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Object-oriented land use classification of polarimetric high-resolution SAR and hyperspectral HyMap™ data

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ABSTRACT: In comparison to traditional pixel-based classifiers object-oriented classification approaches can include information of shape, context and multiple scales for improving classification results. In this study polarimetric and multifrequency high-resolution E-SAR data and hyperspectral HyMap™ data were used to map an agricultural area in southern Germany with the object-oriented techniques provided by eCognition. An advanced rule base was defined to derive different basic land use classes and map a high number of several crop types in both datasets. The overall accuracy of the E-SAR classification was determined with 88% . In comparison, the accuracy of the HyMap™ classification is 5% lower, but more classes with a higher separability could be distinguished. In a fused data analysis the different advantages of each dataset were combined for an improved classification result. In contrast to conventional pixel-based classifications the presented object-based results show comparable accuracies but a more homogenous mapping product with advances in their further processing and analysis in Geographic Information Systems (GIS).

1 INTRODUCTION

During the last decades remote sensing made enormous technical advances with new high spatial and spectral resolution sensors. Despite such developments, most image processing and classification techniques still rely on concepts developed 30 years ago. Most of the remote sensing applications use statistical pixel-based classifications for information extraction. But as many studies in environmental sciences and operational applications have shown, there is a strong need for analyzing meaningful image objects representing the real world instead of single pixels (SCHMULLIUS & NITHACK 1996; BURGER & STEINWENDNER 1997; BLASCHKE & STROBL 2001; DONG et al. 2001).

Until recently, classification results were only improved by basic spatial analyses using GIS functionality or other image processing algorithms. An improved approach is offered by the integration of spatial knowledge directly into the classification process to improve the classification accuracy and to define more complex land use and cover classes (e.g. low vegetated areas, which are surrounded by forest, are likely to be clear cut areas or rivers are water bodies that have a high length to width ratio).

Another problem arises with the development of high-resolution sensors. Due to the higher spatial resolution the spectral variance of specific classes can increase significantly. A specific land cover object appearing homogenous in a LANDSAT TM scene can be very heterogeneous in a IKONOS scene due to environmental variations. This problem increases when using radar data because of the system-induced speckle-effect. As a result traditional pixel-based classifiers produce a very heterogeneous land cover classification even in homogenous land cover types like agricultural fields, insufficient for most applications. For the use as maps in GIS such results are not very suitable (APLIN et al. 1999; MEINEL et al. 2001).

As one of the first operational image analysis software eCognition developed by Definiens Imaging provides an object-oriented classification approach, which could solve the problems mentioned above (DEFINIENS 2001).

In this study the object-oriented approach was evaluated with high-resolution E-SAR and HyMap™ data. It investigated the possibilities and advances compared to conventional pixel-based techniques. Additionally a fused data analysis was carried out, combining the optical and SAR images.

2 TEST SITE

The test site covers a 3.1 km by 2.3 km area near Alling located in the southwest of Munich. It is a mainly flat area on a fluvial terrace and represents a typical rural landscape with heterogeneous agricultural land use, grassland, forest and small villages. The main crop types are cereals (summer and winter barley, wheat, rye), corn and potatoes on relatively small fields (0.05 – 1.5 ha).

3 DATASET

The radar data were acquired with the airborne E-SAR system of the German Aerospace Centre (DLR) on June 16th 2000 (6 a.m.) and are part of the investigations of the project TerraDew (SCHMULLIUS & HEROLD 2000) at the Friedrich-Schiller-University Jena (FSU). The SAR images were processed at the German Aerospace Center (DLR) including polarimetric calibration, multilooking and geocoding. The spatial resolution of the data is 1 m. The computation of the radar backscatter coefficients, i.e. calibration, was carried out at FSU. In this study seven different images, representing different wavelengths and polarizations, were used (table 1).

Table 1. specifications of the analyzed E-SAR data

	X-Band	C-Band	L-Band
frequency	9,6 GHz	5,3 GHz	1,3 GHz
wavelength	3 cm	5,6 cm	23 cm
polarization	HH, VV	VH, VV	HH, VV, HV

No speckle filtering was applied to the data since the segmentation averages the pixel values over the image objects and good segmentation results were achieved with unfiltered images.

The hyperspectral dataset was acquired by the HyMap™ sensor on June 20th 2000 and was provided by the German Remote Sensing Data Centre (DFD). The HyMap™ data consists of 126 bands covering the 0.44-2.5 µm spectral region. The spatial resolution is 5 m. Pre-processing, done by FSU, included geocoding and data compression using a principle component analysis. No atmospheric correction was applied due to clear weather conditions during the overflight and the following non-quantitative classification analysis. For geocoding 100 ground-control points were selected to correct a subset of approximately 3.3 by 3.8 km with a "rubber sheeting" algorithm. The first four Principle Components, representing 98.8% of the total variance, were used for further image analyses.

In addition intensive fieldwork and acquisition of reference data was carried out for training and validation purposes (see HEROLD et al. 2001).

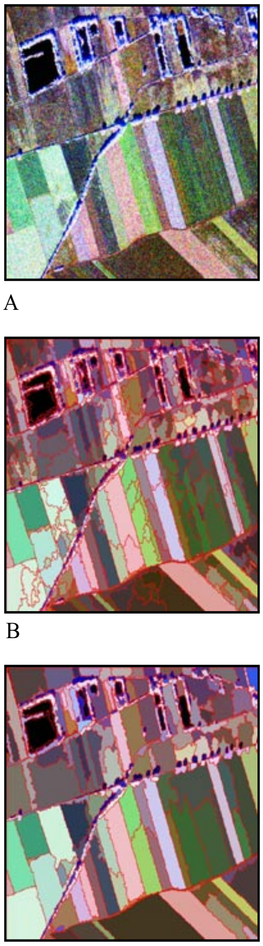
4 THE OBJECT-ORIENTED CLASSIFICATION APPROACH

The object-oriented approach of eCognition follows the concept that important semantic information which is necessary to interpret an image is not represented in single pixels but in meaningful image objects depending on the application and their mutual relations.
The image objects are created by an initial "multiresolution segmentation". This bottom-up region-merging technique starts with one-pixel objects and merges them in numerous subsequent steps into bigger ones. The algorithm minimizes the average heterogeneity of image objects for a given resolution over the whole scene. Heterogeneity is not only based on standard deviation but also on the shape of image objects, where the weighting between these two criteria are application-dependent (BAATZ & SCHÄPE 2000). The segmentation is the first step to build up a hierarchical network of image objects where each object knows its neighbors. This is an important prerequisite for the later use of topological information in the classification. With the network it is possible to represent the image information in different spatial resolutions simultaneously (figure 1).

Figure 1. hierarchical network of image objects (DEFINIENS 2001)

The resulting objects are attributed not only with spectral statistics but also shape information, relations to neighbouring objects and texture. Texture is derived from the spectral variance of sub-objects in the hierarchical network.

Figure 2 shows an example of the segmented E-SAR data. Part A is a subset of the original input data at the pixel level. Parts B and C are segmentation results in different resolution levels. In B the image objects are optimised for the classification of small objects like single trees or small roads. In C larger objects represent complete fields.



A

B

C

Figure 2. Original E-SAR image (A) and segmentation results in different scales (B, C)

The classification is based on these object-attributes by applying a fuzzy logic approach, where each class is defined by a set of fuzzy expressions. With this it is possible to standardise features of different range and dimension and to incorporate them into one classification scheme. Another advantage is the formulation of vague class definitions (BENZ 1999; FOODY 1999; ZHANG & KIRBY 1999). The output of the system is not just a final crisp classification (e.g. map product), but also the information about class mixture and reliability of class assignment, which can be used for an advanced classification validation.

5 METHODOLOGY

The study included the analysis of three different datasets. After pre-processing of the images (see section 3) the E-SAR and the HyMap™ data were classified separately. The hypothesis was that each single dataset has different advantages and disadvantages in classifying the heterogeneous agricultural test site because of the different underlying physical concepts of SAR and hyperspectral remote sensing. This was verified and a classification with a combined (fused) dataset of E-SAR and HyMap™ data investigated the capability of eCognition to combine the advantages of the single sensors in one classification process. Different studies have shown, that the fusion of datasets from sensors with different sensing characteristics leads to better classification results than a monosensoral analysis (HARRIS et al. 1990; SOLBERG et al. 1994; WALD 1999)

The image analysis and classification included segmentation, examination of object features and spectral signatures, design of a rule base as a set of class descriptions, classification and verification of the results with independent ground truth areas. In addition the object-oriented classification results were compared to each other on a quantitative and qualitative basis. Furthermore a comparison between the object-oriented E-SAR classification and a pixel-based result of a related study (PATHE et al. 2001) was carried out.

6 CLASSIFICATION CONCEPT

Figure 3 shows the concept of the E-SAR classification similar to that of the HyMap™ and the combined classification. Three different levels of image objects have been created representing different scales. In level 1, very small image objects represent buildings or trees. They are used for subsequent feature extraction. Large objects in level 3 are classified as settlements if their sub-objects on level 1 have a high contrast. This feature is a powerful texture measure provided by the multiscale approach of eCognition, which makes it possible to examine texture based on sub-objects.

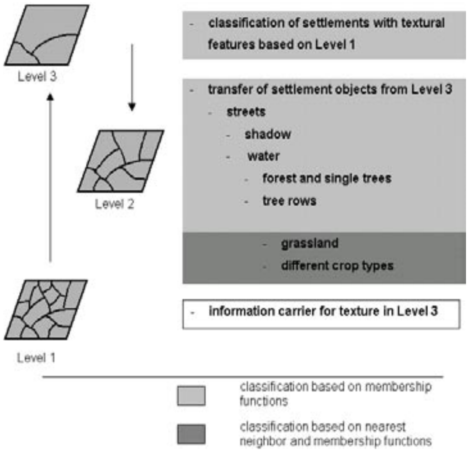


Figure 3. concept of the E-SAR classification

Level 2 is the main classification level. First, classified settlement objects in level 3 are transferred to level 2. Secondly, a fuzzy rule base, using spectral- and shape-information and class related features, classifies the remaining objects. The classes are either described with user defined membership functions or with the use of training samples and the Nearest Neighbor classifier. With membership functions the user can easily incorporate expert knowledge about class descriptions into the system. The Nearest Neighbor classifier of eCognition is similar to a minimum distance classifier.

In the available high dimensional feature space, grassland and crop types were easier classified using training samples and the Nearest Neighbor classifier than by describing them with user-defined membership functions. However, membership functions are used to model local knowledge for classification refinement, e.g. the assumption that very small areas completely or nearly completely surrounded by winter barley belong to winter barley.

7 RESULTS

7.1 *Monosensoral Classification*

Since it is a prerequisite for a successful subsequent classification the segmentation has to result in meaningful image objects, dependent on the application. With the "multiresolution segmentation" a comprehensive extraction of relevant image objects in different scales was achieved (e.g. single trees, complete fields and forests). Even the very noisy E-SAR data could be segmented successfully, resulting in speckle reduction without smearing the edges.

Besides the analysis of spectral signatures and other features eCognition offers the opportunity to examine the separability of classes. The class-separation was analyzed using the membership values of the fuzzy classification output. They express the degree of membership of an object to all considered classes. The values range from 0, representing no membership, to 1 representing full membership. For the final ("crisp") classification result the class with the highest membership value is assigned to each object. The higher the difference between the highest and second highest membership value of an object, the more reliable and stable the classification.

Figure 4 shows that most of the classes in the HyMap™ classification have higher differences to their next possible class thus resulting in a more stable classification compared to the E-SAR result. For example, the class "potato" has a difference of 0,28 compared to 0,05 in the E-SAR classification, where "potato" is mostly confused with "corn". All classes that have a difference to their next possible class of less than 0,1 were considered to be not reliable separable and were therefore fused. Thus resulting in the mixed classes "corn/potato" and "summer barley/wheat" in the E-SAR classification, which could be reliable separated in the HyMap™ result.

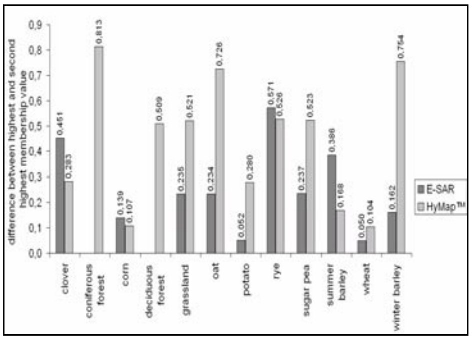


Figure 4. Differences between best and second best membership class values of the E-SAR and HyMap™ classification (coniferous and deciduous forest were not distinguished in the E-SAR classification)

For verification purposes ground truth was collected from 118 crop fields and over 50 grassland areas during the E-SAR overflight. In addition, settlement, water and forest areas have been digitized from aerial photographs. With this, forty percent of the whole area was used to validate the result. The classification accuracy was only evaluated on fields, which were not used as training samples. The crop types alfalfa and canola were excluded from accuracy evaluation, because the number of fields was not representative.

A high number of land use classes in a mostly agriculturally used area could be classified with a high accuracy (see table 2 and 3). The overall accuracy of the E-SAR data reached 88%. Though the overall accuracy of the HyMap™ classification (83%) is a little bit below that it was possible to distinguish reliable between more land use classes (e.g. coniferous and deciduous forest) and obtain a higher class-separation for most of these classes.

Table 2: classification accuracy for the HyMap™ data

Class	producers accuracy	users accuracy
Clover	45,4%	80,7%
Coniferous forest	93,6%	99,9%
Corn	98,0%	90,8%
Deciduous forest	99,8%	70,4%
Grassland	91,3%	90,8%
Oat	74,9%	79,8%
Potato	99,2%	79,5%
Rye	13,8%	98,5%
Settlement	92,8%	97,1%
Sugar pea	72,9%	93,5%
Summer barley	79,1%	75,9%
Water	96,5%	100,0%
Wheat	78,7%	54,3%
Winter barley	92,6%	97,7%
Overall accuracy	82,9%	
Kappa Index	0,80	

Table 3. classification accuracy for the E-SAR data

Class	producers accuracy	users accuracy
Clover	45,9%	93,0%
Corn / Potato	99,2%	97,9%
Forest	96,5%	94,5%
Grassland	94,8%	88,0%
Oat	100%	90,1%
Rye	13,8%	46,4%
Settlement	77,6%	93,4%
Sugar pea	100%	99,4%
Summer barley / Wheat	94,1%	81,9%
Water	90,6%	100%
Winter barley	84,6%	79,7%
Overall accuracy	88,0%	
Kappa Index	0,86	

A major advantage of the E-SAR dataset is the higher spatial resolution which leads to a better detection of small object like roads compared to the HyMap™ data. In addition SAR systems in general have important advantages due to its all-weather capabilities.

7.2 *Data fusion and classification*

A fused data analysis should combine the advantages of each sensor mentioned above and utilize the different information contents synergistically. Therefore a fusion concept was developed which combines pixel based and decision based image fusion techniques (BENEDICKTSSON & SWAIN; SOLBERG et al. 1994; POHL & VAN GENDEREN 1998).

At first a segmentation with all image layers of both datasets resulted in a new image information which integrates E-SAR and HyMap™ data. Objects with a high geometrical resolution were extracted by higher weighting the E-SAR dataset than the HyMap™ dataset.

It is important to point out that the objects are still attributed with the original spectral values of the input data plus other features like form and context. Thus allows a flexible classification, where classes are defined by using the different sensor information on a user-decision basis.

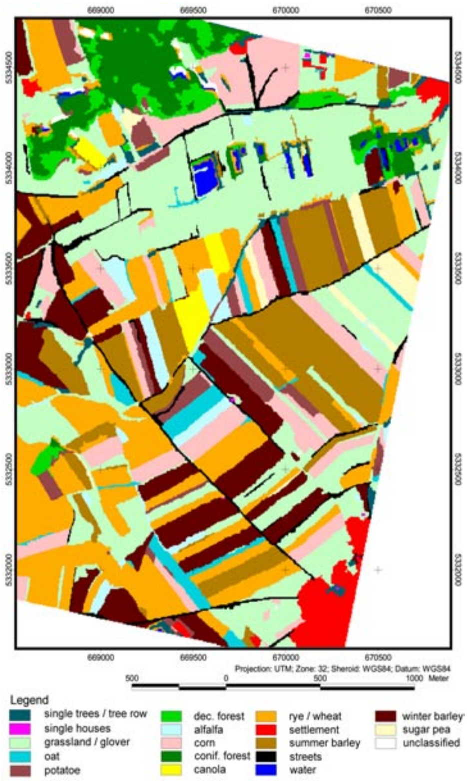


Figure 5. object-oriented classification of the fused dataset

In this study the knowledge obtained by the previous monosensoral analysis was incorporated into the classification of the fused dataset. With the fuzzy classification concept the individual advantages of each sensor were used to build up the rule base. For example the classification of deciduous and coniferous forest is based just on the HyMap™ information. This resulted in a better separation of settlement and forest that had a high confusion in the E-

SAR classification. For the definition of complex classes like different crop types both datasets were utilized.

With eCognition it was possible to successfully integrate the different sensor information into one classification concept. The result shows a higher geometrical accuracy and more classes with a higher thematically accuracy compared to the monosensoral classifications (see figure. 5). Problems only occurred in regions in the image where the georeferenciation between the two images was not exactly.

7.3 *Comparison of object-oriented and pixel-based classifications*

Compared to the pixel-based classification result of the E-SAR data (PATHE et al. 2001) the object-oriented approach allowed the classification of more specific land use classes like streets or the discrimination between single trees and large forest areas. Because of this more land use classes were achieved in the object-oriented result. The accuracy of identical classes are comparable.

The variability of the backscatter is very high due to the high resolution and the speckle noise in the SAR data. This results in the typical "salt-and-peper" appearance within the pixel-based classification. The object-oriented approach leads to more homogenous fields which makes the integration in Geographic Information Systems (GIS) as thematic maps more reasonable (see fig. 6 and 7).

Figure 6. subset of the object-oriented E-SAR classification result

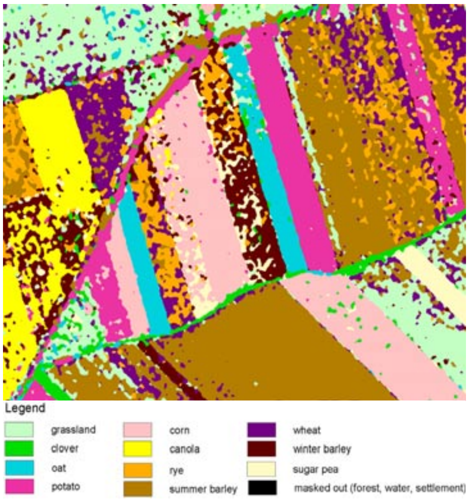


Figure 7. subset of the pixel-based E-SAR classification result

8 CONCLUSION

In the presented study we have examined an object-oriented classification approach. The results show the high potential of such techniques for the extraction of specific and complex land use classes. With a convincing "multiresolution segmentation" image objects are extracted that are attributed with spectral values and form, context and texture features. With this information a fuzzy classification is performed.

A high number of mostly agricultural land uses classes could be obtained accurately with the E-SAR and HyMap™ dataset. In the fused data analysis the advances of each sensor could be combined resulting in an improved land use classification.

In contrast to conventional pixel-based classifications the presented object-based results show comparable accuracies but a more homogenous mapping product with advances in their further processing and analysis in Geographic Information Systems (GIS). This is an important point in analyzing high resolution images of the new satellite sensor generation like IKONOS or QUICKBIRD.

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