'Photogrammetric Week '99' D. Fritsch & R. Spiller, Eds., Wichmann Verlag, Heidelberg, 1999.

Cartographic Production In The Orinoco Area Using IFSAR

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ABSTRACT

This paper is an interim report on the status of a project that aims to map a cloudy tropical region of 266 616 km² in southern Venezuela using single pass airborne interferometric synthetic aperture radar (IFSAR). The paper summarizes the main processing phases involved, the practical experiences and the initial conclusions. It does not attempt to describe the radar processing in depth: only the detail needed to make it understandable is given. The report demonstrates that airborne radar interferometry is an operational tool for mapping projects in cloudy areas.

1. INTRODUCTION

The Servicio Autónomo de Geografía y Cartografía Nacional de Venezuela (the National Mapping Agency of Venezuela) has tackled the challenge of mapping the vast region between the Orinoco River and the Brazilian border (fig. 1). This remote region of Venezuela has a warm and humid climate, with almost permanent cloud cover. The topography is hilly, with few flat areas and very abrupt elevations (the "tepuys") emerging from the plain. The land is mostly covered by rainforest, with trees reaching 40 meters in height. The project consisted in producing 5 meter pixel digital orthoimages and orthoimage maps at 1 : 50 000 scale, with 40 meter contours derived from a 10 meter accuracy digital elevation model over a region of 266 616 km². The total number of map sheets covering the area is 525.

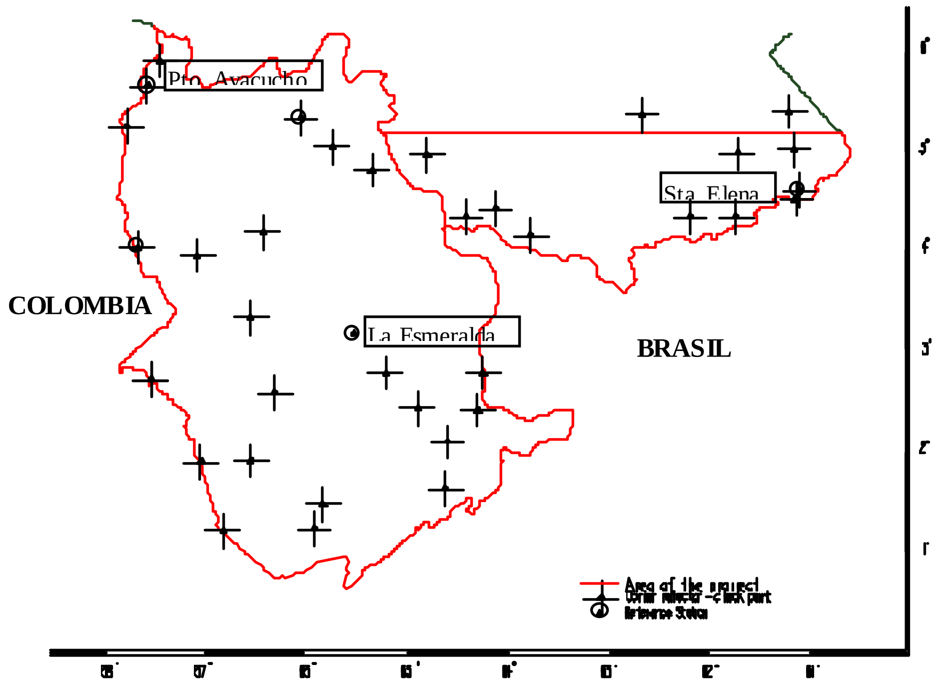

Figure 1: Area of the project with the locations of the corner reflectors and reference stations.

The Institut Cartogràfic de Catalunya (Cartographic Institute of Catalonia) submitted a technical proposal based on interferometric SAR technology to ensure that products would be obtained and delivered in a predictable period of time, regardless of the weather conditions and abundant cloud cover. The accuracy and pixel size specifications excluded the use of satellite radar, and therefore the AeS-1 single pass airborne interferometric radar from AeroSensing Radarsysteme, GmbH (Wessling, Germany) was proposed and selected for the project.

After a preliminary ground survey campaign and the preparation of the logistics, the flight mission was begun on 20 October 1998 and it ended successfully on 5 February 1999. At the time of writing, the radar data are being processed in Barcelona and the first maps have been produced.

2. THE AES-1 RADAR

The AeS-1 interferometric SAR of AeroSensing Radarsysteme (Moreira, 1996) is an advanced radar operating in the X-band that is capable of delivering radar images with pixel sizes ranging from 0.5 to 5.0 m. and elevation data with nominal accuracy of 5 to 50 cm. The radar emits and receives the signals using two antennas that are rigidly mounted on each side of the airplane and 1.5 meters apart, so as to form the baseline of the interferometric geometry. The radar illuminates the terrain laterally at an angle ranging from 20º (near range) to 67º (far range). Due to the separation of the antennas, the range to a point is slightly different as measured by each antenna; this range difference corresponds to a phase difference from which the elevation is determined.

The phase of a point is affected by the motion of the airplane, so this motion has to be recorded and compensated. The current configuration uses GPS and INS data from an Applanix system to determine the effects induced by the motion of the aircraft and to obtain the orientation of the sensor. In addition, the aircraft had to follow the flight lines with almost no deviations (less than 20 m). Therefore, the flight navigation system (a CCNS-IV from IGI, Hilchenbach, Germany) makes use of DGPS data transmitted from a reference station (fig. 2). The transmitter's maximum range is 300 km. and its location was carefully chosen so as to always have visibility to the aircraft. This was achieved by computing a DTM from the contour lines of existing 1 : 500 000 maps and by performing a visibility analysis. GPS data at the reference stations was recorded for post-processing.

Figure 2: Reference station near the La Esmeralda airfield, with the "Druida" tepuy on the background.

3. MISSION PREPARATION

3.1. Flight planning and selection of the airfields

The project area was divided into strips 130 km. long and 14 km. wide, and flown at 26 000 feet with a twin turbo Rockwell Aerocommander 690A from Cooper Aerial Surveys (UK). Depending on the terrain type - flat, hilly or mountainous - the side overlap was 50 %, 67 % and 75 %, in order to guarantee that enough images would avoid the shadowing and layover effects. Consecutive tracks were flown in opposite directions.

The on-board data recording system consisted of three sets of removable disks, each one capable of storing 144 Gb, roughly four tracks, for a maximum of 12 tracks per sortie. At 210 knots, the 12 tracks could be flown in 4 hours. A maximum of 24 tracks per day was possible with two pilots and two sorties per day, but because of the ferries and bad weather, the average performance was only around 10 tracks per day.

The airfields were selected from the few available in the area. The selection criterion was suitability for flight operations: availability of supplies, accessibility and minimization of ferries (the maximum endurance of the aircraft was 5 hours). The selected airfields were Puerto Ayacucho, La Esmeralda and Santa Elena de Uairén. La Esmeralda proved to be the most demanding airfield, due to its isolation. Fuel and food were carried by river and by air. The crew and the technical and support personnel were accommodated in barracks for a whole month. The only air conditioning system was for the computer operations. The DGPS reference station was placed near the airfield.

It should be pointed out that all the material and the personnel had to be moved at each change of airfield. This required coordination and was one of the most demanding tasks for the team dealing with the logistics.

3.2. Ground survey

The AeS-1 system relies on GPS and INS data for georeferencing, so ground control is used for checking purposes only. The check points can be made visible on the radar image by installing radar reflectors (corner reflectors) at known positions. Therefore, a survey campaign was performed together with the Geodetic Department of the National Mapping Agency of Venezuela to measure 35 positions where the corner reflector would be installed. None was installed at that time, due to the risk of being displaced, destroyed or even covered by the vegetation.

4. FLIGHT CAMPAIGN

Before starting the mission, AeroSensing flew a calibration flight, in order to ensure the absence of any systematic error and to measure different parameters: for example, the corner reflector shape and width in the image, a precise measurement of the baseline, radiometric parameters for compensating the different radiometry in the far and near range parts of the swath, and the effective number of *looks* required to maintain the noise level at less than 2dB. The number of *looks* is the number of elementary resolution cells assembled to obtain an output pixel by averaging the radiometry of the resolution cells. More *looks* mean less noise, but less spatial resolution. For this project the number of *looks* was set to 7.

4.1. Data capture

As mentioned earlier, the installation of the corner reflectors was performed simultaneously with the flight. Two reflectors were installed with two different orientations, so that they could be

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imaged on two opposite tracks. Some had to be installed on top of the "tepuys" and required the use of a helicopter to transport the people, the reflectors and the GPS equipment.
The flight campaign lasted from 28 October 1998 to 3 February 1999, including repairs, mandatory revision of the airplane, re-flights, change of airfields, etc. There were 66 effective flying days, with around 10 tracks per day. While cloud cover does not affect the radar images, dense clouds with high water content and turbulence do prevent operations, since they directly affect the quality of the image.

4.2. On-site quality control

After landing, the on-board disks were removed and the contents copied to DLT 7000 tapes (around 35 Gb, one DLT per track). On-site quality control followed, in order to detect any anomaly:

- Radar checking: analysis of parameters such as raw signal variations, power variations, etc., in order to ensure that the radar had operated correctly during data acquisition
- Movements of the aircraft: attitude variations of less than 3º in roll, 1º in pitch and 2º in heading, and variations of less than 30 m. in height and 100 m. in position
- Image quality: a 0.8 x 14 km. segment of each track was fully processed and checked

If the control was passed, a copy of the DLT was sent to the ICC (Barcelona). The quality control detected some bad tracks, which were re-flown immediately. The amount of data collected was around 14 Tb.

5. PRODUCT GENERATION

The AeS-1 software runs on a network of standard PCs. The configuration at the ICC consists of 5 processing lines, each with two DLT drives and 13 slave PCs connected to the Ethernet. The software is predominantly written in IDL and runs on Linux.

5.1. Sar processing

At each string the DLT containing a 130 km. long track (32 Gb) is read, divided into 3 km segments of 0,5 GB with 25 % longitudinal overlap and distributed among the slave PCs. Each segment takes up to 6.5 hours to process on a standard Pentium II 450 MHz microprocessor with 256 Mb RAM and 9 Gb disk. On average, a track is processed every 32.5 hours. The combined throughput of the 5 strings is a track every 6.5 hours. A central PC with a FoxPro DB dispatches jobs to every processing line and takes care of the archival and data management.
The first step in processing consists of the reconstruction of the two complex images (intensity and phase) from the raw data of the two antennas. The aircraft motion is corrected at this stage. The two complex images are then co-registered for computing the interferogram on a pixel-to-pixel basis. A very accurate co-registration is necessary and two polynomials for range and azimuth and a quadratic interpolation are applied for the resampling. The interferogram is then obtained by multiplying the first image with the complex conjugate of the second. The interferogram represents the phase difference due to the elevation of the terrain and is expressed ("wrapped") modulo 2π. The "phase unwrapping" process computes the absolute phase difference by adding 2π if discontinuities of 2π are detected in the interferogram. The AeroSensing method for phase unwrapping is a hybrid least squares combined with region growing algorithm.
All these processes are automatic and involve long computations in the Fourier space. The output is an image coded in slant range and a unwrapped phase interferogram.

5.2. Geocoding

The phase unwrapping process can fail for several reasons. That is to say, there are discontinuities that are not well resolved, as in the case of the layovers and shadows, and terrain returning low signal (i.e. rivers). These errors must be removed by editing the phase manually.
The elevations are then computed from the absolute phase after phase calibration. Two methods can be used: the first takes the elevation of a corner reflector and assigns it to the corresponding phase at this point (the phase becomes “calibrated”). The second method is iterative and is based on the interferograms of the contiguous tracks covering the same area from opposite sides. The process iterates until a solution that minimizes the differences in elevation is found. This method is very time-consuming (around 36 hours on a Pentium II 450 MHz with 512 Mb RAM per map sheet), but it does not require any ground control or operator interaction.
Once the elevations are known, tracks are geocorrected and assembled together in a mosaicking process. It is only at this stage that the operator can see if a non-detected error with the interferogram has been left behind, or the editing of the phase has proved insufficient. In summary, the operator is confronted with a sort of trial-and-error process that takes long hours at every retry. Fortunately, after several weeks, the operators develop skills in editing the phase, and many repetitions can be avoided.
As mentioned earlier, the SAR processing part runs in batch and can be operated by one operator. However, the geocoding requires manual intervention. The configuration at the ICC is operated by a group of 12 operators with two supervisors and a project leader.

5.3. Radiometric corrections

Because the side looking geometry, the radar images are brighter at the nearest side and darker at the far range. A similar effect occurs with the relief: slopes oriented to the radar beam are brighter. Since a map sheet is formed by mosaicking consecutive opposite tracks, a radiometric compensation process is applied to equalize the radiometry. As a result, the images appear flat, that is to say, there are almost no visual cues of the relief. The result of all the geometric and radiometric processes described before is a digital orthoimage as shown in fig. 3.

5.4. Digital Terrain Model

Interferometric techniques provide a very dense grid of elevations. It should be noted that since each pixel has a phase associated, each pixel has a height. Thus one finally gains a very dense 5 x 5 m. elevation grid covering the 266 616 km². Each elevation is a single precision floating point value of the top of the features; in other words, the result of the interferometric process is a very dense digital surface model (DSM).
The DSM is first filtered in conflict areas, such as the zones near the rivers, and in areas that are void due to specular reflections and shadowing effects.
An almost cloud-free Landsat coverage is used for estimating the height of the trees and converting the DSM into the Digital Terrain Model (DTM). After co-registering with the radar images, the Landsat scenes are classified using unsupervised clustering techniques. Height differences between adjacent classes are obtained by drawing profiles across them and then extracting the heights from the DSM. The output is a table with the average differences in height for each type of transition between classes. The bare soil class is used as a reference, and then the heights are subtracted from the DSM to obtain the DTM. The classes are derived from the texture of the radar images in places where the Landsat scenes are covered by clouds. Local minima and maxima are eliminated by interpolating from the neighboring heights.

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Contour lines are then computed automatically; and very small closed contours are deleted. The final result is shown in fig. 4.

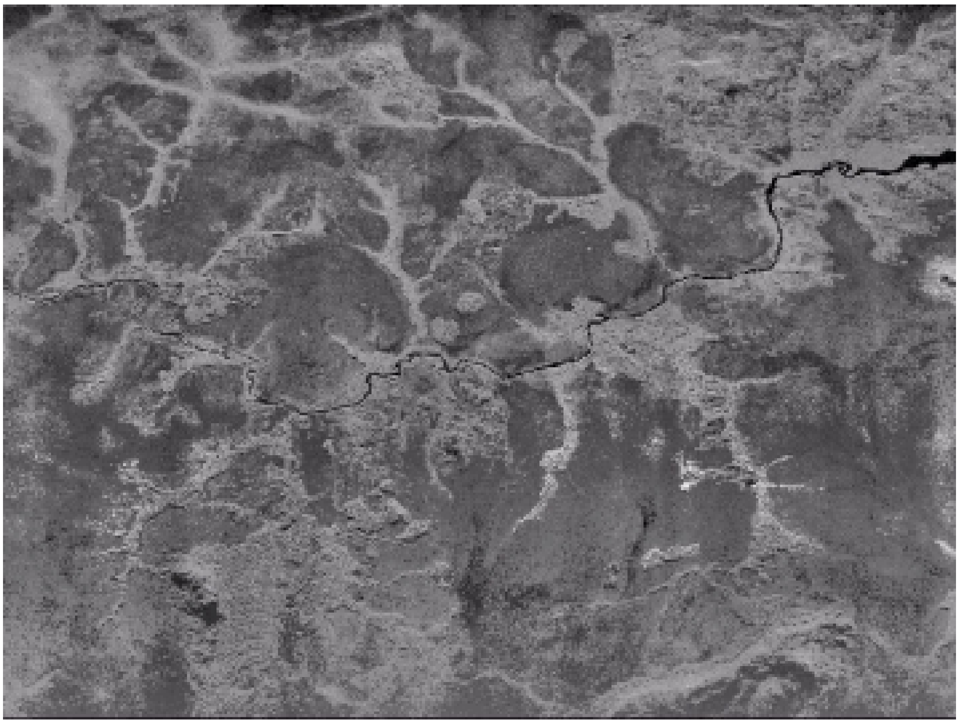

Figure 3: Radar image near Puerto Ayacucho showing grassland and forest.

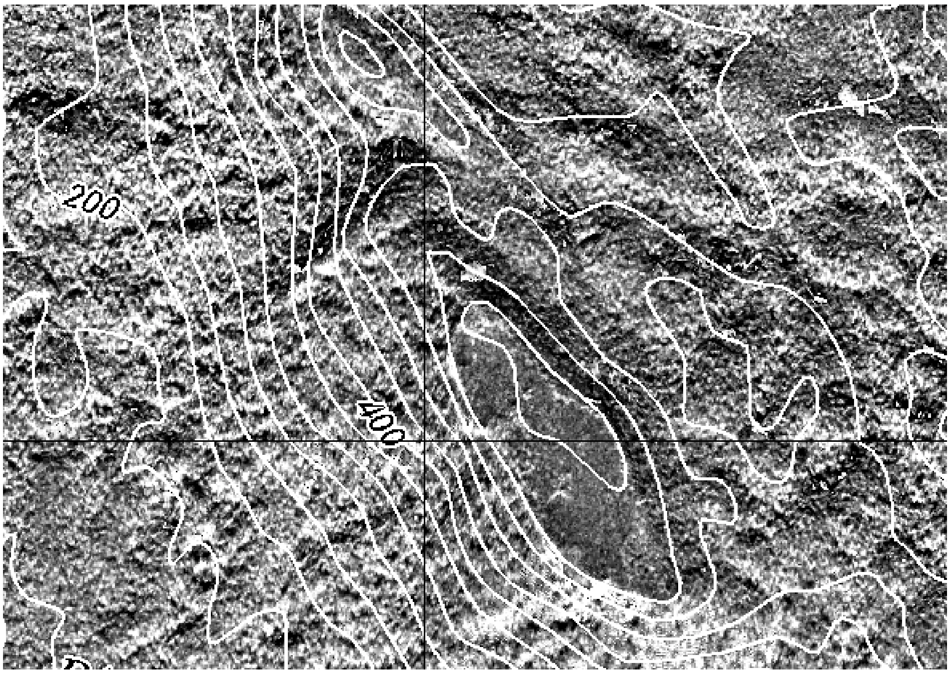

Figure 4: Radar orthoimage with contour lines and cartographic grid.

5.5. Map finishing and editing

Geographical names are extracted from existing maps and placed on the map. Finally, frames, legends and marginalia are placed on the map, plotted on film and printed.

6. QUALITY CONTROL

The quality control of the digital images consists of a qualitative and a quantitative evaluation (Lira, 1999). The qualitative evaluation relies on a visual inspection and checks for defocusing, global contrasts, noise and visual discrimination of small textures and artifacts. The quantitative tests check for the real number of *looks*, the radiometric resolution, spatial resolution, contents of the *speckle* associated with the radar images, contrast, form of the histogram, etc.
Due to the very sparse control, very few check points for the planimetric and altimetric tests have been completed thus far, so no significant accuracy values have been obtained yet.

7. CONCLUSIONS

The most important conclusion is that single pass airborne interferometry is a reliable and operational tool for mapping missions in areas with severe cloud cover. Having become accustomed to the long stand-by of photographic missions in this type of area, the performance of the radar flights is a very pleasant surprise, even though some days can be lost due to excessively dense cloud cover or turbulence.
Rapid, but comprehensive quality control after each sortie is recommended, because the logistics are too complex to justify leaving the zone without knowing whether the data are of the desired quality.
On the other hand, a long period of time is required to process the radar data. This is due not only to the considerable computations, but also to the trial-and-error type of process mentioned earlier. Comparatively, the amount of hardware needed and time spent are several times greater than for an equivalent optical mission. Fortunately, the intensive computer-bound processes run in batch on a configuration which is easily scalable. This is a very positive feature of the AeroSensing processing architecture. Of course, the constant improvements in the speed of microprocessors will help to reduce computation time.
Finally, it almost goes without saying that logistics is undoubtedly a key factor in the success of the project, which must be planned well in advance. An adequate degree of comfort for the crews and technical and auxiliary personnel is also necessary, if long periods of time are to be spent at very remote and isolated airfields.

8. REFERENCES

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