Chapter 9

Conclusions and Perspectives

9.1 Conclusions

The objective of the work presented in this thesis is to contribute to the automatic interpretation and registration of high-resolution polarimetric SAR images.

9.1.1 Low-Level Image Interpretation

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 (region-based image segmentation). These were the first two topics that were investigated in this thesis.

Most of the effort was spend on the development of new and improved methods for edge detection in the specific case of high-resolution polarimetric SAR images. It was seen that for this type of images it is possible to develop edge detectors based on well-established multi-variate statistical hypothesis tests. Two such edge detectors were developed. The first detector is based on a multi-variate test for the difference in variance and can be applied to complex images, the second detector uses a test for the difference of means and is applied to the log-intensity images. The multi-variate methods treat the three polarisations as a single data set. An alternative is to use uni-variate methods, applied on each separate polarisation, and to fuse their results. This approach was also investigated and the results compared to the multi-variate approach. The multi-variate approach has shown to give better results. This is due to the fact that the multi-variate detectors use the polarimetric covariance matrix thus taking into account the full polarimetric information.

Furthermore the two multi-variate detectors provided complementary results. Fusing these results is thus appropriate. In a first attempt the results of the two detectors were fused for values of the threshold corresponding to the same probability of false alarms. Results were very mediocre irrespective of the used fusion method. A new method based on statistical tests for the complementarity of two experts was developed to determine the range of optimal combinations of the thresholds for fusion of the two detectors. This range of optimal combinations was found to be a linear region in the 2D threshold space that does not correspond to the line of equal probability of false alarms. Combining the detector's results on the basis of this optimal fusion line considerably improved fusion results.

During the development of the edge detectors it became soon clear that the performance of the different detectors was influenced by the spatial correlation in the image. In fact all statistical hypothesis tests are based on the assumption of independent observations within a sample. Due to the spatial correlation this assumption is violated and, as a consequence, the measured behaviour of the various detectors differs from its theoretical prediction. In particular the probability of false alarms as a function of the detector's threshold does not correspond to the theoretical model. We theoretically modeled the influence of spatial correlation on the various statistical hypothesis tests used in the detectors. This was done by introducing a correction factor on the variance of means or the covariance of means used in the multi-variate tests. The correction factor is a function of the autocorrelation function of the SAR system. Introducing the correction factor into the detectors would thus cope with the problem. However we showed that a detector based on the correction factor can only be used in regions were the spatial correlation in the image is only due the autocorrelation function of the SAR system. In regions with even a slight texture, it is only possible to obtain a reliable (CFAR) edge detector by subsampling. The optimal subsampling method and ratio was determined for the different detectors.

A bar detector was derived from the developed edge detectors and applied for detecting communication lines (i.e. roads, railways and waterways).

For region segmentation an existing region-merging method, based on a uni-variate statistical hypothesis test for a difference of means, was applied to the multi-variate dataset (the polarimetric image) by transforming the uni-variate test into a multi-variate one. The threshold for merging was made adaptive to the size of the region.

9.1.2 High-Level Image Interpretation

For the image registration we needed to detect forests and built-up areas. The first idea was to use image classification methods based on polarimetric decomposition algorithms. Three decomposition methods were investigated. The decomposition method of Van Zyl and Freeman can not distinguish built-up areas from forests. With the Cloude decomposition it is possible to detect most of the forests although some parts of buildings are still classified as forest. If supplementary features such as the value of the backscattering coefficient (and the polarimetric coherence) are combined with the Cloude decomposition, it is possible to detect some double-bounce scatterers, shadow areas and roads as well. However, it is not possible to detect built-up areas directly. All three methods do detect some double-bounce reflections within villages but these are also found in some locations in the forests. It is thus not possible to delimit the built-up areas.

Therefore we also developed a specific detector for built-up areas. The developed method uses a feature-based approach. The different features are defined based on the radiometric and polarimetric characteristics of built-up areas in polarimetric SAR images. One of the features, the so-called "distance measure" expresses the fact that in built-up areas most uniform regions are small and surrounded by other uniform regions. This feature allows to eliminate false alarms due to edges in the image. The polarimetric information is used by means of the interchannel correlation coefficients in the log-intensity image. Due to the lack of reflection symmetry in built-up areas, the cross-polar correlation coefficients $\rho_{HH/HV}$ and $\rho_{VV/HV}$ are much higher in built-up areas than in fields and even in forests. The features are combined using logistic regression. The features are chosen such that they are likely to be applicable to other radar wavelengths. This still needs to be verified.

9.1.3 Image Registration

For solving the problem of registering SAR images, a hierarchical method based on maps was developed. The basic idea 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.

In a preliminary step the SAR image is converted to ground range and resampled to approximately square pixels.

A first registration between image and map is then obtained by means of a voting method (feature consensus method) that uses the positions of built-up areas and/or forests to find the parameters of a semi-affine transform. The method also matches the objects (forests and built-up areas) detected in the image with those given on the map. The matching seems to be robust but the quality of the corresponding transform is degraded when objects overlap the image.

Two methods for improving the resulting registration between the image and the map are proposed. The first uses the contours of forests. This method allows to improve the registration but it can not lead to a very accurate registration because the 3D structure of the forest does not allow their edges to be localised precisely in the SAR image. Furthermore, forest edges can change quickly in time and it can be dangerous to rely on them for registration.

The second refinement method therefore uses features that are more stable and which have a very limited 3D structure. Communication lines (mainly roads and railways) are used in this refinement step. The developed detector of communication lines only detects parts of the road network. In order to use this incomplete information the parameters of a global affine transform were determined using an optimisation method and solely relying on the minimisation of the perpendicular distance between the road segments found in the SAR image and the roads on the map.

The refinement method allows to overcome the inaccuracies resulting from the feature consensus method.

Once each image is registered with the map, the registration between the different images becomes easy. The registration between the images and the map is used to deduce a first registration between different images. The results of the edge detectors, applied on each image, are used to refine the registration.

9.2 Possible Improvements and Future Work

As in any other thesis, the solving of a problem leads to new unsolved problems and ideas. Since the time frame was limited not all ideas could be realised within the frame of this work. Some of the methods that were developed need still to be improved. On the other hand new research topics can be explored, partly based on the results that were presented here.

The results of the fusion of the two multi-variate edge detectors should be improved further. It was noted that after fusion some linear structures that were detected by the

Hotellings test based detector were lost. This could be avoided by introducing higher-level methods in the fusion. One could for instance detect linear features in the results of the Hotellings test and make sure they are kept after fusion, either based on a partial confirmation by the other detector or on their intrinsic quality (e.g. length).

Another way to improve the result of edge detection is to use an approach based on active contours to complete the edge structure and combine information provided by the edge detectors with information from the region-based segmentation [44, 46, 81].

If the approach based on active contours leads to a better region segmentation, the result can be used to apply the decomposition methods for classifying the detected regions in stead of running them in scanning windows.

For the fuzzy-rule based classification a method should be found to automatically determine the input membership functions from examples of landcovers.

For the image registration, until now only a global affine transform was used. The SAR images we received cover an area around an airfield, which is relatively flat. For such regions an affine transform is sufficient for registration. However, in regions with more relief, the proposed method is probably insufficient and local transformations need to be used. In the near future we will receive polarimetric SAR images of regions with large 3D structure and this topic will be investigated further.

In this thesis we have used results of image interpretation in order to register different images either with each other or with a map. An interesting topic for future work consists in doing the opposite: use the results of the registration to improve the results of image interpretation. Some possibilities are listed below:

- Use of information from a map to improve image interpretation:

  For example knowledge of the approximate location and orientation of a road can be used to improve its detection in an image.

- Fusion of multi-aspect SAR images:

  Combining SAR images acquired from different viewing directions (multi-aspect SAR images) allows to improve image interpretation results.

  Among others, objects with a 3D structure (buildings, forests) can be better localised and the combined set of registered images can be used as an input of the various multi-variate detectors to improve their results. This is currently being investigated.

  For the detection of large buildings it is probably possible to combine the results of the dark and bright bar detector with the decomposition methods to identify double bounce and shadow regions corresponding to a building. Combining this from different viewing directions should allow one to detect and accurately localise such buildings.