MAPPING OF LARGE AREAS IN TROPICAL COUNTRIES BY USING HIGH RESOLUTION AIRBORNE INTERFEROMETRIC RADAR

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ABSTRACT

Recent developments in high resolution airborne synthetic aperture radar (SAR) sensors allow to map large and remote tropical areas, independent of cloud coverage, with high accuracies in position and height. This makes it possible particularly for tropical developing countries to get high quality geoinformation reference data within a short period of time and at a low cost level, compared with conventional mapping methods. Subject of this paper is to present the suitability of this technique on the basis of mapping projects in Indonesia, Brazil, and Venezuela. The whole procedure from the data acquisition to the generation of value-added products is pointed out. In each of the three projects the data acquisition was carried out by the X-Band subsystem of Aero-Sensing's interferometric airborne SAR AeS-1, which is operational since October 1996. SAR ortho images and digital elevation models (DEM's) are the two main products, which are generated from SAR data. Value-added products are for example cadastral maps, topographic maps, SAR orthophoto maps, or data support for geographic and cartographic information systems (GIS, CIS).

1. INTRODUCTION

Vast areas in tropical countries with a high percentage of cloud coverage are currently mapped unsufficiently or in a too small scale. In a lot of cases, ground surveys could not be carried out due to the inaccessibility of the area and the lack of adequate transportation. Because of the permanent cloud coverage of such areas, it is almost impossible to plan and lead aerial mapping campaigns using optical sensors.

Under these circumstances, high resolution airborne radar sensors allow a nearly weather-independent data acquisition. This helps to finish mapping projects according to schedule, and thus, to provide actual geoinformation reference data to tropical countries at a relatively low cost level.

This paper presents the suitability of this technique on the basis of mapping projects in Indonesia, Brazil, and Venezuela. Chapter 2 gives an overview on Aero-Sensing's SAR system AeS-1 and the typical data workflow. In chapter 3, each of the three mapping campaigns is figured out. The generation of value-added products is described in chapter 4. Also, the results of the mapping projects are presented. Finally, chapter 5 gives an outlook on further activities.

2. THE AES-1 SYSTEM AND DATA WORKFLOW

In the beginning of 1996, Aero-Sensing Radarsysteme GmbH started to design and construct a high resolution X-band interferometric SAR called AeS-1. After first test flights in August 1996, the system became operational in October of the same year.

In the following, an outline of the system design is given: The AeS-1 is configured as a two-antenna single-pass interferometric SAR with a ground resolution up to 0.5 m x 0.5 m and a height accuracy up to 5 cm. The system consists of a ground and a flight segment. Figure 1 shows the AeS-1 flight segment, while figure 2 shows the radar antenna construction, installed on a Rockwell Turbine Commander. The block diagram in Figure 3 shows the ground and flight segment of the AeS-1 with its components.

Figure 1: AeS-1 flight segment

Figure 2: Rockwell Turbine Commander with radar antenna construction

The ground segment consists of a laptop computer for flight planning, the data transcription system, the SAR and interferometric SAR (InSAR) processing facility, the archiving management system, and a GPS ground station. The flight segment consists of the radar antennas, a transmitter/receiver, a clock generator, a control computer, a disk array unit for data recording, and a flight control system.

Due to its compact design, the AeS-1 system can be installed on rather small aircrafts. During the projects mentioned, the system was installed in a Rockwell Aero Commander 685 and a Rockwell Turbine Commander. The AeS-1 is a fully automatic system. As the flight control unit offers a display where the real track and its deviation relative to the nominal one are indicated, the pilot simply has to follow the displayed tracks. No co-pilot or operator is necessary. More informations on the system AeS-1 are reported in (Schwäbisch et al., 1999).

In the following, an exemplary workflow during a mapping project is described:

In the beginning of a project the area to be flown has to be determined and entered into the flight planning software. This typically is carried out by using conventional maps. Additionally, flight track coordinates and radar settings like resolution, flight altitude, and swath width are determined. This could be done either in the project area or in the office. Ground activities, which are mainly consisting of differential GPS survey, must also be planned before the data acquisition starts. Examples are the determination of positions of corner reflectors and DGPS-transmitting ground stations. Corner reflectors appear in radar images as bright spots and are used as ground control points. Aluminium made corner reflectors with their smooth surface and triangular form are strongly reflecting radar signals.

The pilot is guided during the flight by the automatic flight guidance system, which consists of a display in the aircraft's front desk and an online kinematic DGPS receiver. The DGPS receiver is coupled with an inertial navigation system (INS). The real time correction signal is transmitted during the flight from a GPS ground station, which is normally positioned on a base point with known coordinates nearby the project area. Additionally, the GPS ground stations are used for differential GPS ground survey of corner reflector and transmitting point positions.

During the flight, the SAR raw data is stored on board on hard disk arrays with a capacity of 432 Gbyte. It is possible and usual to change the hard disks during an acquisition flight. With a maximum recording data rate of 32 Mbyte/s a total acquisition time of nearly 4 hours can be realized. After landing, the recorded data is transcribed to Digital Linear Tapes (DLT's) with 35 Gbytes storage capacity. Also, ground station and aircraft GPS data, as well as the INS data are offline processed to the motion compensation data. Later, this motion compensation data is synchronized with the radar raw data.

In mapping projects in Indonesia, Brazil and Venezuela it was very common to perform two flights a day. This means, that the process of data acquisition, data transcription and GPS processing must be optimized in relation to the computing facilities in order to guarantee a high operational performance.

After the SAR raw data and motion compensation data transcription, the data has to pass through a chain of processing procedures, which are namely SAR processing, interferometric processing, phase filtering, absolute phase estimation, geocoding and mosaicking. The processing chain is devided into the processing and postprocessing part: In the processing part, the raw data is processed to a visible SAR image with a defined geometric resolution. The interferometric processing provides the height information for the same area. The postprocessing includes the process of geocoding, which is done by using the interferometric height, the motion

compensation data, and the corner reflector ground control points. Radiometric processing, mosaicking and filtering of the orthorectified SAR image are final postprocessing steps. All processing software used in the projects mentioned (excluding the GPS and INS processing software) is running in Linux environment and was developed by Aero-Sensing. Further informations on SAR processing are given in (Wimmer et al., 2000).
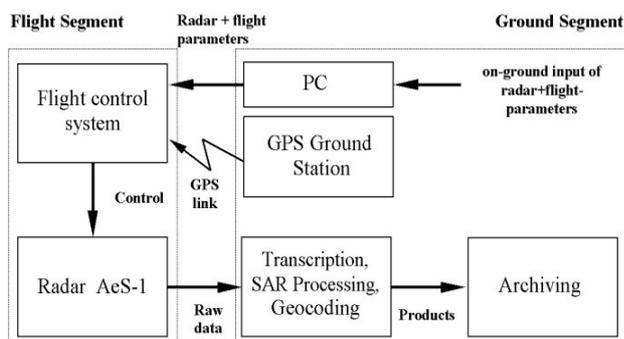

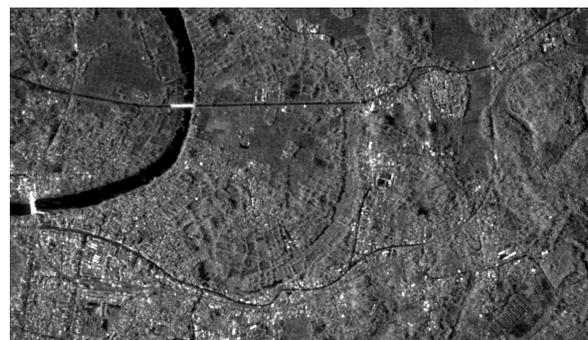Figure 3: Block diagram of the AeS-1 system

Figure 4: SAR ortho image, Indonesia, spatial resolution 2.5 m x 2.5 m

3. MAPPING PROJECTS IN INDONESIA, BRAZIL, AND VENEZUELA

3.1 Indonesia

The mapping project in Indonesia took place from July 1997 to January 1998. 46,000 km² on Java island, on the Molucca islands and on Irian Jaya were mapped with a geometric image resolution of 2.5 m x 2.5 m and a height accuracy of 2 m. The goal of this project was to provide geoinformation data for remote tropical areas on the Moluccas islands and in Irian Jaya, which were mapped unsufficiently and just in small scale maps before. Additionally, in all mapped areas existing topographic maps were updated and completed with thematic forest information, derived by visual interpretation. Because of this, the image resolution was more important than the height accuracy, but the image resolution takes notice of the vast mapping areas: Often, a compromise must be fulfilled between application, image resolution, height accuracy, the dimensions of the project area and of course, the costs of a project. Nevertheless, different forest classes and other land use classes could be determined and mapped. Figure 4 shows a SAR ortho image, captured within the mapping project in Indonesia. As in many other countries, it wasn't allowed to process the collected data outside the country. In this way, the complete SAR processing chain had to be set up in Indonesia, run by indonesian staff. The project in Indonesia was extended later with additional areas on Irian Jaya and the Molucca islands.

3.2 Brazil

In Brazil, an area of about 10,000 km² in the Northeastern part of the country was mapped in October 1998 with a maximum geometric resolution of 0.5 m x 0.5 m and a height accuracy of 0.25 m. The purpose of this project was to provide irrigation for drought areas using water from the large, nearby river Rio São Francisco. High accurate interferometric DEM's were used to plan water pipes, laid optimally, taking advantage of ground slope and natural water run offs. Because of the swath width of about 2 km and the desired height and position accuracies, the flight altitude was about 3,000 m. Figure 5 shows a part of a shaded DEM. The whole processing chain was installed in Brazil and run by brazilian staff. Usually, the amount of ground activities increases with the desired accuracies, thus, a lot of corner reflector and transmitting point locations had to be measured using differential GPS. Finally, the data acquisition in this project could be finished according to a high data collection rate in just two weeks, by meeting all data quality requirements.

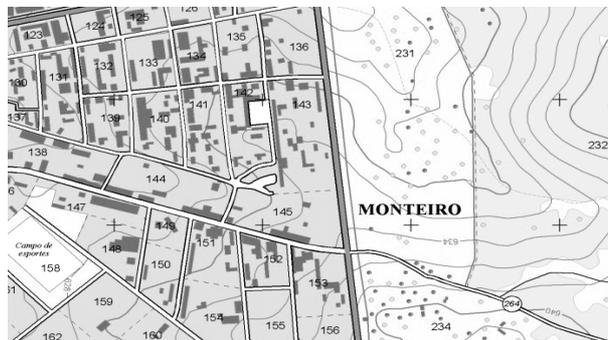Figure 5: Shaded DEM, Brazil, size of shown area 250 x 135 m

Figure 6: Cadastral map, scale 1 : 5,000

3.3 Venezuela

The mapping campaign in Venezuela was carried out in the period of October 1998 until January 1999. 268,000 km² of the nearly unhabited and inaccessible southern part of the country (states of Amazonas and Bolívar) were mapped with an image resolution of 5 m x 5 m and a height accuracy of 5 m. The purpose of this project was to provide reference geoinformation data. The area only was mapped unsufficiently and with less accuracy before, for example in radar survey projects from 1967 to 1971. The main cartographic products are SAR ortho maps generated from orthorectified SAR images, and DEM's. In the SAR ortho maps, contour lines with a equidistance of 40 m and a height accuracy of 10 m are embedded. The position accuracy of an image pixel is around 5 m. Due to the dense cloud coverage, thunderstorms and turbulences, the flight altitude was around 8,000 m. The flown tracks were according to the vast area up to 130 km long, illuminating a 14 km wide swath. In the project mentioned a very large tropical area was mapped in order to produce more than 500 SAR ortho mapsheets.

4. GENERATION OF VALUE-ADDED PRODUCTS

The generation of value-added products starts after the SAR data has passed the complete processing and postprocessing chain. Main inputs for value-added products are both orthorectified SAR images and DEM's. The range of high-end map products reaches from simple SAR ortho maps (with or without embedded height contour lines, see figure 7) to cadastral maps (up to a scale of 1 : 5,000, see figure 6), maps with a reduced number of map objects for planning purposes, to topographic maps in different scales. Other products are three-dimensional views, profiles and others. Increasingly, digital data is provided according to the specific application for cartographic and, in addition with further thematic data, for geographic information systems.

Methods of image information extraction are mainly the visual image interpretation, the automatic image classification, or mostly applied, a mixture of both methods. The visual image interpretation is the most accurate derivation method, but disadvantages are the long lasting, cost expensive and operator-dependant procedure. On the other side, automatic image classification algorithms are providing results in a short period of time. As the quality of automatic image classifications is strongly dependent on the amount and quality of input data, the SAR amplitude image, and additionally, also coherence image and the correspondent DEM are used. Automatic image classification is more suitable for small scale product generation (1 : 25,000 and smaller scales, dependant on specific application), as the cartographic generalization reduces the demand for position accuraccy and map details. A compromise is to use automatic classification for some map objects like for example water and forest areas only, while objects difficult to classify (like settlements and the street network) are still interpreted visually. Figure 8 shows a 1 : 50,000 scale map for planning purposes of the area of Puerto Ayacucho, southern Venezuela. The map was generated by automatic classification (forest areas, water areas, open areas) as well as by visual interpretation (settlements, road network, annotation), while the classified areas were coloured and merged with the corresponding orthorectified SAR image. Figure 9 finally shows a 1 : 50,000 scale topographic map of the same area, which was generated by visual interpretation only.

The height contour lines generated in the three projects are automatically derived from the corresponding orthorectified DEM, with possible settings to the equidistance, annotation and other parameters (Schmieder et al., 2000). The automatically derived height contour lines require later no manual correction or editing. By illuminating with X-band frequency, the radar signals are reflected by the surface of each object. Therefore, generated DEM's and derived height contour lines include building and forest heights. By taking attention of the known forest heights and building recognition, the digital surface model could be corrected to a digital terrain model only representing the ground heights.

More informations on this technique is given in (Schmieder, 1997). For the projects in Indonesia, Brazil and Venezuela this correction technique was not applied due to the required accuracies and the lack of time.

Figure 7: SAR ortho map, scale 1 : 50,000

Figure 8: Map for planning purposes, scale 1 : 50,000

Figure 9: Topographic map, scale 1 : 50,000

5. CONCLUSION

The radar system AeS-1 has shown its suitability for mapping large areas in tropical countries based on three projects mentioned in this paper. The AeS-1 is able to collect data in remote and often cloud covered areas, while in each project specific purpose, project requirements and desired application are considered.

For projects in future, two developments are important: On the one side, the AeS-1 system is continously technically developed: A third radar antenna is installed, which gives the possibility to use two baselines simultaneously (Wimmer et al., 2000). This helps to increase the accuracy of the data. Additonally installed frequency bands will increase the amount of extractable data.

On the other side, new information extraction and application techniques are introduced and existing ones developed: For applications in future, it is planned to arrange the derivation of geoinformation data and the generation of high quality cartographic products increased automatically and database driven, in order to facilitate a faster production and a better integration of the data to cartographic and geographic information systems.

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