DERIVATION OF TOPOGRAPHIC MAPS FROM HIGH-RESOLUTION AIRBORNE SAR DATA

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ABSTRACT

In the year 1996 Aero-Sensing Radarsysteme GmbH designed and manufactured the AeS-1 airborne X-band Interferometric Synthetic Aperture Radar (InSAR) system, capable of generating images with a ground resolution up to 0.5 meters and Digital Elevation Modells (DEMs) with a height resolution of 0.05 meters. Since 1997 the system collected data mainly from tropical areas like Indonesia, Venezuela and Brazil. The automatized processing chain, including SAR focussing, interferometric processing, geocoding, mosaicking and calibration, delivers orthorectified SAR amplitude images, interferometric coherence images and high precision DEMs. Derivation of topographic maps containing cartographic point, line and area features is based on the geocoded data outputted from the processing chain. The DEM itself is used for the automatic generation of labelled contour lines and hill-shadings. Because of the complexity, the first maps were produced solely by the method of visual image interpretation. Current investigations for increased automation and classification by methods of pattern recognition are done and were integrated into the map production chain so as to accelerate and simplify it. All objects not possible to classify were interpreted visually and derived through screen digitizing employing professional WYSIWYG graphic software. The validation of the results is done using other maps, aerial ortho images, fotos and fieldwork. Map samples are presented for illustration.

1 INTRODUCTION

Although cartography can already look back on almost 6,000 years of history, yet not all areas of the earth are mapped at all or only in a small scale. Permanent cloud cover and difficult access, especially in the tropics, render traditional surveying techniques expensive or impossible. The invention of high-resolution InSAR sensors offer the possibility to produce images and Digital Elevation Models (DEM) from these areas used as basis data for the derivation of cartographic information. But not only in that areas SAR technology represents an advantage compared to optical senors, also, if well timed data are necessary, SAR can be used for cartographic purposes.

Since completing the first airborne InSAR-sensor by Aero-Sensing in the year 1996 a new potential of information for the generation of cartographic products was born. Due to the high resolution, both in position (≥ 0.5 m) and height (≥ 0.05 m), combined with the advantages of SAR, like weather-independence, the AeS-1 X-band system delivers cost-efficient data for the derivation of topographic maps with scales down to 1 : 10,000. This paper gives an short overview of the operational processing chain and describes the following map production steps up to map samples of high quality in modern design.

2 AIRBORNE INSAR SENSOR AES-1

The data used for the map derivation described in this paper were solely gathered by the first InSAR system AeS-1, built and operated by Aero-Sensing Radarsysteme, during the last three years. It run up to now more than 1,400 hours. With the AeS-1 different ground resolutions and swath width' can be realized, depending on the desired applications. The main system parameters of the AeS-1 sensor are summarized in Table 1.

The AeS-1 system can be divided into a ground segment and a flight segment. The ground segment is divided into the subsystems: laptop computer for flight planning, raw data transcription system, InSAR processing and archiving system, and a GPS ground station to allow real time kinematic DGPS tracing via radio data link. The flight segment consists of the SAR antennas mounted on the sides of the aircraft (Fig. 1), a transmitter/receiver unit, controlled by a computer, a clock generator, and a disk array unit with a capacity of 256 GB for data recording. The movement and position of the aircraft is measured and stored by a flight control system containing a DGPS system and an Inertial Navigation System (INS). Additional information about the AeS-1 System is reported by Schwäbisch and Moreira (1999).

Operating Frequency	9.35 – 9.75 GHz
Wavelength	3.12 – 3.25 cm
Polarization	HH
PRF	1.5 kHZ – 16 kHz
Peak Power	1.9 kW
Ground Resolution	up to 0.5 m x 0.5 m
Radiometric Resolution	up to 1.8 db
Swath Width	1 – 15 km
Flight Velocity	50 – 200 m/s
Typical Flight Altitude	500 – 9000 m
InSAR Baseline	0.5 or 1.8 m
Dimensions	W: 1.2 m, H: 1.0 m, D: 0.6 m
Weight	210 kg including antennas
Power	28 V, 60 A maximum

Table 1: System parameters of AeS-1 flight segment

Figure 1: Gulfstream Commander 1000 with AeS-1 X-band antenna boom construction

3 DATA PROCESSING AND VALIDATION

The processing of the digitally stored “latent” SAR raw data to visible images can be divided into three processing steps. First the raw data stored on hard disks are transcribed and backuped on Digital Linear Tapes (DLTs). In SAR processing the raw data are read from the DLT, decoded and correlated by using a Range/Doppler algorithm. The positional acurracy is improved by including the motion compensation data, generated itselves of the DGPS and INS data. Single-look images in complex format are the SAR processor output. Multi-look processing eliminates the harmful influence of the Speckle on image radiometry at the cost of lowered ground resolution. Hence, a trade-off between speckled appearance and resolution must be found. In figure 2 for example a 37 look image with ground resolution of 2.5 meters was generated from the initial 0.2 meters single look image. In a further step an interferometric processor coregistrates the images of the two antennas for producing an interferogram and a DEM in slant-range geometry. Also a magnitude of the complex correlation coefficient and the SAR magnitude is carried out. In a last step the geometry of the ready processed data must be changed from slant-range to a georectified cartographic reference system. This is done using marked and measured reference points, so called Corner Reflectors (CR) (see white spot in the center of figure 2). To obtain images of a predefined area, e.g. of a map sheet, the single tracks must be mosaicked and trimmed. To suppress artifacts in the data, e.g. caused by Radar shadows, data sets flown in opposite directions also can be combined.

Before deriving information from the SAR data, the positional and height accuracy must be verified. This was made with a data set from a well-known testsite near Solothurn, Switzerland, located on the border of the Swiss Jura mountains and the tertiary basin. The site contains different kinds of surface structures e.g. plains, hills, and open areas, as well as forests, rivers and build-up areas in a small space.

The positional accuracy was checked by superimposing the SAR amplitude image with a large scaling topographic map (1 : 10,000) (Fig. 2). The deviations between the map and the image are less than three meters. For validating the height acurracy of the InSAR-DEM it was compared with 24 trigonometric fixed points of the Federal Office of Topography Wabern, Switzerland. The average difference was 13.7 cm with standard deviation of 17.3 cm (Meier 1999). This accuracies allow the production of topographic maps in scales ranging from 1 : 10,000 to 1 : 50,000 and smaller. The highest resolution is occasionally necessary for map derivation. For small scaled maps a lower resolution is sufficient, which leads to a faster processing and a cheaper production.

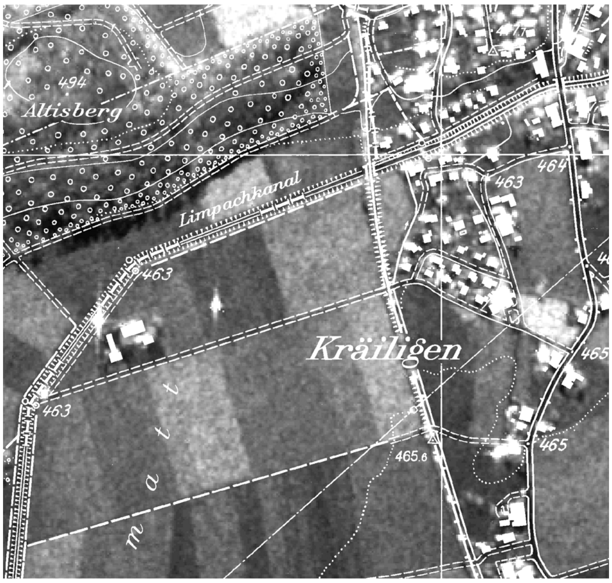

Figure 2: Terrain-geocoded SAR scene of an area near Solothurn with superimposed topographic map (scale 1 : 10,000)
(© Vermessungsamt d. Kantons Bern, Switzerland)

4 MAP GENERATION

For the map production as described in this paper, two information extraction methods are applied: visual interpretation and a supervised classification.

To accerelate and simplify map production the first step after basic data preparation is to investigate the maximum number of distinguishable classes. This was realized by programming a classification software optimized for the high resolution SAR data. The used input data for the software are fully geocoded SAR images and DEMs. Typical classes of interest in topographic mapping are water, forest, build-up and open areas. After the user had choosen training examples inside the graphical user interface (GUI) for the classes of interest an artificial neutral network (ANN) classifier is designed. The used ANN classifier is the well-known Multilayer Perceptrom (MLP) (Rumelhart *et al.* 1986). An interactive component allows inspection of intermediate results and enables feedback to training set selection and classifier learning, thus an online learning capability is established (Fig. 3). The borders of the classes of the improved final results are vectorized, stored in individual layers and outputted in DXF format. This vector data can be integrated e.g. in a DTP program or cartographic information system (CIS) and combined with the data achieved by manual screen digitizing.

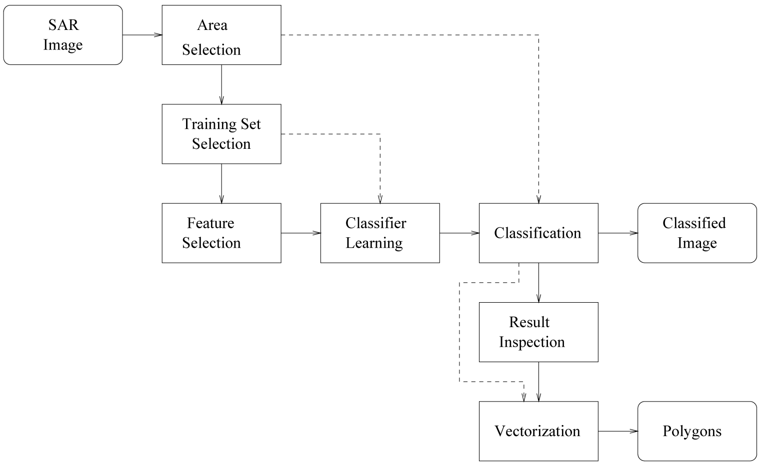

Figure 3: Block diagram of the ANN classifier

In a further step of the InSAR processing chain the third dimension of the terrain, represented by contour lines and hill-shading, must be produced and embedded into the map. To automatize the extraction of the contour lines from the existing geocoded InSAR DEM (see chapter 3), a software system was developed by Schmieder and Huber (2000). Due to the fact, that microwaves with short wavelength' (e.g. X-band) cannot penetrate into buildings and dense vegetation like forests, the contour lines represent only the surface of that areas which lead to an error in height. With complex algorithms its possible to extract that areas and correct the DEM there (Huber/Schmieder 1997). The output product is labelled, generalized employing the Douglas-Peuker algorithm and finally converted to contour-lines in DXF format. The 3-dimensional nature of the terrain can be visualized by simple hill-shading, which was rendered automatically from the same DEM.

Visual SAR image interpretation needs lots of experience and knowledge about the SAR imaging principles and geometry, because they obey other regularities than optical sensors. Before each interpretation an interpretation key has to be elaborated and controlled. In this key all the derivable objects in the data are described. Also in times where analysis of remote sensing images by digital methods increases, the visual information extraction using human interpretation ability is still significant. Till this day the visual image interpretation is the most accurate method of information extraction. On the other hand the method is very cost expensive and time-consuming. For this investigation classification was mainly applied for forests, open areas and large rivers and lakes. Objects like build-up areas, road networks, single buildings and other cartographic signatures had to be interpreted and digitized by the operator. In some cases it is difficult to distinguish small rivers from roads. Therefore the information provided by contour-lines are very helpful and instructive. After extracting the interpreted map objects by screen digitizing in a simplified vector graphic (Fig. 5.2), the layout graphic is transformed into the final map graphic (Fig. 5.3).

All the additional information, not extractable from remote sensing data but important for understanding maps, like map scripting must be taken from other sources e.g. Internet, other maps, or on site. Figure 4.1 to 4.3 show the steps from the SAR data to be interpreted, the three classified classes and the final map completed with visually interpreted objects. The generated data are combined in a professional WYSIWYG graphic software and prepared for printing.

5 MAP SAMPLES

After processing the InSAR data, described in chapter 3, the following map extracts were generated by visual image interpretation (Fig. 5) or by a combination of classification and visual interpretation (Fig. 4).

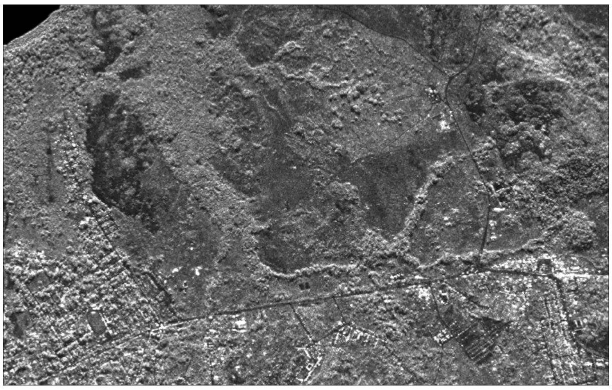

Figure 4.1: Geocoded SAR ortho image, 4.0 km by 2.5 km, scale 1: 50,000

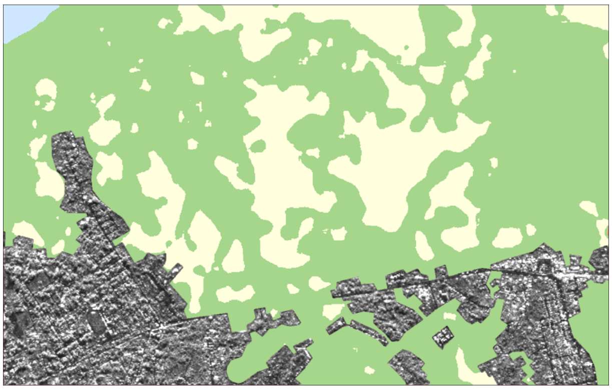

Figure 4.2: Classification result: Forest...green (medium grey), open area...yellow (light grey) and water...blue (upper left corner)

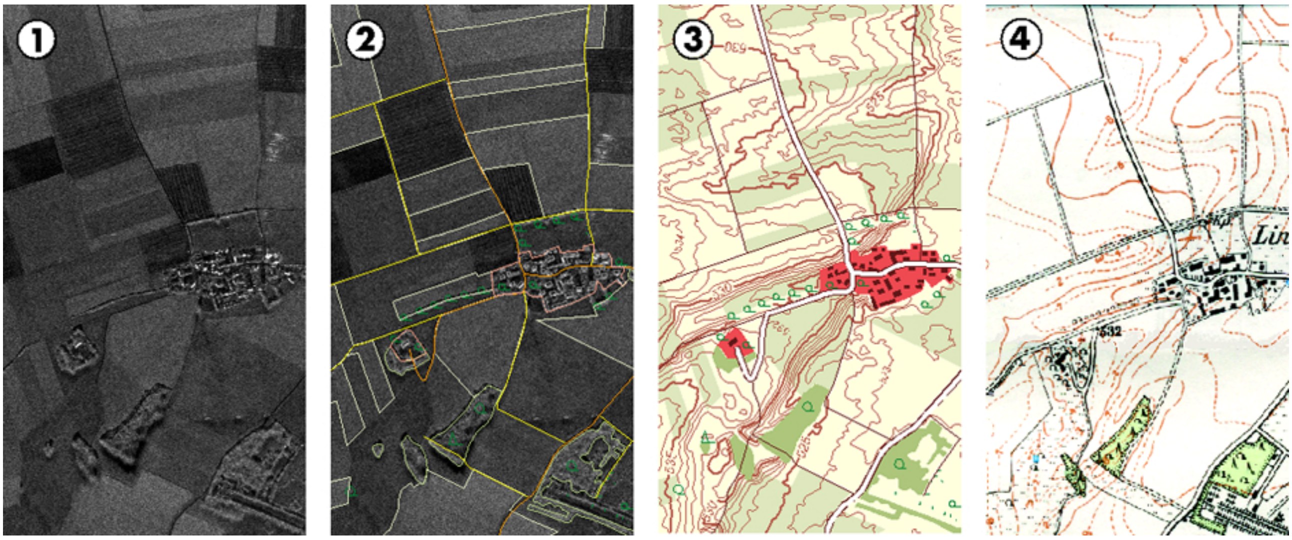

Figure 5: Derivation of a topographic map 1 : 25,000 by visual image interpretation:
(1) AeS-1 X-band ortho image, (2) digitized map layout, (3) topographic map in final map design,
(4) official topographic map for comparison (© Bayerisches Landesvermessungsamt München, Germany)

6 CONCLUSIONS

In this paper an operational approach using high-resolution InSAR data for the production of topographic maps was presented. These type of maps can be produced for countries where only old maps or maps in a small scale are available. Future investigations tend to integrate the derived data into a Cartographic and/or Geographic Information System (CIS/GIS) or using the data for updating of existing databases (Keim 1997). The accuracy of the contour lines in forested areas could be improved by using a SAR-sensor employing longer wavelength (e.g. P-band) (Hofmann *et al.* 1999). The classification results can be improved by assisting the classifier with the information of SAR coherence. To summarize, the shown method supplies maps with a high amount of cartographic and topographic information, produced on a high level of automation and in a cost-efficient way.

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