# ROBUST APPROACH TOWARDS AN AUTOMATED DETECTION OF BUILT-UP AREAS FROM HIGH RESOLUTION RADAR IMAGERY

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**ABSTRACT:**

The actual process of rapid urbanisation is associated with various ecological, social and economic changes in both, the urban area and the surrounding natural environment. In order to keep up with the effects and impacts of this development, effective urban and regional planning requires accurate and up-to-date information on the urban dynamics. Recent studies have demonstrated the applicability of high resolution optical satellite data for the acquisition of spatial and socio-economic information. In contrast, radar imagery has hardly been employed for these purposes so far.

The future TerraSAR-X will provide radar data with a ground resolution comparable to existing high resolution optical satellite sensors. Thus, it will afford detailed urban analysis based on spaceborne radar imagery for the first time. The detection concept presented here serves as a preliminary investigation of the potential use of TerraSAR-X data in the context of urban applications. It introduces a robust approach towards an automated detection of built-up areas using data acquired by the Experimental Synthetic Aperture Radar (E-SAR) system of the German Aerospace Center (DLR). For that purpose different data sets of single-polarised X-band imagery are analysed in an object-oriented classification.

A robust object-oriented analysis strongly depends on accurate and reliable image segmentation. Thus, a classification-based optimisation procedure to stabilise and improve the initial image segmentation step is introduced. Subsequently the identification of built-up areas is performed on the basis of three image segmentation levels in different spatial scales. Here, contextual and textural features along with shape-related and hierarchical characteristics play a major role. Finally, the transferability and robustness of the presented approach is illustrated by applying the developed classification scheme to E-SAR data of three complete flight tracks.

## 1. INTRODUCTION

The suitability of high resolution optical satellite imagery in the context of urban applications has been shown in various studies (De Kok, Wever, Fockelmann, 2003; Imhoff et al., 2000; Meinel & Winkler, 2004; Ryznar & Wagner, 2001; Kressler & Steinnocher, 2001). Thus, the use of value-added remote sensing products gained by analyses of optical data hold certain potential to improve urban and regional planning.

Radar sensors are capable of acquiring data at day and night, independently of weather or environmental conditions. Hence, radar data is more reliably available than optical imagery. This is particularly important when data must be acquired at specific dates, e.g. in the context of damage assessment or disaster management.

Nevertheless, contrary to optical satellite data the use of high resolution radar imagery has not yet been established in the context of urban applications. This circumstance can be traced back to:

- a lack of spaceborne radar sensors featuring a ground resolution suitable for a detailed analysis of urban structures
- radar specific characteristics and effects hampering an automated analysis of radar imagery

The difficulties related to an automated analysis of urban radar imagery arise from extensive modifications of radar backscatter due to the complex geometrical and physical characteristics of metropolitan areas, a varying appearance and visibility of objects subject to the Line of Sight (LOS) and a significant ambiguity of the radar backscattering information (Dong, Forster, Ticehurst, 1997).

Consequently, urban analyses based on radar imagery have usually been restricted to relatively straightforward applications.

The most promising approaches towards classifications of urban radar data include the analysis of multi-frequency or multi-polarised data sets (Haack, 1984; Henderson, Xia, 1998; Lombardo et al., 2001; Corr et al., 2003). To diminish the problems related to the radar specific LOS-characteristics in urban settings, data might also be recorded from opposite or rectangular directions in order to improve the visibility of single structures (Soergel, Thoennessen, Stilla, 2003). Another approach to improve the analysis of radar imagery is the combination of radar and optical data (Fatone, Maponi, Zirilli, 2001; Forster & Ticehurst, 1994; Weydahl, Becquey, Tollefsen, 1995; Xiao, Lesher, Wilson, 1998)

Nevertheless, in order to increase the suitability of very high resolution radar data in terms of urban or regional planning applications, research has to be intensified. In this context the implementation of cost-efficient solutions based on small data sets – which are most likely to fit the financial scope of planning authorities – will presumably increase the acceptance and applicability of high-resolution radar data.

In view of the future TerraSAR-X satellite, this study aims at the development of a concept for an automated extraction of built-up areas based on very high resolution, single polarised X-band imagery (Roth, 2003). This investigation is supposed to serve as the basis for further studies regarding a more detailed analysis of the urban structural characteristics.

## 2. METHODOLOGY

This section introduces the test site and data set as well as the methodological approach to identify built-up areas on the basis of high resolution HH-polarised X-band imagery.
With respect to the image analysis procedure, the main emphasis is placed on both, the improvement of the image segmentation process and the development of a robust classification scheme for an automated detection of human settlements.

### 2.1 Test Site and Data Set

The X-band images used in this study were acquired by the airborne Experimental Synthetic Aperture Radar (E-SAR) system of DLR (Moreira et al., 1994) in May 2003. The recorded images cover the cities of Ludwigshafen and Mannheim and show a large variety of urban, suburban and agricultural structures (figure 4). HH polarised X-band was recorded along three flight tracks. Each track covers an area of 3x10km with a spatial resolution of approximately 1.5 m and a depression angle of 20° in near and 60° in far range.
In order to validate the image classification some classes of a biodiversity GIS vector layer updated in 2000 are merged into a data set providing the built-up areas within the specified region. This data base is complemented by aerial photographs recorded during the radar flight campaign and topographic maps.

### 2.2 Basic Concept

This study represents an enhanced concept of the object-oriented approach towards the identification of built-up areas presented by Esch and Roth (2004).

Beginning with an initial pre-processing, the original 16-bit intensity image is converted to 8-bit. Then both data sets are filtered by means of an enhanced Lee-sigma approach in order to reduce the speckle effect. Based on the filtered intensity images, in each case a texture layer is generated by calculating the "Coefficient of Variation".
Next, the object-oriented image analysis is performed using the software eCognition (Baatz & Schäpe, 1999). Thereby an initial image segmentation step groups spectrally alike pixels into image objects on an arbitrary number of scale levels. Since the 8-bit data turned out to provide more appropriate results the segmentation is performed on the basis of the 8-bit intensity image and the derived texture layer. The final result includes three segmentation levels with the 1$^{st}$ level featuring very fine segments and Level 3 showing the largest image objects. The 2$^{nd}$ segmentation level includes optimised objects. The process of optimising the segments will be introduced in detail in the following chapter.

Subsequent to the image segmentation, the generated objects are classified by means of a rule base. This classification scheme defines both, the classes to be identified and the according features for their description and classification. This knowledge base is stored in the so-called "Class Hierarchy", which employs spectral, geometrical, textural and hierarchical characteristics of the image objects. Moreover, class-related features based on previous classification passes are considered. In contrast to the image segmentation the defined features and rules are based on the original 16-bit intensity image and the according texture layer respectively. The defined classes and the classification flow will also be explained in the following chapter.

During the image analysis procedure each step is protocoled. The resulting protocol is finally applied to the complete data set in order to investigate the robustness of the developed approach.

## 3. IDENTIFICATION OF BUILT-UP AREAS

### 3.1 Optimised Image Segmentation

One of the most important issues in the context of an object-oriented classification is the accurate segmentation of the input images. The analysis of fixed rectangular and thus more or less artificial spatial units in case of conventional pixel-based methods represents a significant limitation. The initial image segmentation performed in the context of an object-oriented approach leads to more meaningful spatial units. The resulting segments come closer to the spatial and therefore spectral and textural characteristics of the real world structures. Additionally, various shape- or context-related attributes are provided. Moreover the possibility to create an arbitrary number of segmentation levels with segment sizes optimized in terms of the best fitting representation of the real world structures is given.

Nevertheless, in practice it turned out that the process of image segmentation involves significant difficulties. On the one hand the determination of the optimum number of levels and the corresponding segmentation parameters is very complex and therefore time-consuming.
In addition the segmentation of the individual structures in the scene is strongly affected by local characteristics. This effect can be illustrated – for instance – by segmenting two identical scenes that were initially filtered differently. Although the structures within the image are very similar and the segmentation parameters have not changed, the resulting segmentation differs significantly.
When determining the optimal segmentation settings the image analyst focuses on the global optimum. Since such a global solution in practice only approximates local characteristics this procedure generally implies a certain amount of inaccurately represented structures.

Particularly in view of a robust classification process these difficulties limit the potential of the object-oriented approach. Therefore we developed a classification-based optimisation procedure in order to ensure a more comparable and therewith consistent segmentation. The basic idea behind this approach is to iteratively optimise the shape of the image objects according to a rule base that affords the identification of significant individual structures.

For that purpose an initial "base level" is segmented. The chosen scale parameter for this segmentation is relatively low to guarantee an accurate representation of all small scale structures. Subsequently, a second "optimisation level" with an increased scale parameter is generated above. Then, for each segment of the base level it is decided whether it represents a part of its super-ordinate object of the 2$^{nd}$ level or whether it can be seen as an individual structure (figure 1). In short, the seg-

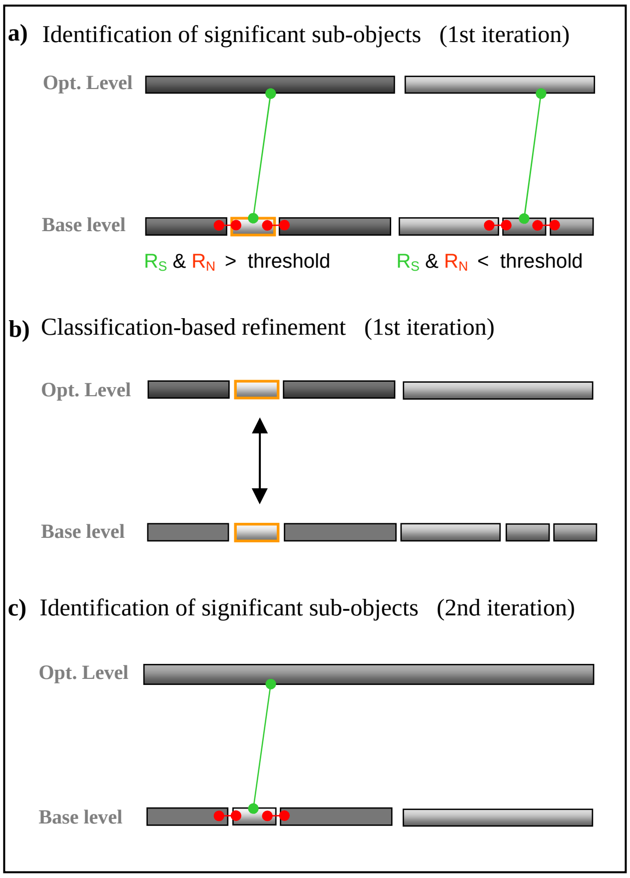



Figure 1. Image segmentation optimisation

ments of the base level are classified as a significant sub-structure if their ratio in intensity to both, the according super-ordinate segment ($R_S$) and to their neighbouring objects ($R_N$) exceeds a predefined threshold (figure 1a). Next, the segments of the optimisation level that cover a base-level-object, which is classified as a "significant sub-structure", are modified. This is done by clipping the respective segment of the optimisation level according to the shape of the identified sub-structure (figure 1b). Finally, the base level is deleted and a new optimisation level with significantly increased scale parameter is generated. Thus, the former optimisation level becomes the base level and the new, coarser optimisation level will be optimised again (figure 1c).

This procedure is iteratively performed with a continuously increasing scale-parameter for the generation of the optimisation level. The final output of this approach provides a single, improved segmentation level that features large segments in homogeneous areas whereas small-scale structures and heterogeneous regions are represented by distinctively smaller image objects (figure 2).

To enable both, the calculation of meaningful texture measures and the utilisation of hierarchical features, the optimised level is supplemented by a very coarse level on top. Finally, a third segmentation level with small objects is segmented underneath (figure 2).

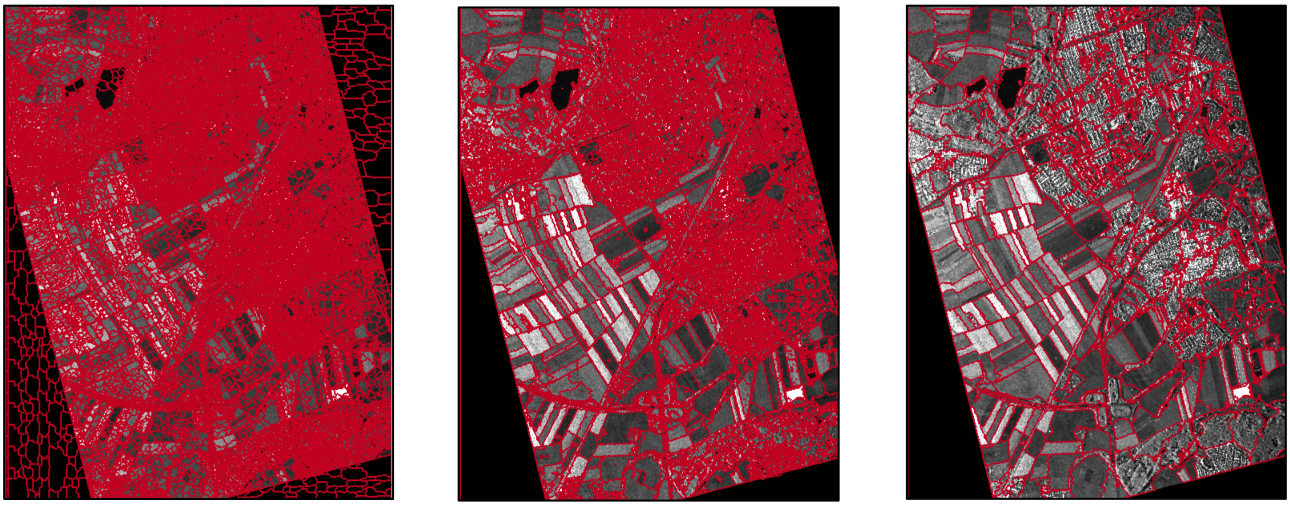
### 3.2 Image Classification

After image segmentation the next goal is to set up a robust rule base which allows for an accurate classification of built-up areas. In this context the identification of robust features for the class description is a key issue.
In view of the limited significance of radar intensity, textural, contextual and hierarchical features prove to be more valuable. One of the most distinctive and therefore most stable features is provided by the objects of the optimised 2$^{nd}$ level. Due to the optimisation procedure heterogeneous areas are characterised by small objects, while homogeneous regions are represented by large segments (figure 2). Thus, highly structured areas can be classified by analysing the average segment size at Level 2.
A classification based solely on this feature leads to an accurate delineation of highly structured regions. These include built-up areas, woodland and highly textured agricultural fields. To distinguish between these three land cover types, further attributes have to be incorporated into the rule base. Very helpful features are the existence and quantity of bright point scatterers and shadow areas (figure 3). Built-up areas feature a significant amount of both. In contrast, woodlands show a large number of shadow areas along with a very limited portion of bright point scatterers. In turn, highly textured agricultural fields might hold a large amount of significant point scatterers, but do not contain any shadow. Thus, the next step is to identify bright point scatterers as well as shadow areas within the zones that have initially been classified as highly structured regions. In combination with shape- and texture-related attributes provided by the segments of the 3$^{rd}$ level this information finally leads to a reliable discrimination between built-up areas, woodland and highly structured agricultural fields.
This part of the classification is performed on the basis of Level 2. The segments located at Level 3 are not classified, but they provide essential textural and hierarchical information for the classification of the objects located at Level 2.
A significant source of classification errors at the second level arises from image objects that misleadingly cover both, highly structured regions and homogeneous zones or vice versa. The relatively small objects of Level 1 exclude the occurrence of such segments. Therefore the classification result is inherited from the second level to the first level in order to correct these failures. For that purpose a new rule base is implemented in the class hierarchy. This rule base identifies potentially wrong segments at level 1 and corrects them when necessary.

Both, the segmentation optimisation procedure and the development of the class hierarchy are based on a subset of the data recorded at flight track 1. In order to evaluate the transferability and therewith robustness of the approach, the developed classification procedure is applied on the complete images of flight track 1 to flight track 3.

## 4. DISCUSSION AND RESULTS

The results are validated by means of an error matrix calculated on the basis of the classification result and reference data. The reference data is generated by a manual classification based on topographic maps, aerial photographs and a biodiversity vector layer.
The resulting confusion matrix shows an overall accuracy of 90% for track 1, 89% for track 2 and 92% for track 3. The built-up areas identified in flight track 1 are shown in figure 4.



**Level 1** **Level 2** **Level 3**

Figure 2. Result of image segmentation

Due to the typical and distinctive characteristics of the settlement's central zones – lots of point scatterers along with various shadow areas – these regions are identified quite well. In contrast, the most significant difficulties occur in the context of the identification of allotments. Dominated by small cottages, surrounded by tress and small-sized gardens this land cover type is difficult to differentiate from woodlands or hedgy zones. Thus, the chance of identifying these regions strongly depends on the amount of clearly "visible" cottages that cause a strong reflectance.

Finally, the large variation of depression angels of the airborne data (20°-60°) lead to noticeable variations in the reflectivity and textural characteristics. For instance the steep incidence angle in near range leads to a predominance of scatterers, whereas the amount of shadow areas is comparably low. In far range the situation is inversed.

Moreover, large strong scatterers are often spread into adjacent areas. This involves considerably varying intensity values. This effect predominately appears in city centres or industrial units and particularly hampers the accurate identification of potential shadow segments.

## 5. CONCLUSIONS

The research has shown the applicability of high resolution HH-polarised X-band imagery for the identification of built-up areas. Due to the very high spatial resolution in combination with the strong dependence of radar backscatter on the geometrical properties of the illuminated surface, high resolution radar data holds certain potential to analyse the structural characteristics of urban areas.

However, the radar specific effects clearly hamper the automated classification of settlements and therefore necessitate the analysis of comparably complex spatial characteristics and their interrelations. In view of this demand the object-oriented approach has proven to be an effective technique to enhance the potential of an automated classification. In particular the multiple tools and features to address textural, contextual and hierarchical properties of image structures are very valuable. Nevertheless, the classification with eCognition requires significantly higher skills, is comparably complex and the development of robust approaches is still very involved and time consuming.

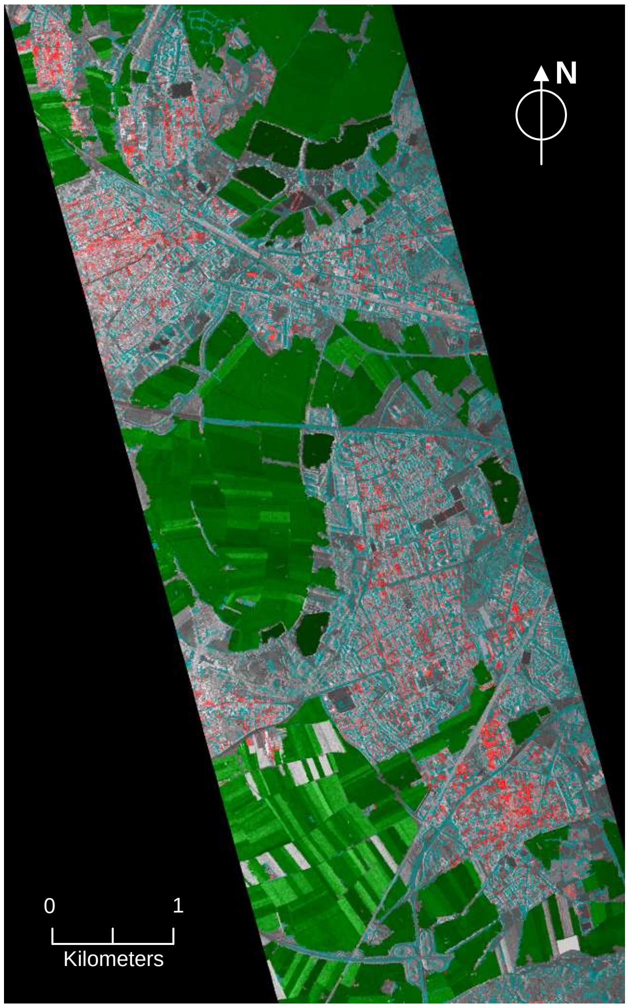



Figure 3. Detection of potential point scatterers (red) and shadows/streets (dark teal) within highly structured areas (grey). Open areas appear green.

## 6. FUTURE PERSPECTIVES

The first future goal is the integration of single- and/or quad-polarised L-band data into the developed classification scheme in order to evaluate the effects of both, a multi-frequency approach and an integration of polarimetric attributes.

A second field of study will be dealing with a more detailed analysis of the structural characteristics within the identified built-up areas. The goal is to investigate the applicability of high resolution radar imagery in terms of classifying different structural types of settlements, such as industrial zones, inner city regions, housing estates etc.

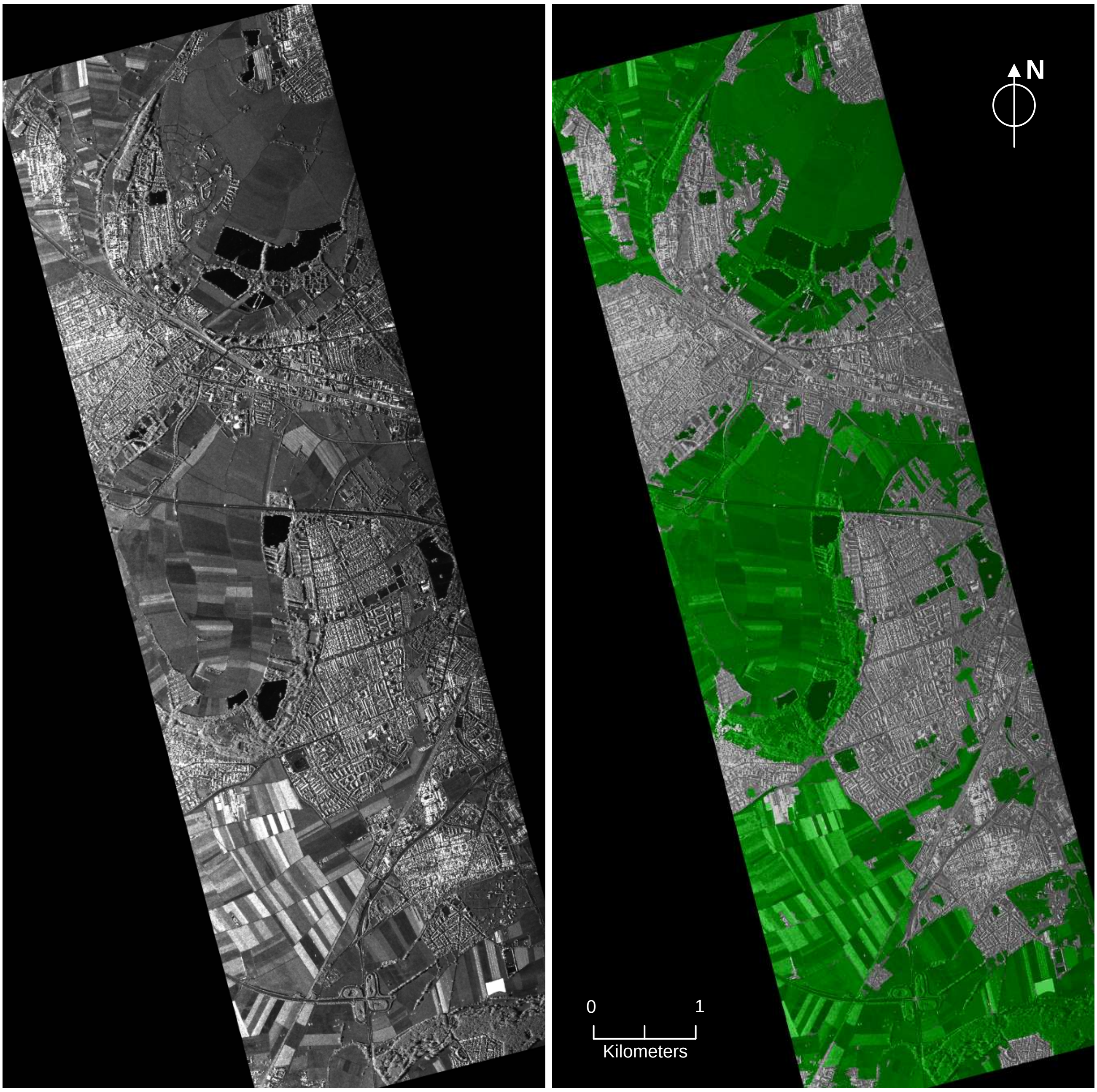



Figure 4. Original intensity image (left) and identified built-up areas (right)

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