FUSION OF SATELLITE IMAGERY AND DIGITAL TOPOGRAPHIC DATABASE BASED ON DISJOINT OBJECTS

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ABSTRACT

Monitoring of changes in an integrated topographic database and remote sensing environment will be a main requirement for future projects. In this paper an approach is proposed for an improved and automated satellite image analysis for the determination of land use classes by means of specific knowledge, which is represented in digital topographic databases. Another aim is a first step to an integration scheme for the updating of digital topographic databases by means of remote sensing imagery. In the second part of this paper an application of the developed processing tool for civil and environmental protection is described.
Because of the relatively poor geometric resolution of common satellite sensors (e.g. Landsat TM with 30 m) the analysis concentrates on main area-based landuse classes like 'settlement', 'forest', 'water' or 'agriculture'. By using integrated knowledge processing (data fusion) in feature extraction, creation of disjoint geometric objects and classification process the resulting semantic scene description is more accurate than with classical methods of satellite image analysis. The detected forest areas show significant differences to the ATKIS data. Thus this data processing instrument can be used to get more current information of the land cover. The land cover is already modelled in such a way, that it can already be integrated in information systems for fire fighting.

1 INTRODUCTION

Most of the strategies for disaster management are based on large-scale maps or databases, but for the management of large emergencies also small-scale topographic databases are needed. Many countries have been building-up such small-scale digital topographic databases during the past few years (e.g. in Germany the ATKIS by the surveying administration (AdV, 1989)). This has already been a very time consuming and expensive task. The costs for a necessarily needed permanently manual update process in the above case of disaster management are too high and are not accurate enough. Consequently there is an urgent need for techniques to automate the updating process.

The progress of satellite image analysis using classical methods (e.g. pixel-oriented multispectral classification) is often limited by the use of only one feature (spectral signature) and interactive selection of training areas. Therefore the accuracy of classical satellite image analysis techniques is not sufficient, methods with more intelligence are needed. The already existing topographic databases could deliver this knowledge for more accurate results of remote sensing imagery in an automated way. This more accurate result can then be used to update the database.

The pixel-oriented satellite image and the vector-oriented topographic database are two different sources of knowledge. Both make a description of the same scene, but from different perspectives. For the comparison of the two different knowledge bases, it's necessary to introduce methods on higher symbolic level. While the ATKIS database is already on a higher symbolic level, which describes position, form and semantic of topographic objects, the image data is first on a non comparable lower level. So, a knowledge based segmentation for the main area-based landuse classes like 'settlement', 'forest', 'water' and 'agriculture' is performed to get a suitable symbolic description of the image content. In this step the topographic database is introduced as a-priori information about the scene.

By means of an intersection of both geometric scene descriptions from segmentation and ATKIS we obtain a new unambiguous scene description with disjoint objects. The semantics of the produced disjoint objects are not limited to the topographic object classes 'settlement', 'forest', 'water' or 'agriculture'. There are new hybrid classes from two or more topographic classes. For this disjoint objects an extented feature extraction is performed. As features not only the (pixelwise) spectral signature, but also parameters like texture, form, size, structure and neighbourhood relations are used. The disjoint objects with their processed features are stored in an object-relational database. This is the knowledge base for the next step of classification.

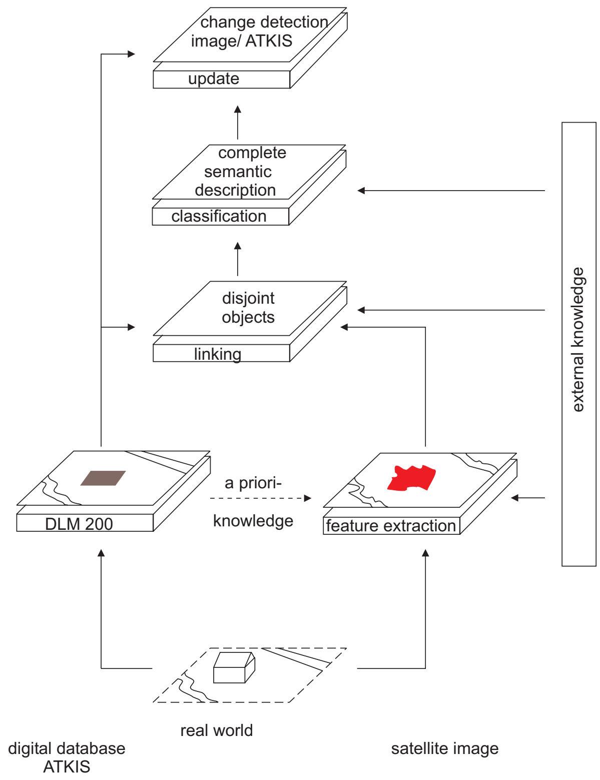

Figure 1: Flowchart of the analysis process

The classification process of the disjoint objects is performed in a semantic network, which is able to process general and specific knowledge about the topographic and disjoint objects. Semantic networks are usable schemes concerning knowledge representation. The use of a semantic network for satellite image analysis is new. After the classification, disjoint objects with the same semantic meaning and a common border are merged. The result is a complete semantic description of the scene.

This scene description is very useful for disaster management. According to the german constitution, everybody has the right to physical safety (Grundgesetz, 1994). In this regard, the german public authorities are obliged to be prepared for (significant) emergencies. One facet of disaster preparedness is to facilitate sufficient current information for the management of a crisis or to prevent the development of a crisis. The proposed process of deriving relevant information for forest fires can be used to update the information systems of the relevant authority.

2 TWO SOURCES OF KNOWLEDGE

Pixel-oriented satellite images and vector-oriented topographic databases are two different sources of knowledge. Both describe the same scene with objects of identical classnames, but from different perspectives and so the semantic of the objects varies in meaning. For example, in a map the class *forest* describes dedicated regions, whereas in an image it describes clusters of pixels with similar spectral features. Nevertheless, the integrated use of objects from DLM and segmented image supports a better understanding of a natural scene and leads to a more accurate scene description. Because of the differences between both knowledge sources the comparison is consequently done with methods on higher symbolic level. The used segmentation and feature extraction process is explained in detail in (Vögtle and Schilling, 1995), (Kunz et al., 1997) and (Kunz et al., 1998).

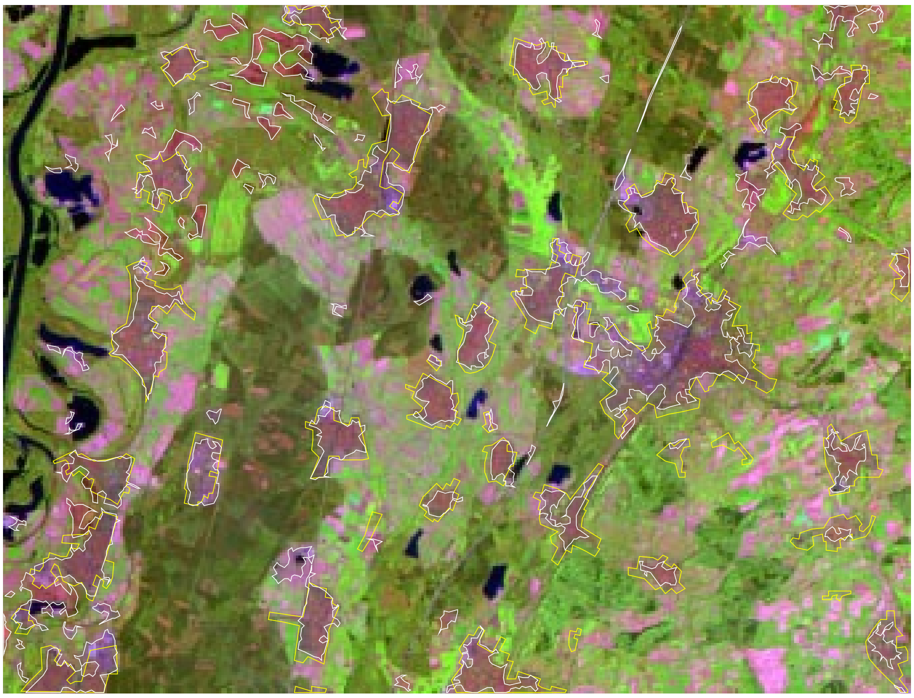

Figure 2: Segmentation and DLM Objects of class *Settlement*.

The result of the whole feature extraction process is a symbolic description of the image content by segments (polygonal contour lines) with a number of attributes (signature, structure, size, shape) and topological information (neighbourhood relations). Starting from the result of the segmentation (see Fig. 2 as an example for the object class 'settlement'), a semantic modelling of the scene content is developed.

3 FUSION OF ATKIS-DLM200 AND SEGMENTED IMAGE

Different kinds of interactions between a topographic database and image analysis are possible. In our case, image analysis and topographic database fully interact, i.e. DLM information is used to guide image analysis, which extracts more complete and accurate information, which is in turn used to update the topographic database.

Quite long is the list of problems, which are encountered with respect to data and information fusion (Baltsavias and Hahn, 1999). Besides others, the following four problems are the challenging and interesting ones for this project:

- Differences between landuse (provided by topographic database) and landcover (provided in images)
- Lacking procedures for interpretation and quality control of fused data.
- Data generalisation in map and database.
- Different data structures for the same object (e.g. raster, vector, attribute).
- Gap between research and practice (which is typical for not matured scientific areas).

This leads to differences in the scene descriptions between a digital topographic database and a segmented image. All kinds of differences have to be treated in the following step of semntic modelling of topographic objects.

4 SEMANTIC MODELLING OF TOPOGRAPHIC OBJECTS

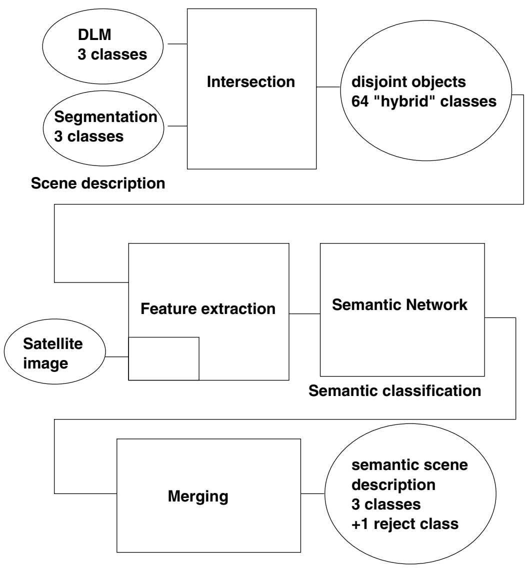

Figure 3: Flowchart of the integrated analysis of image and DLM.

The information from the segmentation and the topographic database ATKIS with their respective extracted features are stored in the object-relational database POSTGRES. Through this, the access on the data is simplified, especially because the used database is capable of storing and processing geometric data.

The flowchart of the integrated analysis of image and DLM is presented in Fig. 3.

By means of an intersection of both geometric scene descriptions from segmentation and ATKIS, we obtain a new unambiguous scene description with disjoint objects as explained in Section 5. The disjoint objects with their processed features are also stored in the relational database. This is our knowledge base for the next step of classification.

The classification process is performed in a semantic network, which is able to process general and specific knowledge about the topographic and disjoint objects. This step is explained in section 6. After the classification, disjoint objects with the same semantic meaning and a common border are merged. The result is a complete semantic description of the scene. This presented method can be considered as an interface between image content from remote sensing and knowledge representation in a geographic topographic database. The direct modelling of ATKIS objects from remote sensing data decreases the error fragility. A lot of errors are arised conventionally from the transfer progress through a data file interface into the database.

5 CREATION OF DISJOINT OBJECTS

Because the scene descriptions from DLM and segmentation have ambiguous semantics for certain areas (see Fig. 2), it is necessary to introduce a method to solve this ambiguity. For this purpose an intersection between corresponding objects is performed.

Fig. 4 and Fig. 5 show the intersection between the corresponding DLM and segmentation object respectively for the object class 'settlement'. The result is a set of disjoint objects with three different semantics:

- The inner object where DLM and segmentation have the same semantics.
- The outer objects, where either the DLM or the segmentation define the object as belonging to the object class 'settlement'.

This is a simple example, because not only objects with the same object class may be overlayed. Obviously, many DLM objects with a class other than that of the intersecting image objects can be found. In addition, because of the classwise segmentation and digitizing errors, both geometric scene descriptions have overlapping objects from different classes. Therefore, the intersection process is not only performed between objects from both scene descriptions; also intersecting objects inside one scene description are treated.

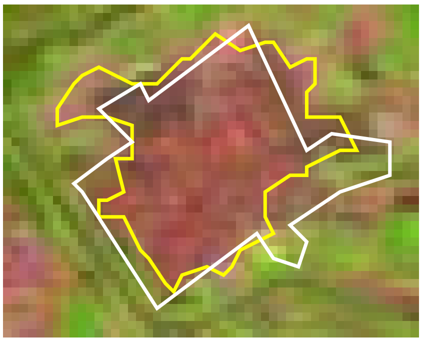

Figure 4: Overlapping DLM- and segmentation object.

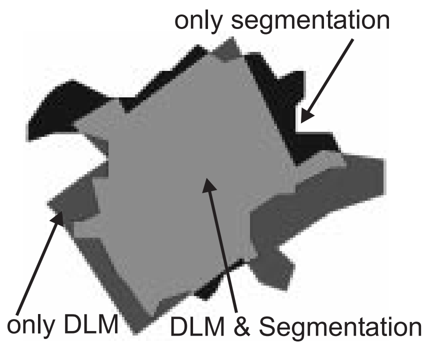

Figure 5: Result of corresponding disjoint objects (lightgray: DLM- and image object; gray: only DLM object; darkgrey: only image object)

There are respectively 3 layers of topographic objects from DLM and segmentation. Starting with one layer A, the intersection with the second B is performed. Hence, the results are divided into 3 classes: A, B and the union of $A \cup B = AB$ (see Fig. 6).

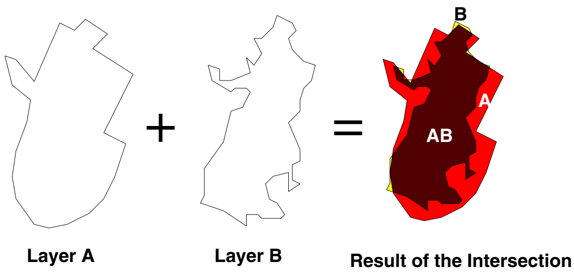

Figure 6: Creation of disjoint object.

This result will be intersected with the third layer C, producing 7 classes: A, B, C, AB, AC, BC and ABC. In this way, all 6 layers will be intersected with each other. As a result

$$2^5 + 2^4 + 2^3 + 2^2 + 2 + 1 = \sum_{n=0}^{5} 2^n = 63 \; \textit{hybrid classes}$$

are possible. In a more general case with n layers

$$\sum_{n=0}^{n-1} 2^n$$

new classes are created. Thus an object has possibly up to 6 subclasses and altogether 64 hybrid classes are possible.

The object identification codes and the classes of the original objects are stored in the new created objects. The resulting new objects have now new hybrid classes, like *'settlement from the DLM and water from the segmentation'*. These new objects are geometrical disjoint and have an unambiguous attribute for their class.

Therefore, the result after creating of the disjoint objects is a new scene description, where the semantics of the produced disjoint objects are not limited to the topographic object classes 'settlement', 'forest', 'water' or 'agriculture'. There are new hybrid classes consisting of two or more topographic classes. In Fig. 7 all disjoint objects for the test area are shown together with their hybrid classes. Not all of the possible 64 classes occur in Fig. 7. Some are quite rare like the overlapping of all six layers for a specific region.

However, the semantic of the object is a little bit confusing, because what is an object with a class like *'settlement from the DLM and water from the segmentation and forest from the segmentation'*? The goal is a unique scene description with the three area based topographic classes 'settlement', 'forest' and 'water' and one reject class.

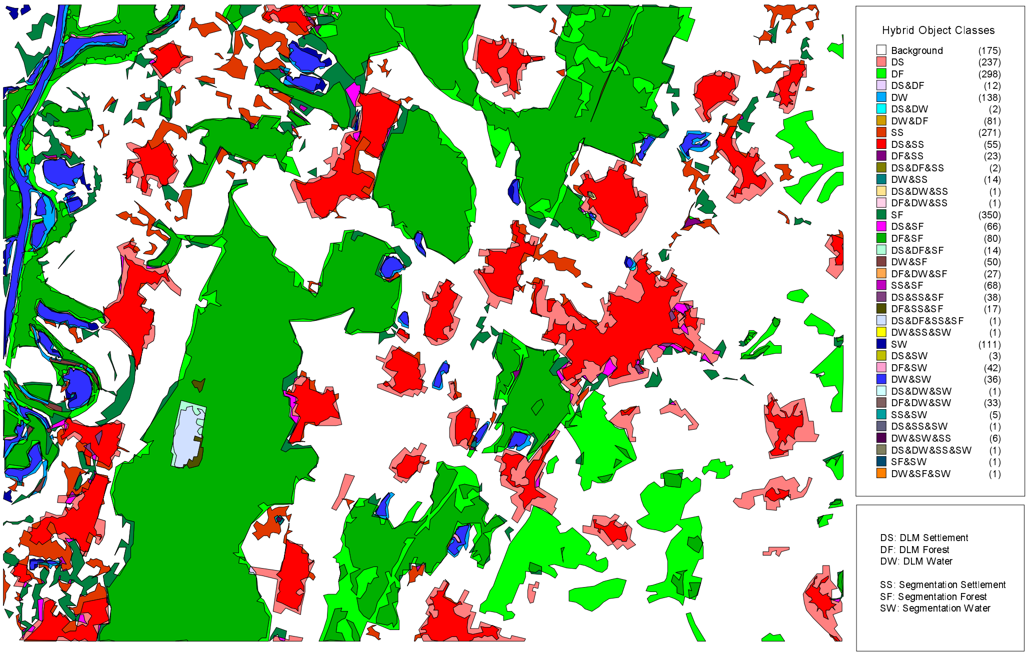

Figure 7: Disjoint objects with hybrid objectclasses for testarea "Karlsruhe-Nord"

In a next step, these 64 hybrid classes will be reduced to the wanted topographic classes. For this task, more information (knowledge) is needed about the objects. A feature extraction process is performed, where the spectral as well as the non-spectral features are extracted for the disjoint objects. All collected information about the objects will be stored in the object relational database. This is then used as the knowledge base in the next step of semantic classification.

6 SEMANTIC CLASSIFICATION

Given that the problem of the geometry is treated in the previous section, only the landuse semantics of the objects are of interest here. The knowledge about the disjoint objects lies on a higher symbolic level; thus, a system for knowledge representation is used.

Semantic networks are common schemes used for knowledge representation. So far, semantic networks have been used in speech recognition (Kummert, 1992), industrial (Niemann et al., 1990a) and medical (Bunke, 1985) applications and aerial image analysis (Koch H.and Pakzad and Tönjes, 1997). The use of a semantic network for satellite image analysis is new. For using and modelling the knowledge about the disjoint objects – as well as serving as central control unit, ERNEST (Erlanger Semantisches Netzwerksystem) is applied in this research (Niemann et al., 1990b); (Kummert et al., 1993). Based on the experiences with ERNEST in aerial image analysis at the IPF (Quint, 1997), a semantic net is designed for the classification process (see Fig. 8).

In the semantic network system ERNEST, there are three different types of links between two nodes: part-of‘ (bst), specialization-of‘ (spez) and concrete-of (kon). The links describe the relation between two nodes. The nodes represent various objects, events, ideas, or abstract concepts. There are three different types of nodes: concept, modified concept and instance. At first, only concepts exist. During the analysis, modified concepts are distinguished from concepts only by more restricted ranges for their attribute values. When a modified concept has concrete values, it becomes an instance.

A semantic network contains two different types of knowledge: declarative and procedural knowledge. Declarative knowledge consists of concepts and links, while procedural knowledge contains methods for the determination of attributes of concepts, as well as for the valuation of concepts and relations.

The concept *primitive* is the interface to the database. It fetches unused and unclassified objects from the database and stores them in the concept object. The semantic net retains in the concept unused the object primitives that were not already used. Because topographic objects consist of one or more outer and inner objects, the contour is built in the concept contour. This contour object is classified because of its features to one of the semantic meanings. The process is repeated until all disjoint objects are classified.

6.1 Data Analysis

Because the scene consists of the four area-based object classes *settlement*, *forest*, *water* and *reject*, the learned features from the feature extraction process were stored in these concepts. It is assumed, that the ’reject’ class is the same as the ’agriculture’ class, because most of the unspecified area in the DLM200 belongs to this class. This assumption simplifies the modelling of the concepts on the semantic level. In a future refining, the ’reject’ concept could be split up into a concept for the agriculture class and a concept for objects which could not be classified with a minimum probability.

In contrast to the automatically learned statistical class features, the valuation and analysis function have to be implemented by an operator.

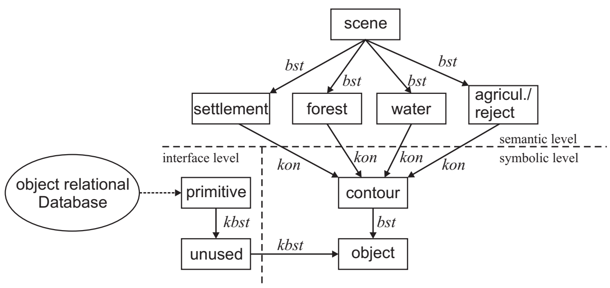

Figure 8: Semantic net for the semantic classification.

7 OUTCOME OF THE SEMANTIC CLASSIFICATION

The outcome of the semantic network analysis is a new knowledge base of classified disjoint objects. Each object belongs to one of the four basic object classes but describes only a small part of the whole topographic object. Therefore, disjoint objects with the same semantic meaning and a common border are merged. The result is a complete semantic description of the scene.

8 SUPPORTING DISASTER PREPAREDNESS BY REMOTE SENSING

Every user of the ATKIS data has different requests to the quality of the ATKIS data. One important aspect of the data quality is the actuality of the data. To overcome the update difficulty of fast changing objects like forests or waters, ATKIS is built as a topographic database which describes the dedicated and not the covered regions. That is, there are differences in land use and land cover.

The actuality of the forest land cover in a digital database is especially important for disaster management. In recent years, the usage of information systems has won recognition for disaster management. A future information system for forest fire management can handle in the ideal situation, four main tasks (Mitschke, 1997), (Wybo, 1998): early fire warning, acquisition of fire damage and fire hazard, the simulation of fire propagation, disposition of the available resources and tracing of the whole mission. Almost all objects that are relevant for performing these tasks are related to geometric location. In Germany, the information systems that are used to coordinate the fire brigards use as geometric reference often the ATKIS data. Unfortunately, forest and water areas in ATKIS are the dedicated regions and do not mirror the relevant changes of land cover. Basically, the forest stand can change rapidly. The hurrican “Lothar” at the 26.12.1999 reached wind velocities of about 200 km per hour. 25 million m^3 timber were thrown down in Baden-Württemberg. This is almost three times the “normal” annual removal. Figure 9 shows the estimated damage for Baden-Württemberg (FVA, 2000).

Whenever the forest areas are needed for planning, one has to request for other sources than ATKIS. If no other database is available, the decisions have to be based on ATKIS. The consequences could be: errors in the simulation, errors in the strategic planning of the resources and malfunction of plausibility checks. Thus some decisions that could then be based on the forest objects of the ATKIS data, may be wrong.

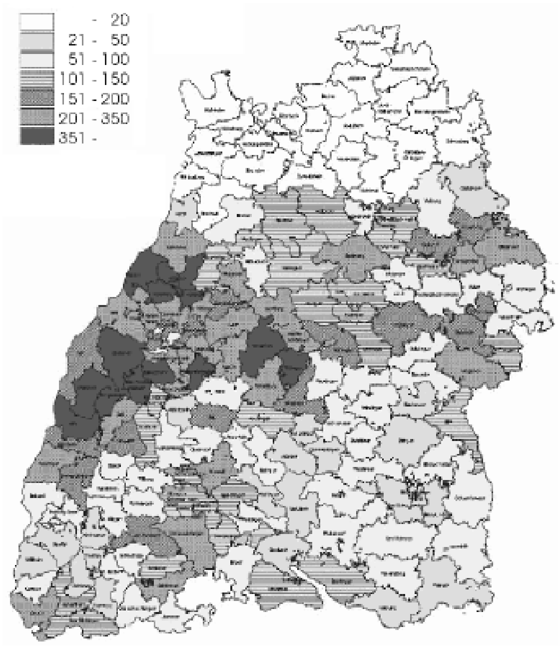

Figure 9: Windthrown timber in $10^3\,\mathrm{m}^3$

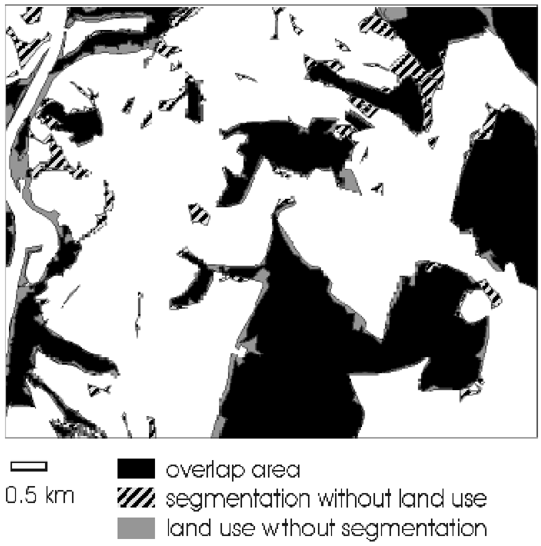

Figure 10: Differences between land use and land cover

Rescue measures are time-critical, and there is almost no time left for the correction of wrong decisions. That means it is very important to add also land cover objects to the database. These land cover objects have to be updated regulary in the forefield, to be prepared for disaster management. The proposed update process detects those classes that are needed in this case: water, forest and settlement. Therefor this process would be a fast and cheap data source to provide the needed information.

In figure 10 shows an example, for detected differences between the land use and the result of the segmentation. The classification errors are in this scene negligible. That means the mapped differences are differences between the dedicated regions and the real land cover. The black areas are the overlaping areas of the land use and the segmentation. The hatched areas are detected by the segmentation, but are not contained in the land use. The grey areas are contained in the land use, but they are not verified by the segmentation. That is, it is possible to detect significant differences between land use and land cover. These differences have to be taken into account whenever forest fire prevention is performed, or disaster management has to be planned. A further advantage of this method of detecting the actual land cover is that, all information is already in the proper data model.

9 CONCLUSION

There is a basic need for techniques to analyse image data in an automated way. With the method presented here, it is possible to get good results without human interaction. Many refinements have to be implemented until this goal is achieved. First experiences with an extended feature base and a special segmentation process confirm the efficiency of our concept by leading to a better separability of object classes. This change detection architecture can also be transfered to monitor other objects than ATKIS objects. For example, an interesting question is the investigation of the behaviour of the method for environmental monitoring (cf. (von Hansen and Sties, 2000)).

The structure of the presented semantic net is still simple, but can be extended in an easy way by adding new concepts and links. A semantic network for the classification is one knowledge representation among many others and its potential has to be verified through additional investigations.

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