

IMALYS – AN AUTOMATED AND DATABASE-INTEGRATED OBJECT-ORIENTED CLASSIFICATION SYSTEM

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ABSTRACT:

Increasing frequency and quality of remote sensing observations created strong demand for high-quality retrieval of thematic information as input for analysis, modeling and decision-making purposes. Furthermore there is growing need to integrate the processes associated with analysis of remote sensing imagery into the workflow of landscape management systems. To meet those demands, research has been carried out to develop novel methods for image analysis and classification. As one result of this research, this paper presents IMALYS, a software prototype developed with the goal to provide automated object-oriented classification procedures for remote sensing data and ancillary information.

Being an independent module IMALYS is part of an Integrated Landscape Management System (ILMS) and currently provides three distinct functions: It (a) performs segmentation of image data, i.e. groups pixels to discrete and statistically homogeneous, yet towards their neighbors heterogeneous, regions, (b) extracts standard and user-defined attributes and features to be associated with those regions and (c) uses the derived regions and features as input for an optimized classification process that is controlled by a set of reference data.

In order to comply with the demands on the analysis of remote sensing observations a set of tasks for the further development of IMALYS has been defined. Development goals include the integration of the software prototype into a GIS environment to increase working efficiency and the establishment of a knowledge library containing persistent information for the object identification and extraction. The established knowledge library and the currently used classification strategy are to be integrated into a relational database environment.

1. INTRODUCTION

With growing demand for regional planning measures that implement principles of sustainability the requirements for landscape management systems have increased. These requirements stand in contrast to the general lack of an integrated system solution able to cope with the complexity and needs of modern planning services. As part of the research conducted in this regard, the objective of the underlying project ILMS is to create an Integrated Landscape Management System that can be considered a consistent prototype for handling, analysis and visualization of spatial data. ILMS constitutes a modularly structured software system that integrates:

- Collection and management of spatial data
- Qualitative and quantitative landscape evaluation
- Prognostic modeling of management scenarios
- Decision support for landscape management

Fields of application for ILMS comprise local and regional land use planning, landscape and water resources management, issues of agriculture and forestry as well as environmental and civil protection. Developed in cooperation with regionally-based small and medium-sized companies, ILMS aims to integrate the expertise of all partners to adjust the resulting system according to the specific demands on information products and planning services.

Technically, ILMS consists of several modules that are functional independently yet are able to communicate and interoperate. At the core stands a management component

designed for effective data storage and contribution. The other modules include a component for mobile handling and processing of spatial data, a modular framework for simulations and modeling and a remote sensing module. Within this modular structure, the module comprising remote sensing functionality aims at the development of a largely automated classification system for discrimination and identification of real-world objects for satellite imagery.

At the core of the ILMS remote sensing module stands IMALYS – a software solution originally developed by H.G. Geo Data Solutions GmbH that at present offers a variety of distinctive functions. These include (a) segmentation of image data, providing statistically homogeneous regions, (b) attribute and feature derivation for the retrieved regions and (c) classification according to the derived features and a set of typical reference data. These functions will be further discussed in this article. Research that is now conducted within ILMS aims to extend and enhance the current functionality of IMALYS by integrating it into a relational database environment. This includes both defined sample objects and objects classes as well as established classification rule sets. Development also aims at the integration of the classification process itself into the database system. Thus IMALYS establishes a knowledge library that will eventually be able to adjust to multiple kinds of input data and different fields of application.

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2. IMALYS FUNCTIONS

2.1 Overview

IMALYS has been designed as a tool for object based image analysis able to process remote sensing data for output in GIS and other spatially oriented software systems. Following is an outline of its main features:

- IMALYS implements various algorithms for the aggregation of image pixels into regions of homogeneous properties, i.e. segmentation. Within the scope of IMALYS these regions are referred to as 'cells'. It is possible to derive cells without almost any user interaction by exclusively using image data statistics.
- IMALYS retrieves color, texture and shape characteristics for the derived cells. It further builds a topology, i.e. registers the spatial relationship between cells and stores both attributes and topology in a database table.
- IMALYS implements different classification methods that use the combination of both derived cells and their associated attributes to identify real-world objects in satellite imagery. The classification is optimized with respect to the number of used input features and feature combinations and is conducted according to provided reference data.

A more detailed discussion – resembling a typical IMALYS workflow – of these major functions follows below. It is accompanied by illustrations based on the sample image shown in Figure 1.

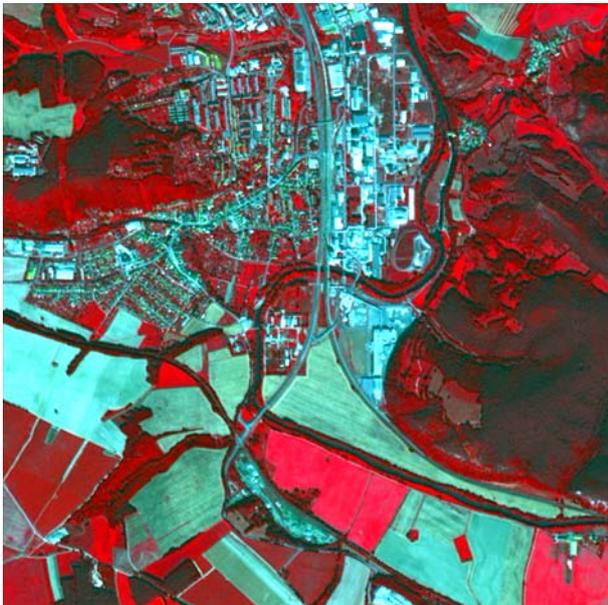


Figure 1. SPOT resolution merge of the sample image utilized to illustrate the existing IMALYS features. Depicted is an area south of Rudolstadt (German federal state Thuringia) with a size of 12 km². The image was acquired on Sep 10, 2006.

Furthermore IMALYS implements ancillary functions that include:

- Import of single- and multi-band imagery in frequently used file formats.
- Import of vector datasets representing predefined cell boundaries or reference data for classification.

- Application of filters on both pixel and cell level to create data views that emphasize different image characteristics.
- Vectorization and smoothing of cell boundaries and their export as separate vector datasets.
- User interaction by means of a predefined script structure that can be edited both manually and via a simple graphic interface.

2.2 Segmentation

Segmentation of image data into finite elements is considered a key step in object based image analysis as it defines size and shape of its basic processing units and therefore influences the quality of the following classification. Finite elements are defined as contiguous groups of image pixels that internally have a significantly lower variance than compared to the surrounding area. Algorithms to retrieve such elements have been proposed repeatedly (Fu, 1981; Pal, 1993; Freixenet et al., 2002). From the great variety of existing algorithms IMALYS implements two that are modifications of (a) a region-growing approach and (b) a watershed approach and have both similar and distinctive properties. The results of the segmentation procedures can be exported as vector datasets ready for display in standard GIS software.

2.2.1 Region-growing algorithm

The first segmentation method implemented is based on a region-growing approach with multiple seed points. Starting at pixel level, each image element is compared to its neighbors regarding its spectral properties. The most similar neighbor pixels are combined to cells. Being an iterative process, the algorithm grows existing cells by merging them with similar neighbor cells or pixels, considering both spectral characteristics and the contrast at the border shared with neighbor. The iteration stops if internal homogeneity and contrast to neighboring cells reach certain thresholds. The user is able to influence these thresholds through four segmentation parameters making the region-growing algorithm highly adjustable. Two parameters have major influence on the segmentation process:

- *Area contrast* controls the average size of the resulting cells. It is specified as a relative number between 0 and 1. With the parameter approaching 0, the algorithm tends to yield smaller, but more numerous cells. Accordingly, increasing *area contrast* increases the size of the resulting regions but decreases their number.
- *Edge contrast* represents a threshold for the accretion of neighboring pixels or cells and controls the tendency of existing cells for growing together. Like *area contrast* this parameter is to be specified as a relative number between 0 and 1. A smaller *edge contrast* corresponds to a lower threshold, meaning that neighboring cells are more likely to grow together.

Additionally there are two minor parameters controlling the algorithm:

- *Weighting geometry* controls the weighting of input channels. It specifies a threshold size until cells are grown by exclusively considering the channel with the highest spatial resolution, normally a panchromatic channel. It is specified as a number of pixels and is only effective when multiple input channels with different spatial resolutions are present.

- *Minimum mapping unit* influences the size of the smallest cell in the segmented image. It is specified as a number of pixels.

A sample segmentation result for the region-growing algorithm is shown in the upper part of Figure 2.

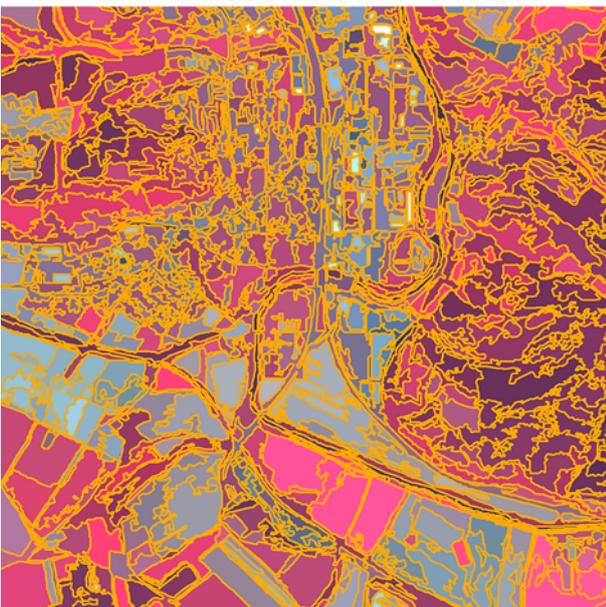
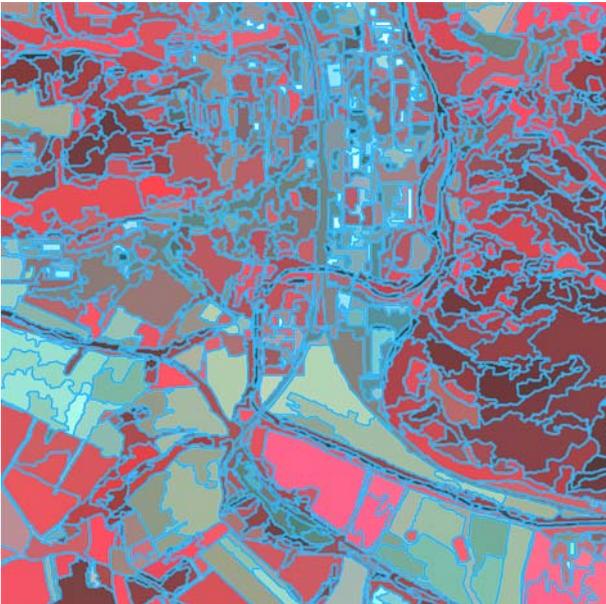


Figure 2. Sample results for the segmentation algorithms implemented by IMALYS. The upper image displays a result of the region-growing approach; the lower image shows a segmentation conducted by using the watershed algorithm.

2.2.2 Watershed algorithm

The second algorithm implemented by IMALYS is a modified watershed algorithm. It differs from the region-growing approach as pixels are not combined by exclusively considering relative similarity with their neighbors. Instead grouping into cells is only conducted if similarity exceeds a certain threshold, i.e. if the contrast between neighboring pixels stays under a given limit. Resembling a rising water level, each iteration increases this limit allowing for more pixels to be added to

existing cells. The watershed approach almost exclusively adds single pixels to neighboring cells and is therefore very restrictive regarding the merging of already existing larger cells.

As this algorithm uses the normalized maximum contrast or modulation (Schowengerdt, 2007) as foundation for the comparison of neighboring image elements, it is able to calibrate itself by retrieving this statistical parameter from image data first and then using it as input parameter for the segmentation process. The parameters influencing this algorithm can still be adjusted manually and include:

- *Modulation factor* represents the basic contrast threshold between pixels that can be considered as not being induced by noise. It is possible to apply the value calculated beforehand by IMALYS or to adjust it according to special needs.
- *Capturing threshold* is a modification of the minimum-mapping unit parameter of the region-growing algorithm. It controls the minimum size of the created cells. Provided that maximum possible contrast between neighboring pixels is present in the image, a value of 1 for this parameter will yield in the smallest resulting cell having a size of 1 pixel. Starting at 1, this parameter is specified as a natural number.

A sample segmentation achieved by the watershed algorithm can be found in the lower part of Figure 2.

2.2.3 Segmentation quality assessment

As it is crucial to provide image segmentations that can be objectively referred to as good quality, effort has been put into the evaluation of the IMALYS segmentation procedures. An empirical assessment based on a goodness measurement approach is described in Reinhold et al. (2008). Results from this assessment have been incorporated into the further development of IMALYS' segmentation algorithms.

2.3 Attribute retrieval

The homogeneous regions derived by image segmentation serve as foundation for the retrieval of a variety of attributes and features. The combination of cells and their associated attributes represents an abstraction of the analyzed imagery that – with the choice of suitable segmentation parameters and significant features – is able to hold as much information content as the original data. Thus this combination allows the application of methods of object based image analysis during the classification process conducted later on.

Initially IMALYS regards the physical characteristics of cells as features. They are derived from the original image elements, the geometry of the derived cells and their proximity relations. Additionally for each cell a spatial context is established that represents the physical characteristics of its geographical environment. The user is enabled to define new features by combining existing ones using simple mathematical expressions.

2.3.1 Retrievable types of attributes

Following is a more detailed outline of the types of attributes integrated in IMALYS:

- Spectral features are primarily derived from cell color by using an average calculation comprising the entire cell area; e.g. channel mean, color density, brightness.
- Pixel-related features include texture calculations for each of the derived cells. IMALYS is also able to

identify repeating feature characteristics within a certain distance of the currently examined cell, i.e. feature 'echoes'. The user is able to adjust both distances and directions to be used in the search for such echoes.

- The retrieved cells are used to derive simple shape characteristics such as area, length and width as well as combinations of them.
- The relative location of the cell within the entire image is registered. Additionally IMALYS establishes a complete cell topology, i.e. it identifies and registers the spatial relations of each cell and its neighbors.
- Context features assess the frequency distribution of certain feature characteristics in the surroundings of each cell considering both direct and indirect neighbor cells.
- Combined features are complex combinations of the features discussed above. Typical standard combinations such as NDVI (cf. Figure 3) are already incorporated; user-defined combinations are possible using an in-built formula editor.

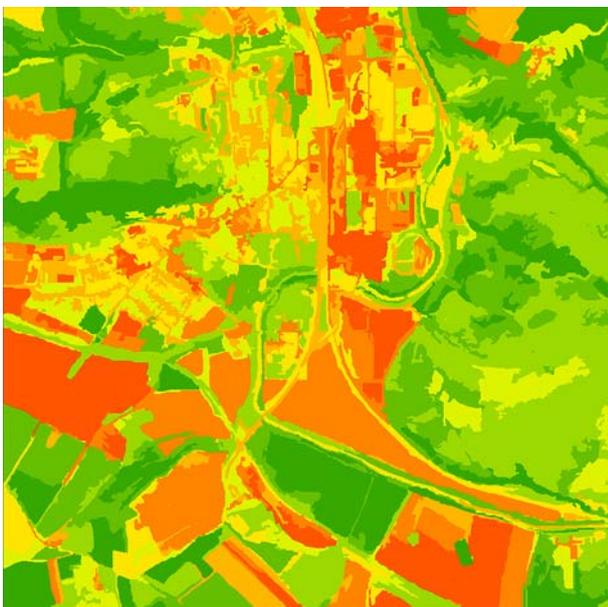


Figure 3. A sample result of the IMALYS feature retrieval. Depicted is the NDVI of each cell. The more greenish colors represent cells with higher vegetation activity.

Both incorporated and combined features are stored in a database table. This table can be modified externally to integrate results of previously conducted classifications or other thematic attributes. The IMALYS classifier treats all registered attributes equally, i.e. it does not distinguish between features IMALYS derived itself and such that were complemented by the user.

2.3.2 Filter application

Using the attribute retrieval capabilities of IMALYS it is also possible to create different views on the data currently studied. In Figure 4 the result of a modified Laplace filter operation is shown that was applied to allow the discrimination of settlement and non-settlement regions. Besides from its use during the classification process this kind of structure information can also be exported and used separately.



Figure 4. Result of a modified Laplace filter operation conducted with IMALYS. In combination with a dataset as shown in Figure 3, this kind of information can for example be used to discriminate different residential sealing classes.

2.4 Classification

IMALYS has been designed as a system supporting users with a given area of expertise that are in need of object based image analysis capabilities. To use the IMALYS classification system it is therefore basically sufficient to select geographical objects in the examined imagery and to make them available to the system as reference data. Provided that it can access enough information, IMALYS then classifies the image according to these references.

Two different classifiers are implemented by IMALYS: (a) a pattern classifier using fuzzy logic and (b) a rule-based classifier. Usually both are used in succession with the rule-based classifier reducing the possible classes for certain cells to a manageable number first and the pattern classifier then assigning the final class in ambiguous cases. To reduce the number of possible feature combinations a parameter optimization is conducted for the provided reference data before the implemented classifiers are applied to all of the derived cells. A special case is the (c) fabric classifier that combines both pattern and rule-based classifier to act exclusively on pairs of cells.

2.4.1 Reference data and feature optimization

References in IMALYS serve as examples for an automated classification process as they designate typical and well-known geographical areas that can be considered as part of a certain object class. The system is able to apply references that are provided in both vector form or as thematic bitmap, an exemplary reference data set is shown in Figure 5. Internally IMALYS creates separate subclasses for each reference, allowing for the subsumption of relatively heterogeneous areas under a single class name. Under the assumption that reference areas contain numerous and very similar cells, IMALYS uses an optimization function to filter features and feature combinations from the provided attributes to describe the desired object classes as completely as possible yet with as few features as possible. This is accomplished by a genetic

algorithm that tries to reproduce the provided reference data exactly while continuously applying small modifications to the range of features being used to do so. It retains successful combinations and discards unsuccessful ones until a stable state is reached. Thus the number of input attributes into the classification process is reduced and the significance of certain feature combinations for specific object classes can be determined. Using the defined references and the optimized input features a classification is conducted using the different implemented approaches resulting in a thematic dataset (cf. Figure 6).

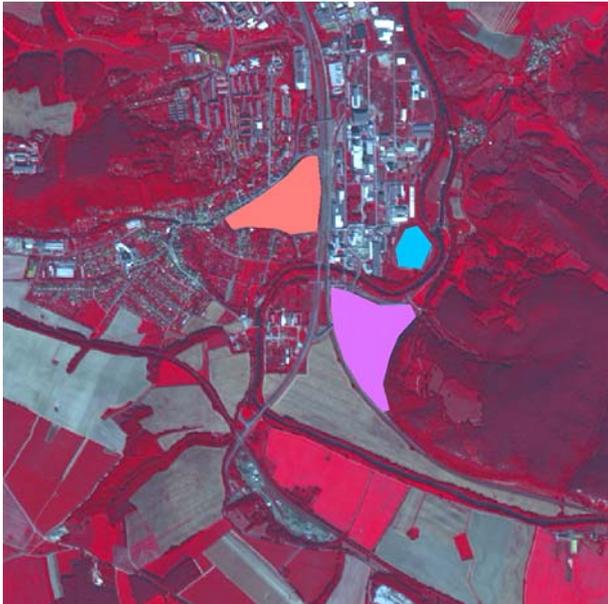


Figure 5. A sample reference data set. The specified polygons represent residential (red), industrial (violet) and other anthropogenically influenced (blue) areas. Comparing with Figure 2 it is noticeable that reference areas need not to fall together with cell boundaries.

2.4.2 Pattern classifier

The pattern classifier is based on fuzzy logic. It compares each cell with all provided reference areas and then calculates an according degree of similarity. Finally the cell is assigned to the object class with the highest degree of similarity. As IMALYS is able to weight certain features and feature combinations for specific object classes, it is able to classify each class with a range of specially defined input features. Normally, the image is classified completely by using this approach. Yet if reference areas overlap in feature space, IMALYS is able to reject a class designation for each cell falling in this space. Instead these conflict situations can be assigned to a special class that eventually includes all rejected cells.

2.4.3 Rule-based classifier

This classifier bases its decisions on features spaces that can be considered as very reliable for a given object class. A cell is assigned to a certain class if and only if it complies with a number of rules defining this class. Otherwise it is assigned to special rejection class. The classifier can be adjusted to act restrictively, thus only allowing cells to be classified that correspond to at least one reference in each of its features. In combination with very accurately defined reference areas this approach rejects most of the examined cells – which can be a desired effect given the analysis task.

2.4.4 Fabric classifier

This approach uses both pattern and rule-based classifier in one single working step. It is able to collectively detect typical feature combinations of the cell itself and in regard to its neighbors. The fabric classifier is not applied on single cells but only on pairs or groups of neighboring cells. To comply with this classifier two adjacent cells will have to have matching features and feature combinations according to the ones that were specified as references.

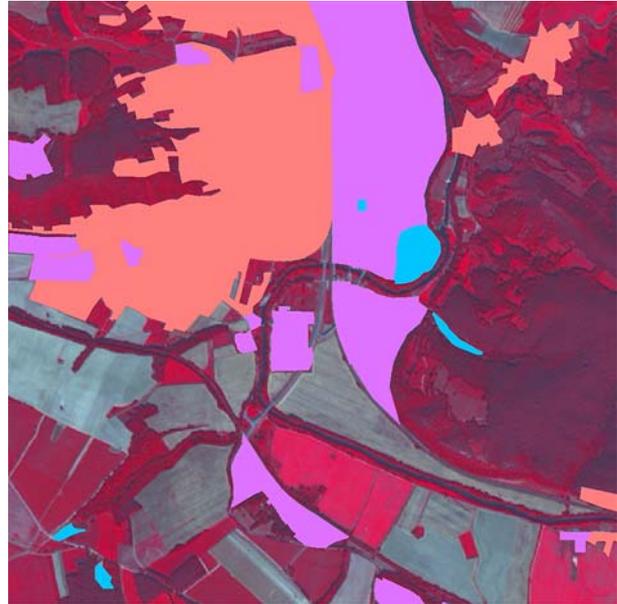


Figure 6. Classification result using the reference data shown in Figure 5. Here IMALYS was used to discriminate different types of settlement structures.

3. IMALYS DEVELOPMENT

3.1 Identification of development tasks

Further development of IMALYS is conducted within the scope of the ILMS research project and aims at enhancing its current functionality by increasing the degree of automation and portability of the provided object based image analysis capabilities.

In order to accomplish these goals the following development tasks have been identified:

- The conceptual design of a database structure able to contain a knowledge library that is to be established by information retrieved from manual and automated examination of imagery, 'experience' from existing thematic analyses and external ancillary data.
- The development and implementation of algorithms to assess features stored in the library and their relevance for a stable thematic classification that is independent of the original data quality.
- The conceptual design of a suitable data model and logic that is able to conduct the currently implemented classification procedures with the help of the established knowledge library and within the database environment.
- Suitable methods to allow a subsequent generalization of cell boundaries according to their respective class assignment.
- The integration of the IMALYS system into a GIS environment and thus enhancement of its usability and

productivity; this will also allow the communication with other modules of ILMS.

3.2 Recent activities

In preparation of the knowledge library, a catalog containing sample single objects and object classes has been established using high-resolution satellite imagery (QuickBird and SPOT) from study areas in Europe including the cities of Erfurt (Germany), Barcelona (Spain) and Dublin (Republic of Ireland). To assemble object definitions, the satellite scenes have been interpreted visually and typical object measures have been registered manually. Additionally, the definitions have been complemented by sample pictures and verbal descriptions. Figure 7 shows a sample excerpt from the catalog. Additionally, a comprehensive research on standard definition schemes for land use classification has been conducted. The comparative analysis allowed for the preparation of class definitions that are both consistent and comprehensive.

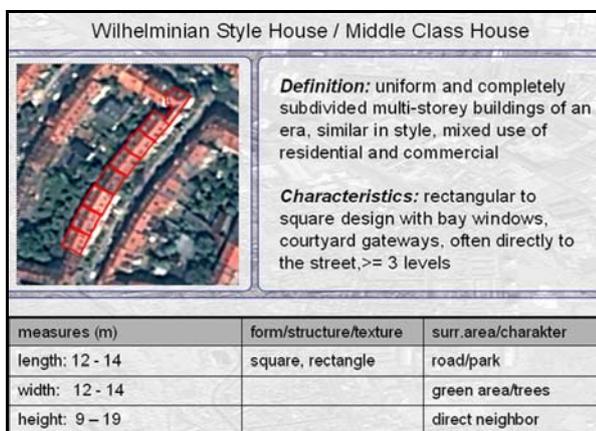


Figure 7. Excerpt from the established object catalog.

Furthermore, effort has been put into the conceptual design of a knowledge library. Starting with the database table containing retrieved cell attributes the next goal is to implement the rule-based classifier within the relational database system. As environment for this development PostgreSQL was chosen as it provides a variety of functions for the management and processing of spatial data.

Concurrently the existing functionality of IMALYS as independent software prototype is steadily refined and extended.

4. CONCLUSIONS

With IMALYS, this work presents a software prototype for the identification and classification of real-world objects from satellite imagery using methods of object based image analysis. It is designed to work highly automated and is already used in a production environment. IMALYS currently implements robust algorithms for the extraction of cells from image data, the retrieval of features for these cells, and the classification process including feature optimization and the incorporation of reference data.

Practical and structural efforts are needed to establish a knowledge library comprising experience from previous classifications as well as ancillary information and to integrate the software prototype into a GIS environment. Furthermore IMALYS is to be integrated in an Integrated Landscape

Management System (ILMS), providing image analysis services to other ILMS modules.

The goal of IMALYS development is a software environment that enables the user to retrieve, store and apply information on image representations of real-world objects simultaneously with his practical work. If IMALYS succeeds, it will be able to cope with the complexity of contemporary satellite imagery and comply with the risen demands on object based image analysis.

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