OBJECT-ORIENTED DETECTION OF URBAN AREAS FROM TERRASAR-X DATA

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ABSTRACT:

Urban environments represent one of the most dynamic regions on earth. Even in developed countries the yearly conversion of natural or agricultural space into residential, industrial or transport areas frequently exceeds 100 ha. Due to these rapid changes in landuse short-term data collection is demanded. Thus, remote sensing satellites and particularly the new German radar system TerraSAR-X with its independency of weather and daytime and a revisit of up to 3 days can serve as a valuable instrument. The goal of this study was to show the potential and the limitations of TerraSAR-X in view of the automated object-oriented detection of human settlement. In view of the limited significance of single-polarized radar intensity data a second layer is integrated which provides textural information derived from an analysis of speckle statistics. Two urban environments were analysed in this study: the Upper Rhine Valley and the region of Munich in Germany. The presented approach towards the detection of urban areas by means of TerraSAR-X data achieves overall accuracies around of 95% and 89% - an indicator for the high potential of TerraSAR-X data in terms of identifying built-up areas.

1. INTRODUCTION

Various studies have shown the potential of high resolution optical satellite data for the detection and classification of urban area (Taubenboeck, et al. , 2006, De Kok, et al. 2003, Imhoff, et al. 2000, Meinel, et al. 2004). Nevertheless optical satellite imagery is characterized by a high dependency in wether conditions and daytime. Thus, particularly in case of regional and national surveys within a short period of time, disaster management or when data have to be acquired at specific dates radar systems are more valuable. The new generation of civil space born Synthetic Aperture Radar (SAR)-Systems as ALOS-PALSAR or TerraSAR-X also supply a ground resolution, which is suitable for detailed mapping of urban structures (Roth, et al. 2003). Promising approaches towards the classification of urban area include the analysis of at minimum two data sets for multifrequence or multipolarized image analysis (Henderson and Xia, 1998, Corr, et al. 2003, Boehm and Schenkel, 2006, Soergel, et al. 2003, Ainsworth, et al. 2008).

2. METHOD

2.1 Test site and data set

Two different test sites were chosen for this study: the Upper Rhine Valley (URV) and the region of the Bavarian metropolis Munich. Both test sites represent areas with a high human impact and are characterized by a large variety of urban, suburban and agricultural structures.

The work was based on two TSX X-band images that were acquired in July 2007. Both co-polarized scenes were recorded in the TSX stripmap mode (SM) with a ground resolution of about 2.75m on an area of approximately 770 km2 (Upper Rhine Valley) and 1.25m on 120 km2 (Munich) respectively. Further information about the image parameters are shown in Table 1. The specific characteristics of the SM are described by (Roth, et al. 2003). The pre-processing for the 'Multi Look Ground Range Detected' (MGD) and 'Geocoded Ellipsoid Corrected' (GEC) products are defined in (Eineder, et al. 2005).

Test site	URV	Munich
Polarisation	25	1.0
Ground resolution	25	1.0
Incident angle	20	0.8
Pre-processing	20	0.8

Table 1. Image parameters of the TerraSAR-X data used in this study.

In order to check the plausibility of the results we also used GIS vector data of the year 2000 (Upper Rhine Valley) and 2006 (Munich) respectively. The aerial photographs for both regions were taken in 2005.

The pre-processing of the data included speckle suppression. SAR speckle significantly hampers the analysis of radar data. Thus, various filtering algorithms have been developed to enhance images degraded by speckle noise. When analyzing urban areas with SAR data structure-preserving speckle suppression is indispensable since these regions are characterized by small-scale structures and a specific texture. In our study we used a novel selective mean filter that aims at a structure-preserving removal of noise in SAR data (Esch, 2006). This filter is based on the idea of a sigma probability of the Gaussian distribution of speckle noise. The approach is based on a comparably straightforward analysis of local statistics and achieves more appropriate noise suppression com-pared to established filtering routines while true structures, texture and contour information are preserved. This filter also provides a texture file - the so-called speckle divergence - which accentuates true structuring in the SAR images. Besides the intensity information the speckle divergence is used as an additional input layer for the identification of urban areas. Figure 1 shows both the filtered intensity layer of Munich (A) and the corresponding speckle divergence image (B). Remarkable on the speckle divergence image is the high values in urban area and the low values at open space regions.

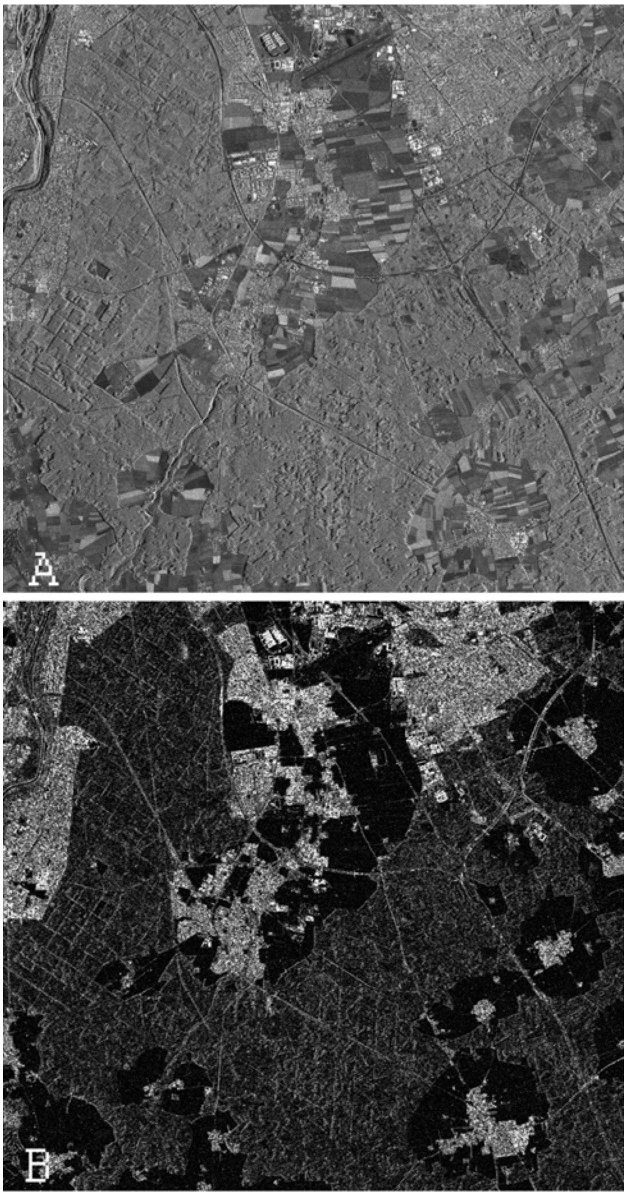

Figure 1. Filtered TerraSAR-X intensity layer (A) and calculated speckle divergence layer (B) of a subset of the region of Munich. Remarkable is that built–up areas are characterized by high values of the speckle divergence.

The development and application of the rule base was performed on the basis of two different test sites: the Upper Rhine Valley and the region of the Bavarian metropolis Munich. Both test sites represent areas with a high human impact and are characterized by a large variety of urban, sub-urban and agricultural structures.

2.2 Detection of Built-up Area

The following section introduces the basic concept and the implementation of a robust rule base for the automated detection of settlements based on high resolution TerraSAR-X data. The image analysis - including segmentation and classification - is performed by means of the object-oriented image software Definiens Developer (Baatz and Schaepe, 1999).

As seen in Figure 1 settlement areas are characterized by high values of the speckle divergence and numerous bright scatterers in the intensity image. At first the image analysis is focused on large segments in order to roughly delineate settlement areas. This is realized by an initial coarse segmentation level (L1). On this level large objects such as agricultural fields or settlement bodies are represented by few image objects. At this level smaller objects - e.g. buildings or streets - are embraced with the surrounding area in dependency of the intensity. In order to map these small features accurately those objects of L1 featuring high values of speckle divergence and intensity - which is typical for man-made structures - are subdivided into a second object level (L0). The following classification process is focused on these smaller objects of L0.

Based on the image segmentation the next goal is to develop a robust rule base which allows for an accurate classification of built-up areas. Thereby the image classification proposed in this paper describes an enhanced concept of the object-oriented approach towards the identification of built-up areas presented by (Esch and Roth, 2004). The key issue in this context is the identification of features which speeds up the detection of urban area.

In view of the limited significance of radar intensity a combination of intensity and speckle divergence was applied whereas settlement areas are characterized by a high speckle divergence and the presence of numerous bright scatterers (Figure 1). Additionally we used features that describe neighborhood-relations. Thus, the first step in classification is to identify distinct urban point scat-terers (UPS) which are characterized by a combination of a high intensity and a high speckle divergence. Assuming that all settlement areas feature clusters of UPS and in order to differ urban scatterer from wood further analysis is concentrated on the neighborhood of the UPS. First ambiguous urban scatterers (AUS) are detected. Thereby both UPS and AUS are combined as urban scatterers (US). AUS are characterized by a high intensity - but lower then UPS -, a high speckle divergence and by numerous US in their neighborhood. This detection procedure runs in loop while no new AUS is found. The next step is the identification of urban areas (UA). UA are characterized by a relative high divergence in addition to the existence of numerous US in the surrounding area. Finally all objects with a speckle divergence value larger than TSD and which are totally enclosed by urban area are also classified as urban area.

The segmentation settings as well as the rule-base for classification were developed on a subset (11 km2) of the images of the Upper Rhine Valley. In order to evaluate the transferability and therewith robustness of the approach, the developed procedure was applied on both the complete image of the Upper Rhine Valley and the scene of Munich.

3. RESULTS

The rule base developed on the basis of small subsets is applied to the whole image of the Upper Rhine Valley to determine the transferability of the classification scheme.
The outcome is validated by comparing the classification to aerial photographs (Upper Rhine Valley and Munich) based on 300 randomly distributed control points. The result shows that the built-up areas could be identified with an overall accuracy of 95.3% for the Upper Rhine Valley and 89.3 % for the region of Munich (Table 2).

Class	Users Accuracy	Producers Accuracy
Upper Rhine Valley		
Not Urban Area	93%	98%
Urban Area	98%	93%
Overall	95%	
Munich		
Not Urban Area	95%	83%
Urban Area	85%	96%
Overall	89%	

Table 2. Classification Accuracy of the test sites.

For both test sites promising results were achieved. Settlement areas of differing scales, e. g. small villages as well as cities are detected by the developed method. Figure 2 shows the classification result for the Upper Rhine Valley (B) for a visual comparison with the settlement area derived from the GIS layer from the year 2000 (A). It is seen that a very good fit of the distribution of the settlement area over the whole scene could be found.

For both test sites errors occurred mainly in the context of settlement areas which were highly interspersed by trees and hedges, e.g. allotments and graveyards and in highly structured areas possessing diverse scatterers, e.g. power poles.

4. CONCLUSSION

The presented method for the detection of settlement areas was tested on two TerraSAR-X images with different image parameters, whereas on both test sites promising results could be presented. The accuracies of the analyses illustrate the potential of the TSX data in terms of urban regional applications such as monitoring of urban sprawl and spatial and temporal distribution.

The first future goal is to improve the classification of the areas which were highly interspersed by trees and hedges due to the large areas which are affected by these objects. The second goal is the transfer of the developed method on test sites of differing environmental and developing regions. Thereby the focus lays on different sprawling cities such as the Turkish metropolis Istanbul, the Mexican metropolis Mexico City and the city of Hyderabad in India. The third goal is the extension of the classification with simple land use classes, e.g. wood, open land, water. At least, the effect of the combination of TSX data with optical sensor data, e.g. Rapid Eye or with differing radar frequencies of the classification results will be analysed.

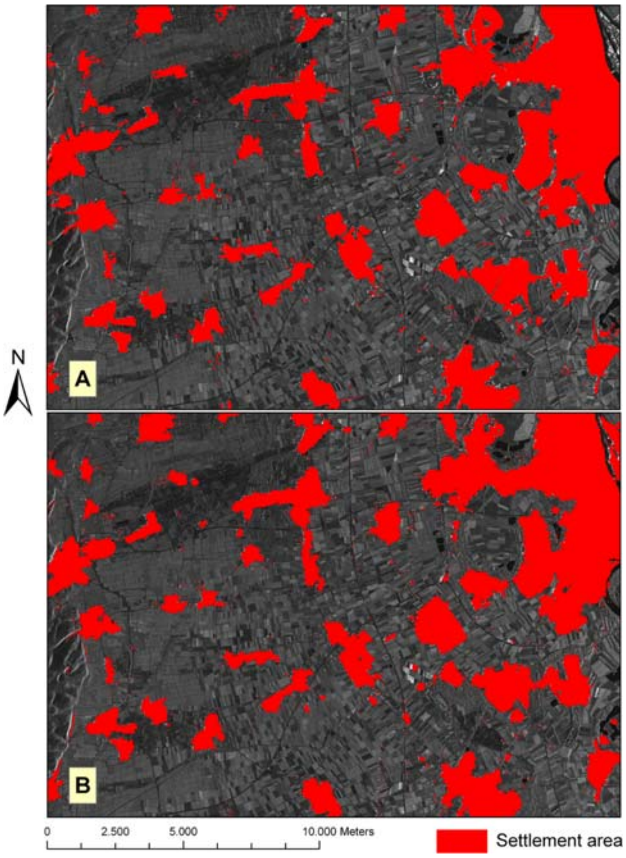

Figure 1. Visual comparison of the classified urban area (B) with the GIS vector layer of the settlement area from the year 2000 (A).

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