of the antenna, using, for example, corner reflectors is difficult to perform and may not give the desired accuracy.

The antenna gain function has been determined in two different ways. First, by measurements of the antenna itself and secondly, by measurements from the SLAR system over distributed targets (sugarbeet fields). Figure 3 shows the results. These measurements are described in more detail in ref. 9,1Ø.

Determination of the backscatter coefficient

The application of the correction factors as described in the previous chapters enable us to calculate the radar cross section σ . Since this

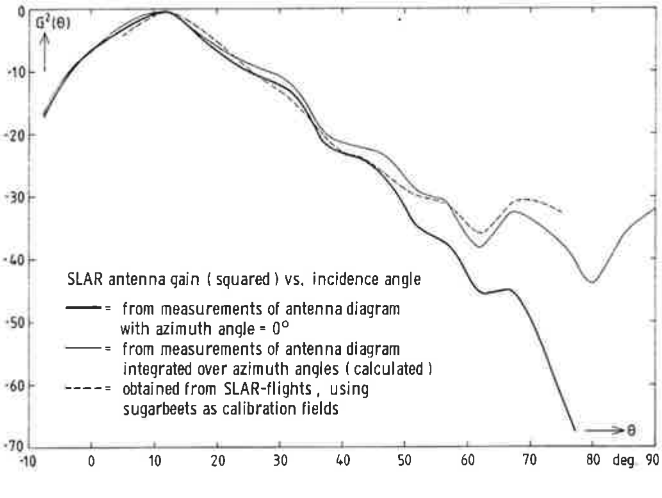

Figure 3: Results of antenna gain function measurements.

is not the quantity of interest, it is converted to the backscatter coefficient γ by dividing σ by A, the cross section area of the illuminating beam. The imagery will now look better, since the angular dependence of γ is smaller for many natural targets.

Substitution in the radar equation gives:

$$\gamma = \frac{P_R}{P_T} \frac{(4\pi)^3 \ R^3 \cos\theta}{G^2(\theta) \ \lambda^2 \ \beta \ L \ \sin\theta}$$

with: β = antenna beamwidth (in horizontal plane)

L = pulse length ($c\ \tau/2$)

Since the SLAR system is presently operated in a relative calibration mode, this expression may be reduced to:

$$\gamma \sim \frac{P_R \ R^3 \ \cos\theta}{G^2(\theta) \ \sin\theta}$$

This final expression can be used as a correction algorithm in combination with the previously described geometric correction.

The PARES system for processing SLAR images

Introduction

The freedom for realization and implementation of the PARES software for SLAR imagery is limited by constraints, due to the special properties, format and registered content of the HBR tape. Conversion of the HBR tape to Computer Compatible Tape (CCT) must be executed on the special purpose computers of the National Aerospace Laboratory NLR, where image data and flight data are dumped in seperate runs, to be merged in a later stage of the process. In this stage synchronization by means of the registered time is essential. The output CCT must be in a suitable format for later treatment on image processing systems.

The design of the system is such that final image pixels correspond with dimensions of 15 x 15 m (to be improved to 7.5 x 7.5 m shortly). The characteristic features of SLAR require that about 30 data values will determine the final pixel value (speckle reduction)[11]. This results in a data reduction factor of app. 30 during the conversion run. The preprocessing session is split into two parts in order to reduce the required computing time:

- Scanlines are reconstructed from the data and averaged up to the resolution of the acquired flight data in a first process. In this stage sub-processes are initiated that require the original unaveraged SLAR signals.
- The second session performs the synchronization with the flight data, the conversion from recorded, averaged data values to backscatter coefficients (radiometric correction), the determination of grid-nodes (pixel centres) and resampling of pixels into an earth fixed coordinate system.

The output product of the second session should be a resampled image, corrected for system errors. No further image enhancement functions are incorporated.

Two main parts of the PARES program will be discussed here: the screening and averaging of lines and the so-called outlier-problem.

Screening and averaging of lines

Due to high speed data recording, radar scanlines are recorded in two sub-frames, one containing the even data values, the other containing the odd data values. The first task is to restore lines, using the synchronization characters, time data words and the frame counter. Each line is uniquely identified by a time value and should be tested for excessive parity errors. Data frames with too many parity errors are rejected.

Two characteristic values must be determined for each line: the height above ground (previously described) and the noise level.

The noise level is extracted by using the first 15 data values per line, when the digitizer is sampling and the crossover signal of the transmitted pulse is not yet received, as the sampling starts app. 750 ns prior to the transmission of the radar pulse.

The data values recorded by the radar are measured in dB. In order to properly average data values, they should be transformed to a linear scale before taking together any number of them. Thereafter they are averaged up to the temporal resolution of the flight data set. The linearized, averaged data are then written to an intermediate file where noise value, height and time identification word are added to the record. The reverse process, from linearized to logarithmic values of backscatter coefficients, is not executed but after the resampling procedure.

One of the important steps of the second session is the resampling process where radar data are merged with flight data. The final user may choose special parameter specifications in this stage, if the default image product is not to be used. The data are resampled after the orientation of each averaged line in the earth fixed coordinate system of the output image is calculated. This orientation is based on integration of the velocity and by calculating the resulting rotation matrix based on the angles of roll, pitch and yaw (true heading). A transformation is derived from the original slant range projection to the earth fixed coordinate system.

Outliers

A SLAR image should be built up exclusively from signals backscattered by the terrain and received by the radar. A radar line may be contaminated, however, by disturbing signals (e.g.

Figure 4: A raw image, no checks or corrections applied.

Figure 5: Radiometric corrections have been applied, but no geometric corrections.

Figure 6: As image 2, but geometric corrections have been applied as well.

from other radars operating in the same frequency band). These signals will strongly influence the final image. They may be recognized as stripes perpendicular to the flight path. The averaging procedure does not necessarily remove these contaminations, because of their high values after the expansion to the linear scale. As a consequence data sets containing outliers should be cleared.

Two characteristics can be used to detect outliers. First, outliers should appear in single radar scanlines and not in adjacent lines. This implies that a suspected outlier should be tested on a significant deviation of its data values with regard to the corresponding data values in neighbouring lines.

Secondly outliers may be recognized on general appearance in a set of data values. A general appearance is experimentally determined: a steady rising slope, a constant high level and a minimum width. The result of outlier tests turns out to be more stable when tests are performed on smoothed data sets.

Results

The success of operation of the PARES-system can be judged by the results of the conversion process of a SLAR data set into an image (fig. 4 - 6). The general conclusions of the first experimental results may be that the pictures are upgraded in quality. The picture is more homogeneous after corrections, the possibility for selecting objects and for classification of areas is getting better, while the geometric corrections show undoubtedly a better image of the real world.

Figure 4 shows an area of roughly 7.9 x 4.4 km near Lelystad in The Netherlands. This uncorrected image is one of the worst cases we have recorded with our SLAR system sofar. The influence of interfering radar signals (ships radar) is clearly visible.

In figure 5 the outlier test and the radiometric corrections have been applied, but no geometric corrections with exception of the slant range to ground range conversion.

Figure 6 shows the fully corrected image of this area. The improvement is clearly visible. The horizontal stripes that appear are due to the limited buffer size that is available in the computer for the output image. As a result of excessive aircraft motions the orientation of some lines points outside this buffer size. A loss of pixels, seen as black stripes results. This problem can easily be solved when the algorithm is operated on a special purpose computer, that has sufficient memory capacity (core).

Conclusions

The correction of SLAR imagery for geometric and radiometric effects due to system distortions and aircraft position and attitude changes is shown to be successful with the present version of PARES. Some elements like the antenna gain function and the roll angle form very critical points. The final results strongly depend on these elements and presently more work is underway for further improvement and optimization. The latter is also important with regard to the consumption of computer time. In the present version the execution times are high, but it is foreseen that the use of an existing image processing facilty instead of a general purpose computer and a further optimization of the algorithms will solve this disadvantage.

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