MAPPING BY AIRBORNE SYNTHETIC APERTURE RADAR (SAR)

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ABSTRACT

Using advanced SAR data from the Danish airborne SAR, EMISAR, a research project was initiated in 1998 as a collaboration between the Technical University of Denmark and the Danish National Survey and Cadastre to investigate the potential of using SAR data for production and updating of cartographic maps. The ultimate objective of the research is to be able to perform quickly and efficiently compiling and updating of topographic maps using satellite and airborne remote sensing data. The specific objectives for the project are to evaluate the potential of the polarimetric and interferometric SAR to detect the necessary object classes to be used for the thematic map content, and to assess the complementary information gained relative to the results of the traditional methods, and to evaluate the accuracy of methods for retrieval of the necessary map information from SAR data. In the project methods have been developed and studied for extraction of relevant information from the polarimetric and interferometric SAR data about objects like roads, buildings, lakes, fields, forests, etc. A number of feature extraction and land-use classification methods have been implemented and analyzed. Also, the very important issue to use the SAR for change detection as a means of fast, frequent and cost-efficient updating of existing map information has been studied.

1 INTRODUCTION

Topographic maps containing both thematic information about objects (e.g. forests, agricultural areas, lakes, heath, roads, and buildings), and elevation information for the land surface are used in numerous applications, both for registration and planning purposes in municipalities, counties, government agencies, economic forecasters, and private civil engineering companies, and for science applications, such as plant and animal ecology, mapping of wetlands, hydrologic modeling, and general circulation modeling. The traditional cartography using traditional surveying and aerial photogrammetry normally produces detailed maps with a relative long time interval between updating, i.e. up to 5 to 6 years. The different users have different requirements for the map content, but especially with the increasing utilization of Geographic Information Systems (GIS) a more frequent updating process for the maps is of key importance for many users.

The availability of high-resolution Earth observation data from spaceborne and airborne sensors both today and in the future has focused the attention on the role that such sensors could play in speeding up and making more efficient the process of compiling and revising topographic maps. Only sparse experience has been gathered using spaceborne SARs (Synthetic Aperture Radars), such as those on ERS-1/2, and Radarsat, and using airborne SAR systems, such as the Danish EMISAR. Plans are emerging both in Europe and in US for high-resolution spaceborne SARs using the small satellite concept (e.g. the NASA LightSAR mission) as well as high-resolution optical satellites. The advantages of the SAR sensors are their all-weather mapping capabilities (since in particular longer radar waves are not affected by cloud covers), their lower sensitivity to atmospheric correction compared to optical sensors, and the fact that they provide complementary information to optical data.

In the present paper, results from a research project using data from the advanced Danish airborne SAR system, EMISAR, will be presented. The project is collaboration between the Technical University of Denmark and the Danish National Survey and Cadastre with the purpose of studying the potential of using SAR data for production and updating of cartographic maps. Methods for extraction of relevant map information from SAR images have been studied and developed, and below results are discussed for methods related to land use classification, feature extraction and change detection.

2 DATA SET

SAR data from the EMISAR system are used in the project. The Danish airborne EMISAR system is developed at the Department of Electromagnetic Systems (EMI) at the Technical University of Denmark. The EMISAR system is a fully polarimetric and interferometric SAR (Christensen et al., 1998). It operates at two frequencies, C-band (5.3˚GHz/5.7˚cm wavelength) and L-band (1.25˚GHz/24˚cm wavelength). The SAR system is flown on a Royal Danish Air Force Gulfstream G-3 aircraft. The SAR system is normally operated from an altitude of approximately 12.500˚m, the spatial resolution is 2˚m by 2˚m, the ground range swath is approximately 12˚km and typical incidence angles range from 35 to 60 degrees. The processed data from this system are fully calibrated using an advanced internal calibration system. In a new research project at EMI a prototype of a new system with a much better spatial resolution is being developed.

The polarimetric SAR measures the backscattered signal for different combinations of 1) the polarization of the wave transmitted from the radar antenna, and 2) the polarization of the receiving antenna. If the transmitted signal is horizontally polarized and the receiving antenna also is horizontally polarized, the resulting signal is called HH (H for horizontal). Accordingly, the VV signal corresponds to a vertically polarized transmitted signal and a vertically polarized receiving antenna. If the transmitting and receiving antennas have different polarizations (i.e. H and V, or V and H, respectively) the resulting signal is said to be cross-polarized, i.e. VH or HV, respectively. The backscattering coefficient depends on the radar parameters such as frequency, polarization, and incidence angle, and on different characteristics of the target, such as the geometrical structure and the dielectric properties. The backscattering coefficient for a bare surface depends on the roughness of the surface, i.e. a smooth surface will not backscatter any signal toward the radar, whereas a rough surface will scatter the transmitted radar signal in all directions, and part of that will be backscattered toward the radar. Consequently, a smooth surface (e.g. a lake in calm wind conditions) will appear dark in the SAR image, whereas a rough surface (e.g. a newly ploughed bare field) will appear bright in the image. The dielectric properties depend on the composition of the material and the moisture of the target, e.g. a ploughed field will appear brighter if the soil moisture is larger. The radar s sensitivity to these properties depends, for instance, on the radar wavelength and the polarization of the radar signal. The latter fact is utilized in the polarimetric SAR, and the possibility of discrimination between different targets on the ground is improved significantly, when such data are available.

Polarimetric and interferometric SAR data have been acquired by the EMISAR from 1994 to today for a large number of scientific applications, such as agricultural crop monitoring, hydrology, monitoring of natural vegetation, studying of glacier dynamics, dune dynamics, and sea ice monitoring. In connection with the present project, also urban areas have been covered by EMISAR. Aerial photographs are available for an urban as well as a rural area, together with appropriate *in situ* observations. In addition, topographic maps are available in digital form for the two areas. The complete data set including multitemporal, multifrequency, polarimetric SAR data and aerial photographs for two years has been geometrically corrected to the same map projection.

3 THEMATIC INFORMATION

Dependent on the size and shape of the objects different categories of methods may be used for the thematic information extraction. Features like roads, buildings, pylons, rivers, etc. may be enhanced and detected using e.g. filtering, edge detection, line detection, and point detection methods adapted to the special speckle statistics of SAR images and utilizing the multi-frequency, multi-polarization, multi-temporal polarimetric and interferometric SAR information. Using the same range of SAR information, methods for detection of classes like forests, lakes, wetlands, heath, agricultural areas and urban areas may be applied. In this case, available methods may include traditional classification schemes, knowledge-based classifiers, classification based on polarimetric decomposition, interferometric correlation, etc. Some methods and results have been reported but further development is strongly needed including investigation of the sensitivity to e.g. acquisition time, radar parameters, spatial resolution and environmental conditions. In addition, the potential of combining SAR images which are acquired at different radar frequencies, at multiple polarizations, and at different times, as well as of combining polarimetric and interferometric data has to be investigated further. A very important issue is to study SAR s change detection potential to assist fast, frequent, and cost-effective updating of existing map information. Another important aspect is to study the possibility to separate between relevant change detection, e.g. a new building, and irrelevant change detection, e.g. from varying environmental conditions.

Below, results of the extraction of thematic information from SAR data are described. In view of the available processing techniques, we define three different approaches for information extraction; namely classification and

characterization of area objects (e.g. agricultural fields and forests), feature detection (e.g. roads and buildings), and change detection.

3.1 Area objects

The discrimination between different object types and identification of the individual objects are of decisive importance for production of topographic maps. Different SAR images may be combined for the same area to obtain the optimum data set for discrimination and identification of objects. Polarimetric SAR images are, as mentioned above, sensitive to the geometric structure and dielectric properties of an object. SAR images acquired at different wavelengths will improve the possibility of discrimination between objects, because the SAR images are sensitive to shape and orientation of geometrical structures at the same size as the wavelength. Consequently, a SAR with different wavelengths will be sensitive to different geometrical structures. The radar waves penetrate to a certain extent into, for instance, the vegetation. The penetration depth depends on the wavelength, where a longer wavelength penetrates deeper into the vegetation. Furthermore, SAR images acquired at different times during the year may be combined. This is especially an advantage when discrimination between different types of vegetation is important, because the geometrical structure of the vegetation will change through the year (for instance, agricultural crops through the growing season) and hence the polarimetric response will change (Skriver et al., 1999a).

Classification of agricultural crops is possible using SAR data, and polarimetric and/or multitemporal acquisitions ensure a high accuracy (Skriver et al., 1999b). In Fig. 1 are shown classification results for agricultural crops for different combinations of polarimetric SAR data. The SAR data available are L- and C-band data acquired in both May (early in the growing season) and in July (in the middle of the growing season). Using the full polarimetric information in the classification, Fig. 1(a) shows that combinations of both frequencies and/or combinations of multitemporal data improve the classification accuracy. Furthermore, it is clearly seen from Fig. 1(b) that the use of full polarimetric information compared to single (VV) or dual polarization (VV+HH) strongly improves the classification accuracy. The classification errors shown in Fig. 1 are obtained using a large number of test areas for the individual crop types, making these error estimates realistic.

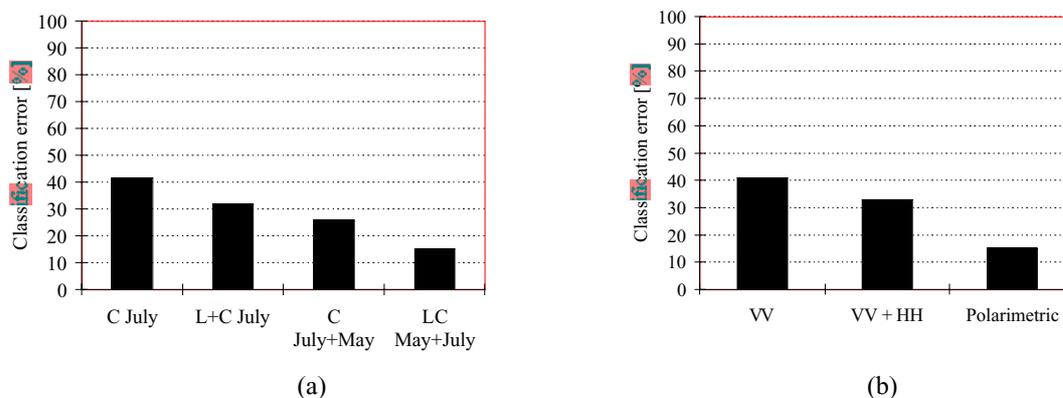(a)   (b)

Fig 1. Classification error for agricultural crops for different combinations of EMISAR polarimetric SAR data. (a) Full polarimetric classification with different combinations of multitemporal and dual-frequency combinations. (b) Classification using combined L- and C-band in May and July for single, dual, and full polarimetric data.

In general, it is possible to discriminate between forest and non-forest areas with a high accuracy. Reasonable results are normally obtained for discrimination between the different forest types. In Fig. 2 are shown the results of the above-mentioned classification using full polarimetric information from L- and C-band acquisitions in May and July for forest and hedge areas with all other classes shown with the same color except the lake area. It is clearly seen from the comparison with the aerial photographs shown in Fig. 2, that the SAR has a great potential in identifying and classification of forest and hedge areas, which is of paramount importance in the monitoring of natural vegetation. The backscattering from water surfaces is normally very low, because these surfaces are rather smooth, except in very windy condition, where the water surfaces become relatively rough. The SAR will probably also be able to detect and identify some of the protected natural vegetation types. In this case, the spatial resolution of the SAR could be a limiting factor, because these areas are relatively small and heterogeneous.

Fig. 2. Aerial photograph and a classified SAR result, showing forest and hedges as black, lake as grey and everything else as white.

3.2   Features

The utilization of SAR images for mapping of urban areas is relatively difficult due to the very complicated scattering mechanisms for the radar signal in these areas, which consist of a mixture of man-made structures and vegetation. When mapping urban areas, the spatial resolution and the look direction are two very important parameters. The spatial resolution of some SAR systems might prove an obstacle for detailed mapping of man-made features; this problem, however, is met with the current and planned high resolution airborne SAR systems having sub-meter resolution. The look direction describes the viewing angle used when mapping the area, and this parameter is important for two reasons: 1) The scattering mechanisms for man-made features, e.g. buildings, are highly dependent on the look direction. If a building is oriented in parallel with the azimuth direction, double-bounce scattering occurs as the walls together with the ground surface act as a dihedral reflector for the incident radar signal. 2) Tall objects obstruct the radar signal, effectively shadowing the areas behind them. This effect results in dark areas behind the objects, making it difficult to infer information for these areas.

To evaluate the possibilities of mapping urban areas, a number of EMISAR acquisitions have been acquired from an urban area. They cover a number of different aspect angles, dual frequencies, and polarimetric as well as interferometric acquisitions. From the interferometric data a number of digital elevation models (DEM) are generated, which are subsequently used for geometric correction as described in the next section. The DEMs will also be used for inferring information about the thematic objects; especially the detection of pylons and buildings is expected to benefit from this investigation.

Fig. 3 shows an aerial photograph, and the corresponding L-band EMISAR image, from an urban area, and it is observed, that some of the features appear very distinct in the two images. The scattering mechanisms for the roads are similar to calm water, hence they appear dark in the SAR images; buildings, on the other hand, appear bright due to high backscattering, and when the previously mentioned double-bounce effect occur, they will have a dominant HH term, making them green in the images. The speckle noise mentioned previously is primarily observed in the forest areas, as these are the dominant extended targets in the scene. When working with SAR images, the speckle often makes the extraction of information more difficult than for normal aerial photographs, and speckle reduction has received much attention for the last decade. As part of this work, a speckle reduction algorithm capable of working on multi-frequency and/or multi-temporal polarimetric SAR data has been developed, and the result is shown in Fig. 4. The filtered data have clearly reduced speckle for the extended targets, while almost all the features, e.g. roads and buildings, are preserved. Also seen in Fig. 4 is the result of a road detection algorithm. This is an example of an algorithm, where we have defined a set of characteristics for the feature of interest, and then utilizes this information in the algorithm; in the case of roads, they are thin, dark linear features in SAR images, and we use this for growing the roads from a number of starting points using active contours. At present the starting points are provided manually (10 points for the result shown in Fig. 4), but this will be automated as well. Also, the result is expected to improve when using images acquired with different aspect angles.
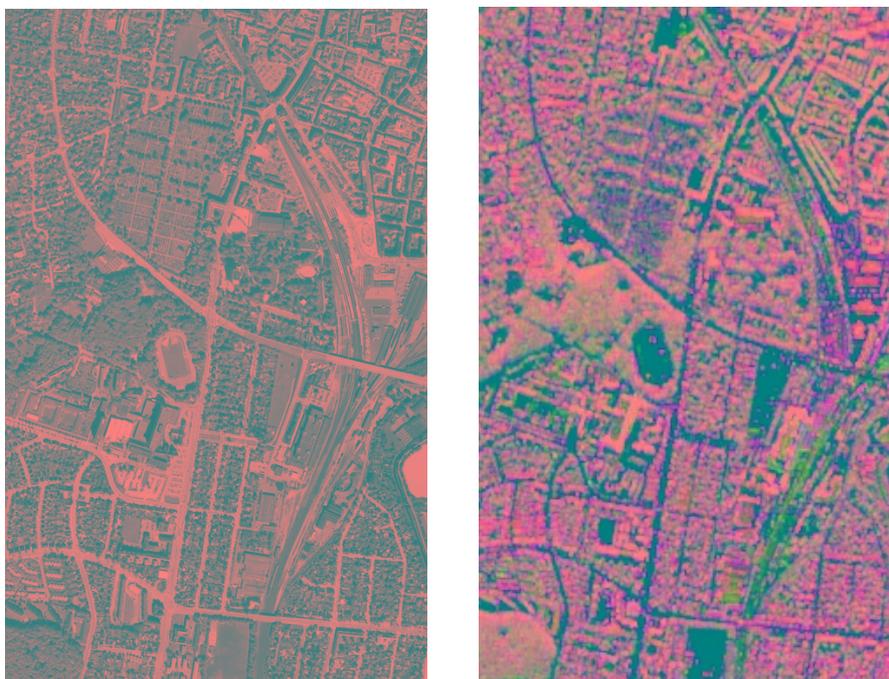
Fig. 3. Aerial photograph from an urban area and a L-band polarimetric EMISAR image (2x1.2 km)
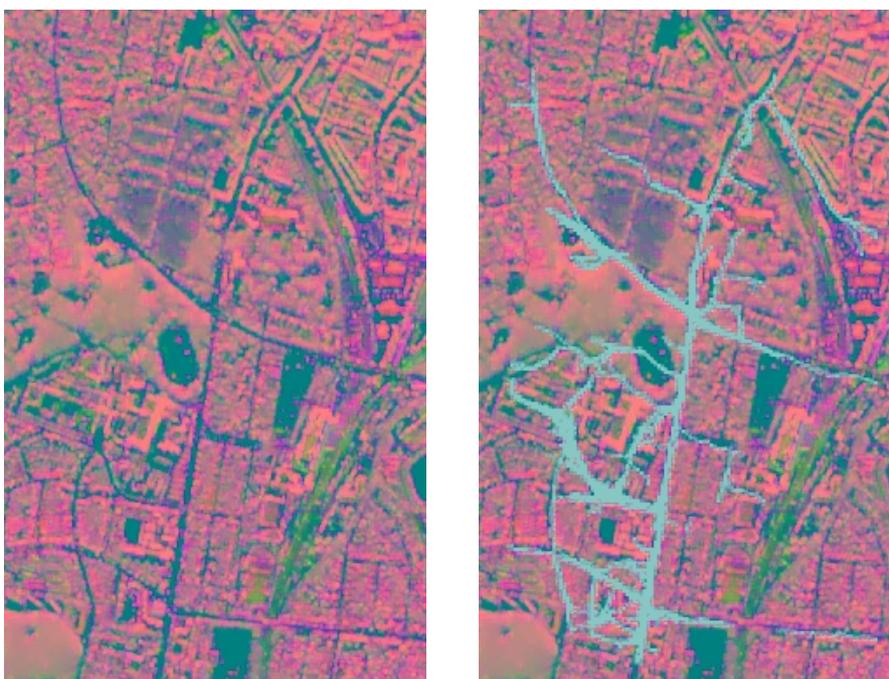((Red, Green, Blue)=(HV, HH, VV))

Fig. 4. Speckle reduced EMISAR image, and road detection result using 10 seed points.

3.3   Change detection

During the last decade, the use of SAR images in change detection has been discussed and demonstrated in the literature now and then. The emphasis, however, was more on testing different processing techniques rather than on detailed analysis of the detected changes. It was found that the intensity ratio between two SAR images is better suited for change detection than the intensity difference (Rignot and van Zyl, 1993). Another important issue is speckle

reduction, e.g. by filtering the logarithmic-scaled ratio of SAR images (Dekker, 1998) or by means of wavelet techniques (Bao, 1999). A third important topic is the accuracy of image registration (White, 1991).

In the framework of our project, we have put a major effort on a more detailed analysis of the detected changes themselves. An important question asks How large are observable intensity changes in the radar images due to slightly different flight paths (the ideal situation for change detection are identical flight paths) and processing artifacts (e.g., slight displacements of single targets), but in particular due to natural and man-made changes within the imaged scenes? Investigations of this kind are aimed at developing a strategy to distinguish the changes we are interested in (e.g., man made changes in and close to urban areas) from the overall intensity variations. In view of the small size of many of the objects, which have to be considered in upgrading topographic maps, this is a demanding task.

For our investigations, we prepared a multitemporal polarimetric radar data set, which was acquired over n rural area in 1998. The data set consists of seven C- and seven L-band images. The images have an effective spatial resolution of about 7-8˚m. These images have been filtered during the operational processing of the raw SAR data in order to reduce speckle noise. A geometrical correction, which takes into account the actual elevation changes of the mapped area, is essential if the radar images are to be compared directly with aerial photography or topographic maps. The geometric correction is carried out by using a digital elevation model (DEM) in order to reconstruct the actual position of a target in the image. To this end, a program package was developed which utilizes a DEM generated by means of airborne across track interferometry. Since the original images are given in a special mapping coordinate system related to the interferometric flight track, the program package includes the possibility of coordinate transformations, e.g. to the UTM grid. The achieved registration accuracy between two polarimetric images is better than one pixel (5 m).

Different object classes were selected for more detailed analysis. Buildings, which in most cases comprise only a few pixels in the radar image, are treated as point targets. Typical line features in the rural area are hedgerows, which can be easily detected in the radar images (as seen from the classification in Fig. 2), and roads, which often are much more difficult to identify. As examples of area targets, we chose forests and, within a village, the area not covered by houses and buildings (village background). Several objects within each class were identified and marked in the radar images by means of aerial photography. In ongoing work, the typical backscattering characteristics and variations of the different object classes are analyzed and compared to backscatter changes due to removal, adding, or change of an object at a certain position.

4 CONCLUSIONS

The application of SAR for extraction of thematic information and height information for topographic maps is a topic of ongoing research. The technique has great potential both due to the independence of the radar signal of weather conditions and daylight, and to the well-defined and stable measurement characteristics, which will enable the utilization of automatic or semiautomatic methods for information extraction. Consequently, a more frequent updating of maps will be possible. Since the radar sensors cover a range of the electromagnetic spectrum, which until now has not much been utilized, additional information (relative to the traditional optical sensors) can be, gained which might be useful in the production of topographic maps.

5 REFERENCES

Bao, M., 1999. Backscattering Change Detection in SAR Images Using Wavelet Techniques, IEEE International Geoscience and Remote Sensing Symposium, Hamburg, pp. 1561-1563.

Christensen, E.L., Skou, N., Dall J., Woelders, K.W., Netterstr¿m, A., J¿rgensen, J.H., Granholm, J., Madsen, S.N., 1998. EMISAR: Polarimetric L- and C-band SAR, IEEE Transactions on Geoscience and Remote Sensing, 36(6), pp. 1852-1865.

Dekker, R. J., 1998. Speckle Filtering in Satellite SAR Change Detection Imagery, International Journal of Remote Sensing, 19(6), pp. 1133-1146.

Rignot, E. J., and J. van Zyl, 1993. Change Detection Techniques for ERS-1 SAR Data, IEEE Transactions on Geoscience and Remote Sensing, 31(4), pp. 896-906.

Skriver, H., Svendsen, M. T., and Thomsen, A. G., 1999a. Multitemporal C- and L-Band Polarimetric Signatures of Crops, IEEE Transactions on Geoscience and Remote Sensing, 37(5), pp. 2413-2429.

Skriver, H., Svendsen, M. T., Nielsen, F., and Thomsen, A. G., 1999b. Crop Classification by Polarimetric SAR, IEEE International Geoscience and Remote Sensing Symposium, Hamburg, vol. 4, pp. 2333-2335.

White, R. G., 1991. Change Detection in SAR Imagery, International Journal of Remote Sensing, 12(2), pp. 339-360.