Chapter 1

Introduction and Motivation

1.1 General Framework and Motivation

Synthetic Aperture Radar (SAR) image products are very important and useful for remote sensing applications because they can be acquired independent of time of day or weather conditions and because their characteristics (wavelength, polarisation, observation angle) can be chosen in function of the phenomenon under investigation.

The first satellite-based SAR systems used for remote sensing were single-band mono-polarisation systems with a spatial resolutions of a few tens of metres (e.g. 25m for ERS1, 30m for Radarsat). In future satellite systems, the spatial resolution will be improved to a few metres and the systems will be capable to acquire polarimetric (and/or multi-frequency) data. Current airborne SAR systems are already capable to acquire polarimetric SAR images with a metric resolution.

Scene interpretation results can be greatly enhanced by combining different SAR images [1] e.g. multi-polarisation, multi-frequency and multi-temporal. In order to do this, an accurate co-registration of the different images is needed.

The topic of this thesis is to investigate new and improved automatic image interpretation tools for high-resolution (metric resolution) polarimetric images and to find a method for automatic registration of these images with each other, with other types of images or with a map.

The basis of any image interpretation system consists of low-level image processing methods such as methods for edge detection and detection of uniform regions.

Current edge detectors were designed to work on low-resolution, single-band, multi-look SAR images. The most widely used edge detector for such SAR images is the ratio-detector, proposed simultaneously by the research teams of Touzi [2] and Bovik [3]. The ratio-detector is based on the speckle distribution in uniform regions in single-band multi-look intensity images.

While it is possible to find an analytical expression for the speckle distribution in multi-look single-band intensity images, it is not possible to find a similar expression for multi-band, and in particular polarimetric intensity images. Yet it is possible to apply the ratio-detector to polarimetric data by applying it to each polarisation separately and then fusing the results. Unfortunately such an approach does not take into account the polarimetric covariance matrix, and therefore does not use the full polarimetric information.

An alternative is to use multi-variate statistical methods which do take the polarimetric covariance matrix into account. Especially when high-resolution images are available it is possible to use well-established multi-variate statistical methods for detecting edges. This was the first path that was explored in this thesis. Two new edge detectors were developed for single-look high-resolution polarimetric SAR images. Both are based on multi-variate hypothesis tests. One is applicable to the complex image, the other one to the log-intensity image. Such a multi-variate approach has several advantages:

- all polarisations are used as a single multi-dimensional data set and there is no need for a posteriori fusion of the results obtained for the different polarisations
- the methods use the polarimetric covariance matrix and therefore take into account the full polarimetric information
- the methods can be easily used on any type of multi-band SAR image. This means that it is possible to use the same methods for multi-frequency or multi-temporal datasets.

An alternative to using multivariate methods is to use uni-variate methods and fuse their results. This approach was also investigated and results were compared with the results of the multi-variate approach. During the development of the edge detectors it became clear that the spatial correlation of the speckle has an important influence on the behaviour of the detectors. The spatial correlation is partly due to the impulse response of the SAR system and partly to texture features of the terrain. Its effect on the various detectors was studied.

For the segmentation of uniform regions we investigated the possibility to expand a uni-variate method called “Merge using Moments” to the multi-variate case.

As already mentioned, in order to be able to combine the information from different types of images, it is necessary to register them. This is why a second part of the thesis investigated a way to register high-resolution polarimetric SAR images.

The basic idea for the registration is to use vectorised topographic maps as a help in the registration process. Defining and detecting some major objects on the different images and matching them to the same objects extracted from a map provides a first registration. This registration is then refined by using common features extracted from the different images. The vectorisation of maps is beyond the scope of this work. Maps are supposed to be available under digitised form. The type of objects, available on a map, of which we thought they would be easily detectable on a polarimetric SAR image are forests and built-up areas. We will see that such objects are useful for obtaining a first registration but, because of their 3D structure and the special image acquisition geometry of the SAR images, they can not lead to an accurate registration. The obtained registration needs to be refined using objects with a low 3D structure. For registration of a map with a SAR image, roads, rivers and railways (i.e. communication lines) are good candidates. For registering different SAR images, or for registering a SAR image with other types of images (visual or infrared image) edges corresponding to borders of agricultural fields are also good candidates.

For the registration we thus also need to detect forests and built-up areas. The first idea was to use a polarimetric decomposition method to classify the pixels in the image as belonging to fields, forests and built-up areas. Several decomposition methods were tried. Two of these methods were unable to distinguish forests from build-up areas. They are just able to distinguish the combined set forests/buildings from other parts of the image. A third decomposition method allows to detect the double-bounce reflections from the walls of large buildings facing the radar and the shadows on the other side of the buildings. In villages they again lead to a confusion between forests and built-up areas.

This is why we also developed a new detector that specifically focuses on finding built-up areas. Combining its results with the results of the decomposition methods allows to detect the forests and built-up areas needed for registration.

1.2 Structure of this Thesis

Having read the text above, it is probably clear to the reader that it is necessary to explain some aspects of SAR processing and SAR images before explaining the actual image processing that was developed during this thesis. Therefore in the first part of this thesis some characteristics of SAR images are described. Chapter 2 briefly describes some of the principles of SAR image formation. In chapter 3 some aspects of polarimetry are explained while chapter 4 describes statistical properties of SAR images that are important for the development of the different image processing methods.

The second part of this thesis describes the image interpretation tools that were developed. The subject of chapter 5 is edge detection in high-resolution polarimetric SAR images. The developed edge detectors are based on hypotheses tests.

Two methods based on uni-variate statistical tests are proposed for single-polarisation SAR images and two new edge detection methods, based on multi-variate tests are presented for detection of edges in multi-channel images. The main purpose of the developed edge detectors is to find edges between large areas that are likely to be found on topographic maps or other images. In this chapter the influence of spatial correlation on the different detectors was studied. Furthermore a strategy for fusing the results of the edge detectors was developed.

In chapter 6 the segmentation and classification of large regions is presented. For the segmentation we did not use the results of the edge detection but rather developed a method based on region-growing. It is a multi-variate form of a method called "Merge Using Moments".

The classification of the SAR image is applied in the frame of the registration with maps. We are therefore not directly interested in determining the type of crops in individual fields but rather in distinguishing forests from fields and villages. For the classification the use of existing decomposition methods for the specified task was investigated. It appeared that the decomposition methods do not allow to distinguish forests from built-up areas.

This is why in chapter 7 a new supervised approach, based on a the combination of various statistical and polarimetric features, was developed for specifically detecting built-up areas. Although the combination is supervised -logistic regression is used - the features are chosen in such a way that their combination is likely to detect built-up areas in polarimetric SAR images with other incidence angles or frequencies.

In chapter 8 the registration between the SAR image and a corresponding map and other images is presented.

A hierarchical approach was developed starting with a rough registration using the location of built-up areas and forests. For this first registration a voting method is used, thus avoiding prior matching of corresponding objects and increasing robustness against incomplete or contradictory information. The registration is then improved by successively taking into account other information such as the contours of forests and the position of communication lines. Once each image has been registered with the map, the results of the edge detectors are used to refine the registration between the different images.

All developed methods were tested on a set of high-resolution (resolution around 1m) polarimetric L-Band E-SAR images of the Oberpfaffenhofen area near Munich.

Reviewers of early versions of the current text indicated that it was sometimes difficult to follow the bottom line because that bottom line was cluttered by side aspects. Although the text was completely revised in an attempt to take these remarks into account, I also added some features, that may seem peculiar, aiming to further improve readability. In particular at the end of most of the chapters there is a section called "Lessons Learned". Its aim is to recall the most important results of the chapter very briefly and to explain in what sense they are relevant to the remainder of the text. Furthermore some parts of the text are boxed-in and headed "Intermezzo". It is not necessary to read them in order to be able to follow the main text. They just mention some side-aspect of the research, which the interested reader is wellcome to read.

1.3 Original Contributions of this Thesis

The original contributions are listed below:

- the application of multi-variate statistical hypothesis tests to the problem of edge detection in high-resolution polarimetric SAR images
- the systematic study of the influence of spatial correlation on the various developed edge detectors
- the development of a strategy to fuse the results of the edge detectors and in particular the method proposed to fuse the results of the two multi-variate edge detectors
- the introduction of a multi-variate test into the "merge using moments" method for region-based image segmentation and the introduction of an adaptive threshold into the method
- the method developed for the detection of built-up areas
- the proposed hierarchical image registration method based on topographic maps
- the adaptations made to the feature consensus method for image registration

Note:
Many of the figures in this thesis are in color. If you have a copy of the text printed in B/W, some features may not be clearly visible. If you need a color version of any of the pages for your work, feel free to contact me by E-mail (Dirk.Borghys@elec.rma.ac.be).