SEMI-AUTOMATED CLASSIFICATION OF URBAN AREAS BY MEANS OF HIGH RESOLUTION RADAR DATA

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ABSTRACT:

Almost two thirds of the world's population will live in cities by 2030. Thus, human settlements typify the most dynamic regions on earth. To cope with this development urban planning and management requires up-to-date information about the various processes taking place within the urbanised zones. As radar remote sensing allows for the collection of areal data under almost all weather and environmental conditions it is predestined for a frequent and near-term retrieval of geo-information.
In view of the future TerraSAR-X mission the German Remote Sensing Data Center (DFD) researches into the potential use of high resolution radar imagery. In this context our main objective is to develop concepts for a mostly automated detection and analysis of human settlements by means of high resolution SAR data. The studies are based on multi-frequency single-, dual- and quad-polarised SAR data recorded by the airborne Experimental Synthetic Aperture Radar (E-SAR) system of the German Aerospace Center (DLR). This paper presents first results of an object-oriented approach towards a semi-automated identification of built-up areas based on single-polarised E-SAR X-band imagery. The basic concept includes an optimised speckle suppression procedure in order to improve and stabilise subsequent image analysis as well as the development of an object-oriented classification scheme for an automated detection of built-up areas from high resolution X-band imagery.
The developed concept for a semi-automated extraction of urban areas from single polarised X-band data yields promising results. Built-up areas could be detected with an accuracy of 86%, 85% and 91% for three flight tracks. While the main body of the settlements could be identified with an accuracy of more than 90% inaccuracies were mainly associated with flanking parks, recreation areas and allotments.

1. INTRODUCTION

Numerous studies have focused on the utilisation of satellite imagery to analyse human settlements, monitor urban sprawl or map urban land use patterns and infrastructure. Most of these applications deal with an analysis of regional or local phenomena based on spectral characteristics or indices derived from high resolution optical satellite imagery (Ehrlich, Lavalle, Schillinger, 1999; Masek, Lindsay, Goward, 2000; Ridd, Liu, 1998). In the context of urban applications radar imagery has played a minor role since the strong dependence of radar reflectance on geometrical characteristics of the illuminated scene has hampered its interpretation significantly. In radar images the agglomeration of di- and trihedral corner reflectors in urban environments makes these regions standing out as clusters of more or less bright signal returns. This effect has been used for monitoring the urban footprint and subsequently estimating socio-economic characteristics (Haack, 1984; Henderson, Xia, 1998). In this regard polarised and/or multi-frequency radar data have proven to be particularly valuable. Radar imagery has also been used successfully in combination with optical data (Forster, Ticehurst, 1994; Weydahl, Becquey, Tollefsen, 1995).
The strong dependence of the signal return on the geometrical properties of the illuminated objects results in an ambiguity of its intensity signature with respect to its physical characteristics. This demands the use of alternative features for a distinct classification.
The applicability of textural information in urban applications has already been shown for optical and radar based imagery (Henderson, Xia, 1998; Kressler, Steinnocher, 2001; Ryherd, Woodcock, 1996). While most of these analyses were based on conventional pixel-based techniques recent studies have increasingly focused on object-oriented approaches (De Kok, Wever, Fockelmann, 2003; Kressler, Steinnocher, Kim, 2002; Hofman, 2001). These more sophisticated techniques provide possibilities to describe and utilise the geometric, textural and especially contextual properties of the real-world objects in the classification process.

With the perspective of the future TerraSAR-X satellite (Roth, 2003) this study aims at the development of a concept for the automated extraction of built-up areas based on high resolution, single polarised X-band imagery. The main emphasis is placed on both, the improvement of image pre-processing with respect to a subsequent object oriented image analysis and the development of a robust classification scheme for a mostly automated identification of human settlements. In the first part of this paper an overview on the methodological concept is given. Then preliminary results of the developed approach are shown. Finally an outlook on the further research is given.

2. METHODOLOGY

This section provides a description of the method to detect built-up areas on the basis of high resolution single-polarised X-band imagery automatically.

2.1 Basic Concept

The methodology consists of two main steps:

- the preparation of the initial data including speckle suppression and the generation of an additional texture layer
- the image segmentation and classification.

Subsequent to an initial speckle suppression by means of an optimised filtering technique a texture layer is generated. Along with the despeckled intensity image this texture layer is used for the segmentation of the data set. The classification itself is based on the despeckled intensity image and the original data. Both, the image segmentation and the classification are performed on the basis of the object-oriented image analysis software eCognition (Baatz & Schäpe, 1999).
This technique partitions the complete scene into groups of spectrally similar pixels by means of an image segmentation to form image objects on an arbitrary number of scale levels. The analysis of these objects instead of single pixels is particularly applicable for the classification of very high resolution imagery. It facilitates the distinction between different structures and their function by considering spectral, geometric and textural characteristics along with information about properties of the area surrounding the image objects. Moreover the object-oriented approach is capable of displaying different objects in a single image at various scales. With respect to radar imagery the initial segmentation also helps to reduce the effects of radar speckle because the intensity of the generated segments results from an averaging of the underlying pixel values.
Subsequent to image segmentation a “knowledge base” is created. This knowledge base defines both, the classes to be identified and the according features for their description and classification. The rules for the class description might include spectral and textural characteristics of the objects, the hierarchical context of the segments or the relationship between neighbouring objects. According to these predefined rules the image is analysed and classified by means of fuzzy logic or a nearest neighbour algorithm (Baatz & Schäpe, 1999). Each step performed during the image analysis can be stored in a separate protocol which might then be applied to other data automatically.

2.2 Test Site and Data Set

The X-band SAR imagery was acquired over the German cities of Ludwigshafen and Mannheim in May 2003 by the airborne Experimental Synthetic Aperture Radar (E-SAR) system of the DLR (Moreira, Spielbauer, Pötzsch, 1994). Both cities are in the Rhine-Neckar region, which represents Germany’s 7^{th} largest conurbation.
During the flight campaign single polarised X-band, dual-polarised C-band and fully polarimetric L-band data was recorded along three flight tracks featuring a depression angle of 20° - 60°. Each track covers an area of 3x10km in a spatial resolution of 2-3m. The recorded images feature a large variety of urban, suburban and agricultural structures.

In order to validate the image classification some classes of a biodiversity GIS vector layer updated in 2000 were merged into a data set showing the built-up areas within the specified region. This data base was complemented by additional aerial photographs recorded during the radar flight campaign.

3. SETTLEMENT DETECTION

3.1 Data preparation

In initial experiments it became apparent that a segmentation based solely on the initial intensity image is difficult. First, significantly textured medium- or small-scale structures are often not recognised or reconstructed by the segmentation. At a low segmentation level consisting of small image objects these structures are often split up into several individual segments with distinctively differing backscatter values. Increasing the size of the objects frequently results in a fusion of the textured segments with those adjacent objects, whose backscatter is quite similar. Sometimes the structure isn’t even noticed at all. Moreover the shape of the resulting image objects is frayed and does not follow the actual boundaries satisfactory.
As a proper image segmentation is crucial for the subsequent classification we improved this work step by supplementing the intensity information with an additional texture layer (Mean Euclidian Distance) calculated for the intensity image. Since the speckle effect clearly constricts the computation of a meaningful texture the speckle of the initial intensity image has to be minimised first. Strong speckle suppression with conventional speckle filters smoothes edges to a certain degree. Thus, we developed an optimised filtering technique to preserve major edges while significantly smoothing homogeneous areas. This moving window filter represents a combination of a “selective” mean filter and a conventional Lee Sigma approach. The effect of this filter is shown in Figure 1.

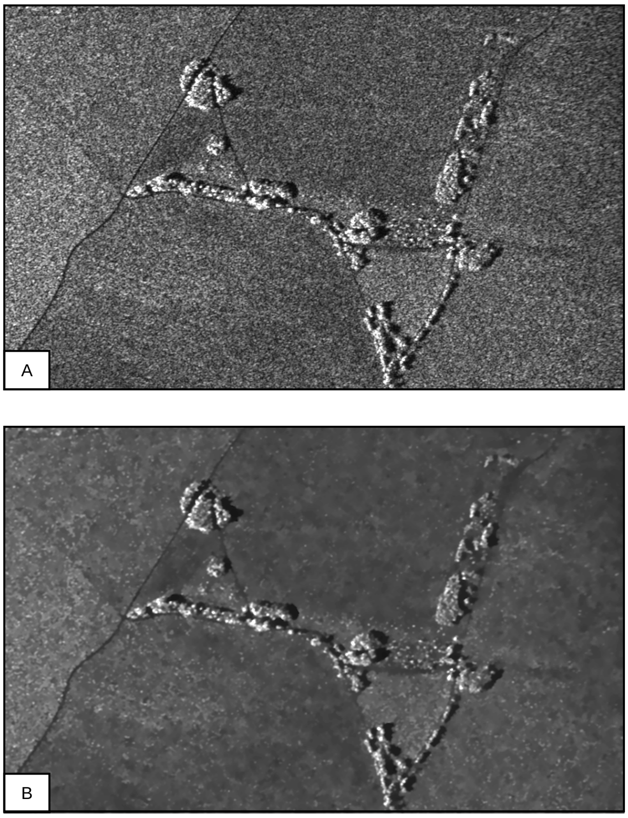

Figure 1. Speckle Suppression (A: original ; B: filtered)

3.2 Object-oriented image analysis

3.2.1 Image Segmentation The despeckled intensity image and the generated texture layer are used for the segmentation procedure described in this section.
In various tests we found that slightly different input images resulted in significantly different segmentations of the scenes, even though the segmentation settings were identical. As this severely restricts the ability to automate the classification process a first classification phase is interposed. The goal of this phase is to create comparable image objects on a specified segmentation level, independently of the input image characteristics.
This is achieved by iteratively performing a classification based border optimisation on an initial, relatively coarse image object level. For that purpose a set of sub-levels with constantly decreasing segment size is generated underneath the initial image object level. Then for each segment of the new layers it is successively tested whether its intensity value significantly diverges from both, its respective super-object located at the initial segmentation level and its directly adjacent segments. If it does, it is classified as a "significant substructure". Consequently, the appropriate super-object on the initial segmentation level is cut according to the shape of the identified structure. After the procedure has finished, only the initial, henceforth trimmed image object level is retained for further analysis. The effect of this adjustment is illustrated by Figure 2.
The optimised level serves as the basis for the actual classification. Additionally, a level with small objects is created underneath this base level and another one with very large segments is generated above. The newly generated fine level is best suited for the characterisation of single small-scale structures like houses or roads, while the segments of the third, coarse level cover large areas. Thus they represent complete quarters, agricultural fields or forest stands optimally.
The described image segmentation finally results in three image object levels.

3.2.2 Image classification The images are then classified according to a set of class rules collected in a "rule base". A key issue of the rule base development is the use of robust features for the class description. This is achieved by basing the classification procedure on textural and contextual features primarily.
For the definition of the rule base the segments of the coarse level are analysed with respect to the spatial composition of the underlying small-scale structures using textural features, in particular Haralick parameters (Haralick, 1979). Moreover the shape of these segments is utilised, e.g. to separate built-up areas from spectrally and texturally alike agricultural fields. The latter are typically by far more symmetric and uniform in shape.
The fine segments of the lowest level are classified to characterise small-scale urban structures like houses, other significant scatterers or shadows. They are mainly defined on the basis of their intensity, their difference in brightness to the surrounding objects and the composition of the neighbouring area. In addition, the textural and shape-related characteristics of the appropriate super ordinate segment situated at the coarse level are considered by obtaining the according information from the segments of the third level. The information provided by the fine and the coarse level are then combined at the initial medium level to calculate the final "settlement mask".

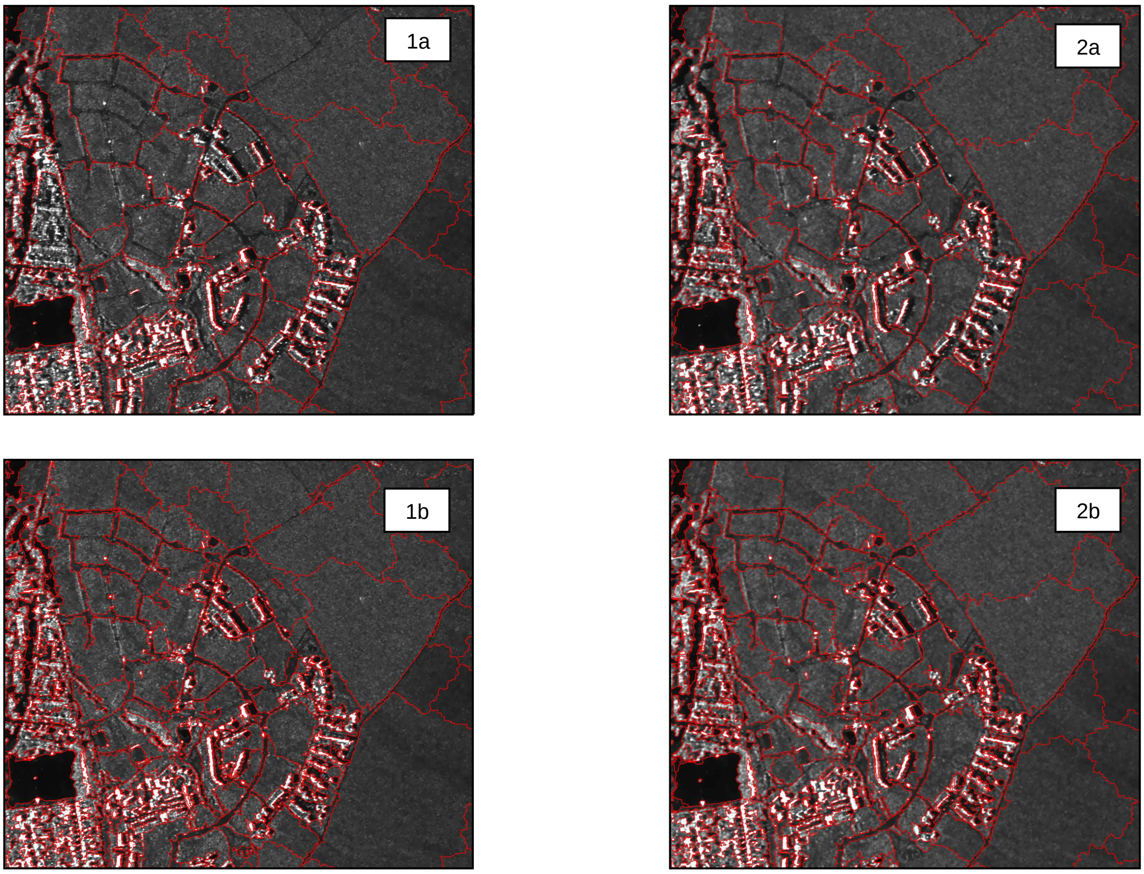

Figure 2. Adjustment of image objects shown for two differing input segmentations (a: initial; b: optimized)

4. RESULTS

The rule base developed on the basis of small subsets is applied to each of the three flight track images to determine the transferability of the classification scheme. The outcome is validated by comparing the classification to the reference GIS data set and the aerial photographs based on 500 randomly distributed control points. Since the vector data isn't available for all of the area covered, the accuracy for the respective regions is determined solely by a comparison to the aerial photographs.

The result shows that the built-up areas can be identified with an overall accuracy of 86% for track 1, 85% for track 2 and 91% for track three. The classification for flight track 1 is illustrated in Figure 3 along with the reference vector data on its right. It can be seen that the main body of the settlements – shown red in the reference map - is detected very accurately. These areas could be classified with an accuracy of more than 90%. This promising result can be traced back to the fact that these zones contain quite characteristic features like high texture, significant spectral difference of the single structures to their neighbours and the existence of multiple strong scatterers and shadow areas. In this manner even recently built-up development areas could be identified, which are not yet included in the reference data (see blue arrows in Figure 3).

Errors occurred mainly in the context of highly structured areas possessing diverse strong scatterers and significant shadow, e.g. non-urban street crossings surrounded by groups of trees.

The most significant false assignments occurred in recreation areas or allotments flanking the settlements. These zones - represented by greenish colours in the reference map - could only be identified when featuring significant texture along with the existence of some bright scatterers. Those spots situated in the far range region of the image lack these conditions due to the decreasing influence of surface roughness in far range. Consequently, these areas appear as dark, smooth zones without significant scatters. Thus, they can not generally be separated from areas in mid- and near-range featuring a significantly lower meso-scale roughness in reality. In mid- and near range the recreation areas and allotments possess the same characteristics as smaller forest stands, groups of trees or rough agricultural fields – consequently these zones remain unclassified.

5. CONCLUSIONS

The study has shown the applicability of high resolution, single polarised X-band imagery for the detection of built-up areas. Nevertheless, the significant variation of radar backscatter along the surface of a single structure (e.g. a building), the interaction of the scattered waves with multiple objects, the range-dependant effects of surface roughness and the visibility of objects subject to the line of sight result in considerable ambiguities of the recorded signature. Thus, the intensity information has to be analysed in consideration of its spatial context including the attributes of the surrounding objects as well as the characteristics of the super ordinate structure instead of solely regarding the backscatter signal. The object-oriented approach has proven to be very efficient as it provides multiple tools and features to address textural, contextual and hierarchical properties of image structures.

6. FUTURE PERSPECTIVES

A first future goal is the improvement of the presented classification scheme in view of a more accurate detection of recreation areas, parks and allotments. In addition the development of comparable procedures for single-polarised C- and L-band imagery is designated.

A second field of study will be dealing with the potential improvements associated with an analysis based on a combination of single-polarised X- and L-band data (multi-frequency analysis). Finally the integration of polarimetric decomposition properties considering the quad-polarised L-band data is planned.

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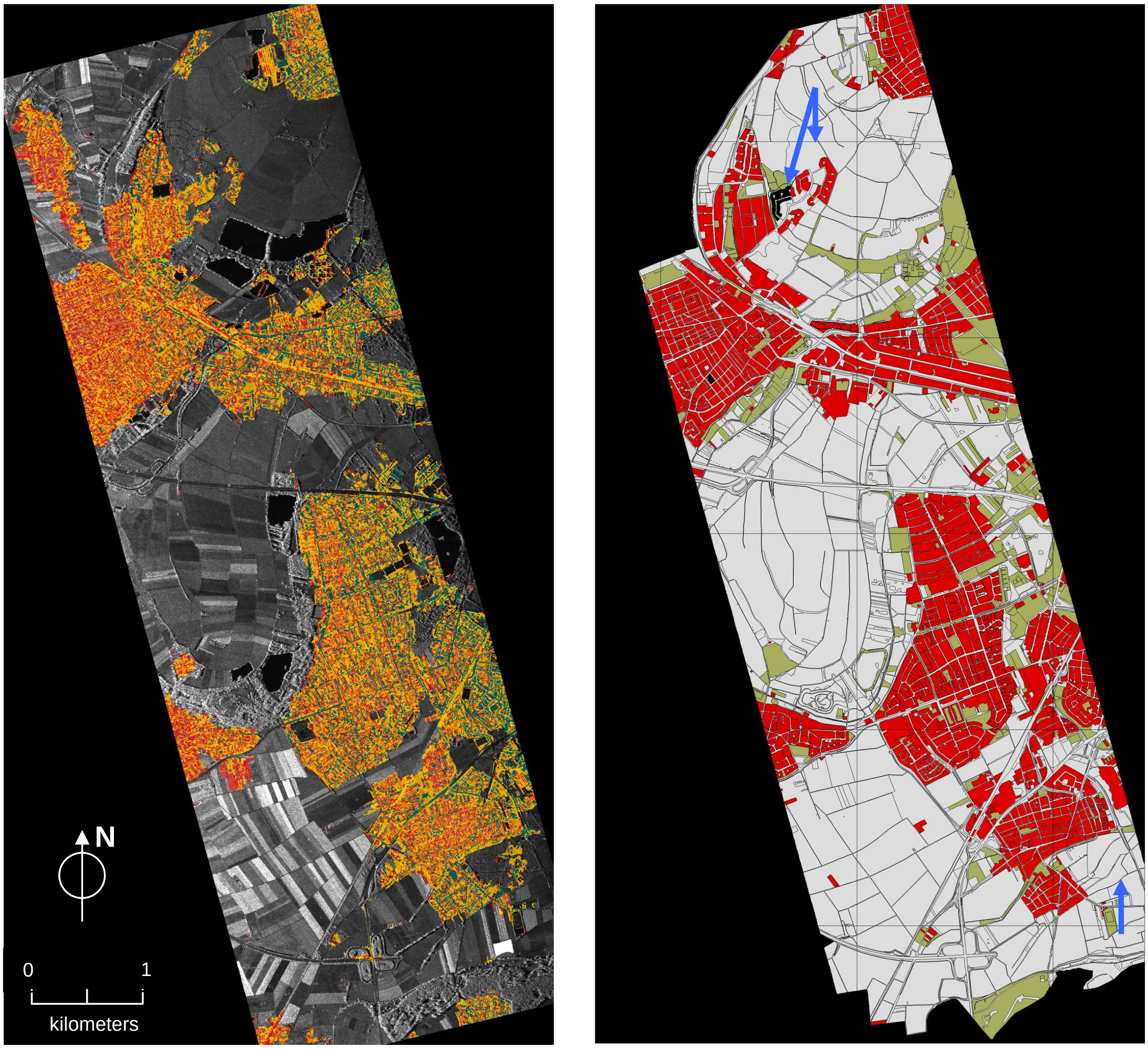

Figure 3. Detected settlements for flight track 1 (orange: built-up area ; greenish: shadow, road) and reference data set (red: main body of settlement; green: recreation area, allotment, park)

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