AUTOMATED CHANGE DETECTION FOR THEMATIC DATA USING OBJECT-BASED ANALYSIS OF REMOTE SENSING IMAGERY

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Commission VI, WG IV/4

KEY WORDS: Software, Change Detection, Automation, Segmentation, Method

ABSTRACT:

Change detection is a major application domain for image analysis techniques in remote sensing. Besides the analysis of multi-temporal imagery there is also the need to update or revise previously created thematic data with the help of recently acquired imagery. The emergence of object-based image analysis provides another approach to the change detection problem and derived methods and algorithms have been applied to it accordingly. Simultaneously there is continuous demand for techniques that produce results that are GIS-ready. In this study we put forward a proposal for automated change analysis for thematic data using an object-based image analysis methodology. It is implemented within the scope of IMALYS, a software system able to conduct a comprehensive object-based investigation of remote sensing imagery including segmentation, feature retrieval and classification. Segmentation is conducted based on a hybrid approach with the emphasis on a low-degree-of-freedom system. Retrievable attributes for the created segments include a number of built-in features as well as ones defined by the user. For identification of real-world objects the presented software implements a two-stage process consisting of an unsupervised classification based on self-organizing maps and a supervised classification based on a context-sensitive object model. For change detection the latter process can be provided with training data based on existing thematic mappings. Using statistical analysis the presented software is capable to relate the underlying imagery to previous mappings or classifications results. The result of this process is a measure of probability of a certain segment to be still part of the previously assigned class. As this process is based on statistical calculations it is not only suitable to be applied on large areas and data volumes but also dependent on such conditions. The introduced software is integrated in a GIS-environment and its results can be therefore easily incorporated in following workflows and processes.

1. INTRODUCTION

Remotely sensed imagery is characterized by a number of challenges arising in the processes of its retrieval, storage and analysis. Adding to the amount of digital data that requires efficient handling it provides complex information content at more or less regularly repeating intervals demanding standardized and operational analysis. This includes the detection and assessment of real-world changes between two points of time or during a given period of time.

Additionally there is growing demand to integrate remote sensing data and their processing into information systems for integrated management of landscape and other resources. With ILMS (Kralisch et al., 2006) one of these efforts serves as underlying development framework for the presented software system IMALYS that in turn provides image analysis capabilities implemented to cope with the aforementioned challenges. IMALYS was developed as software prototype to apply highly automated information extraction procedures to remotely sensed data.

Following this introduction, a short section will summarize object-based image analysis and change detection – two key areas of research that are connected with the presented work. Afterwards the current implementation of IMALYS and the proposed method for automated change detection will be presented. This study is completed by a brief overview of current development goals and concluding remarks.

2. BACKGROUND

The proposed method is based on two key concepts, namely object-based image analysis and change detection. The following section will therefore give a general outline of theories and developments concerning these two focal points of research.

2.1 Object-based image analysis

Object-based analysis is a concept of image investigation that encompasses spatial and semantic context into the extraction of real-world phenomena from remotely sensed data. Research in this domain focuses on complexity reduction techniques for image data, loosely combined under the term image segmentation, and on strategies for thematic classification and object extraction using the resulting image entities and their corresponding attributes and features.

Image segmentation is a prerequisite for object-based image analysis as it aggregates image pixels to larger groups that, while being statistically homogeneous internally, differ from their neighbouring regions. Image segmentation has been a well studied field of research in both geographic (Lübker, 2009; Neubert, 2008) and non-geographic domains (Freixenet et al., 2002).

Using shape of and spatial relationships between image segments allows for the incorporation of additional information into the subsequent process of image analysis. The inclusion of

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ancillary data (Chen et al., 2009) and the application of sophisticated classification strategies (Marpu et al., 2008; Zhou et al., 2009) are two additional focal points of studies conducted within the scope of object-based image analysis.

With IMALYS we have a software system for object-based image analysis at hand that does not disregard pixel-based approaches completely but aims at their integration into object extraction and classification as valuable pre- and post-processing methods.

2.2 Change detection

Analysis and assessment of changes in multi-temporal data has been a key area of research ever since the introduction of remote sensing techniques (Dueker, 1972; Weismiller, 1977). This is natural as only the ability to detect and qualify changes allows making full use of repeatedly acquired imagery. Accordingly, a great variety of approaches has been proposed (Ghosh et al, 2009; Ouma et al, 2008) and numerous areas of application (Li, 2010; Bishop et al., 2007) have been presented. Several attempts have been made to construct a systematic overview of change detection techniques, most recently by Gong, 2008 and Lu, 2004.

The most common approach to change detection has been the analysis of multi-temporal imagery predominantly acquired by the same or a similar sensor system. (Bazi, 2009) More recent efforts aim at the establishment of techniques that include multiple and differing sources of imagery as well as different types of data as foundation for analysis and assessment. The latter include approaches to use change detection techniques in order to update existing databases of vector type information, i.e. represented and visualized by GIS (Tourneret et al., 2009; Walther, 2004). These approaches are getting more and more important as with the increasing number of sources for original imagery the amount of thematic data derived from these sources also multiplies. Other motives to focus on the development of change detection techniques that use thematic data as input may be inaccessible original imagery for the required point or period of time or the aspiration to include data that has been retrieved from non-remote sensing sources.

The presented change analysis method was implemented in IMALYS as a tool for automated comparison between existing thematic datasets, represented by a corresponding set of GIS layers, and remotely sensed imagery of the according investigation area. IMALYS then uses its object-based capabilities to detect real-world variations between both points of time.

3. CURRENT IMPLEMENTATION

3.1 Development platform IMALYS

The underlying development platform for the presented methodology is provided by IMALYS, a software prototype implementing several capabilities for object-based analysis of remote sensing imagery. IMALYS uses a multi-level abstraction starting with the original imagery as input and aiming at the extraction and classification of real-world objects as output. More detailed descriptions of the system can be found in Matejka et al. (2008) and Reinhold (2009). Here we will confine ourselves to a short explanation of IMALYS' key concepts following a typical workflow including (1) image segmentation, (2) attribute and feature calculation, (3) unsupervised classification based on self-organizing maps and (4) supervised classification utilizing a set of reference data. Figure 1 displays a sample remote sensing dataset that will be used to visualize features and results of working with the IMALYS system.

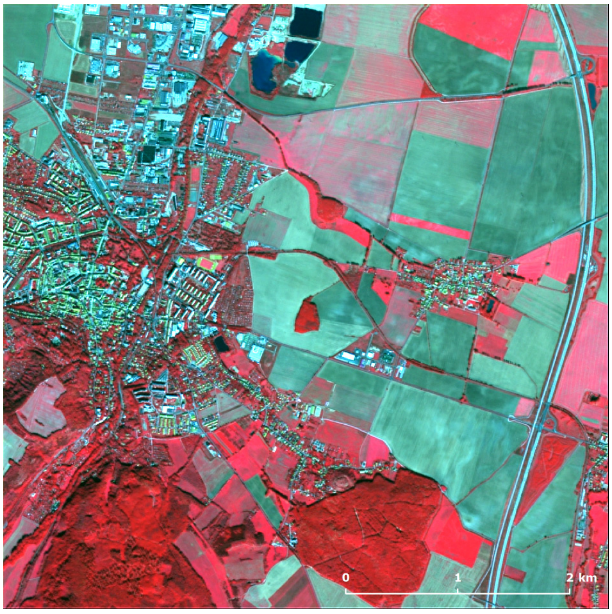

Figure 1. SPOT resolution merge of the demonstration scene. The area depicted is the municipality of Arnstadt and its vicinity (German federal state Thuringia). Covered area is about 5.5 by 5.5 km².

3.1.1 Image segmentation

Using intensity and contrast information IMALYS performs segmentation of a provided input dataset, which optionally can consist of multiple channels with multiple spatial resolutions. The underlying algorithm is a combination of region-growing and watershed transformation approaches and was designed to provide a relatively low mandatory degree of freedom. That is why the method can be controlled using a single major input parameter, represented by a measure for the average size of the resulting segments based on the normalized maximum contrast or modulation (Schowengerdt, 2007) of the input data. Optionally it is possible to further adjust image segmentation by a number of minor parameters such as minimum mapping unit, etc. The segmentation process results in an initial abstraction of the original data. Elements comprising this level of abstraction can be considered objects in the image domain, however they don't necessarily represent objects in the real world. A sample segmentation result is displayed in Figure 2.

3.1.2 Attribute and feature calculation

As realisation of a second abstraction level IMALYS is able to calculate a variety of standardized and user-defined attributes and features that are associated with the segmented regions. These are derived from the physical and geometric characteristics of the image segments as well as their proximity relations. The user is enabled to define new features by combining existing ones with the help of simple mathematical expressions. Eventually segments and derived attributes are linked to each other using a database table. By choosing suitable segmentation parameters as well as significant variety of attributes the combination of image segments and their features is able to hold as much information content as the original data. That is why IMALYS disregards the original data further on and continues to solely operate with the image segmentation layer and its derived attributes.

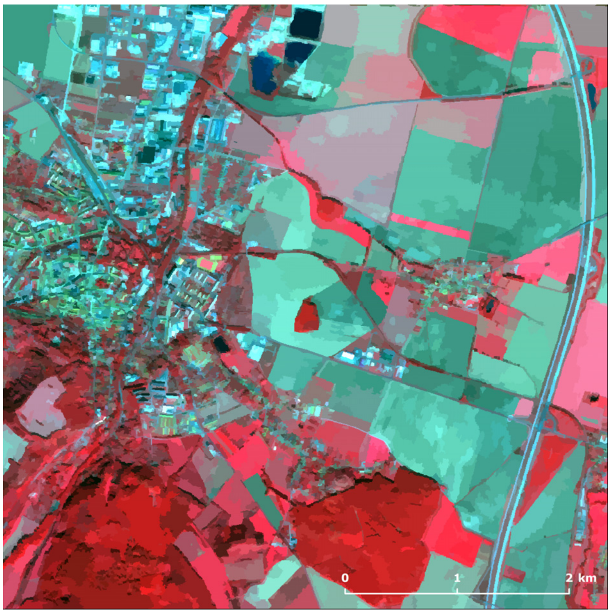

Figure 2. Sample result for the image segmentation combining region growing and watershed transformation approaches. Image segments are coloured using the average values in the near-infrared, red and green bands, respectively.

3.1.3 Unsupervised classification

As an initial classification step IMALYS implements an unsupervised classification based on the approach of self-organizing maps (SOM). Using the derived attributes and features IMALYS divides the image segmentation layer into clusters representing segments with similar characteristics. The number of resulting clusters is adjustable using a corresponding parameter. A sample result of this processing step is displayed in Figure 3.

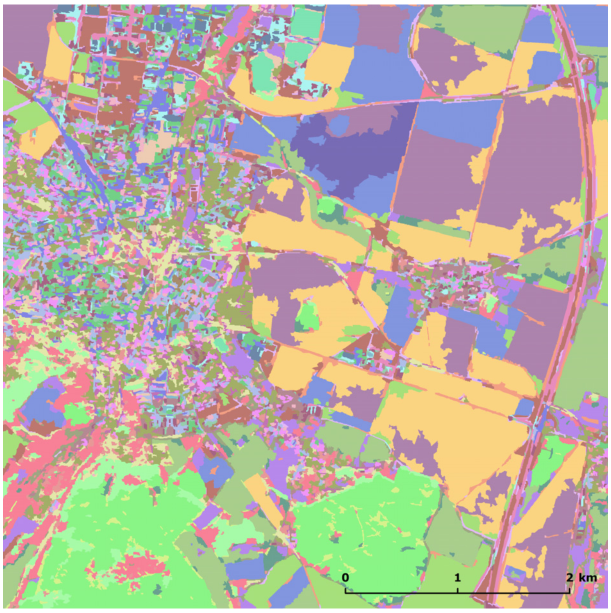

Figure 3. Sample result of the unsupervised classification conducted with the help of self-organizing maps. Image segments assigned to identical clusters are depicted with the same colour.

3.1.4 Supervised classification

Provided with a set of reference data representing the targeted classification scheme, IMALYS is able to classify the investigated data using the created clusters of image segments. In the process classes are defined as spatial combinations of different types of segments, i.e. clusters.

IMALYS uses a multi-layered and context-sensitive object model allowing for the characterization of complex compounds of segments that includes the following processes: (1) Neighbouring pairs of segments are compared to each other according to the set of derived attributes allowing for the identification of significant feature value combinations for the currently examined class. (2) The spatial proximity of each segment is analyzed to assess the relative frequency of occurrence of certain feature values in order to derive typical context characteristics for the current examined class. (3) The typical size and position of the segment in regard to the currently examined class is assessed. The result of this characterization is a classification that is represented by a fuzzy value indicating the probability of a given image segment belonging to a certain target object class. A sample result of the supervised classification process is depicted in Figure 4.

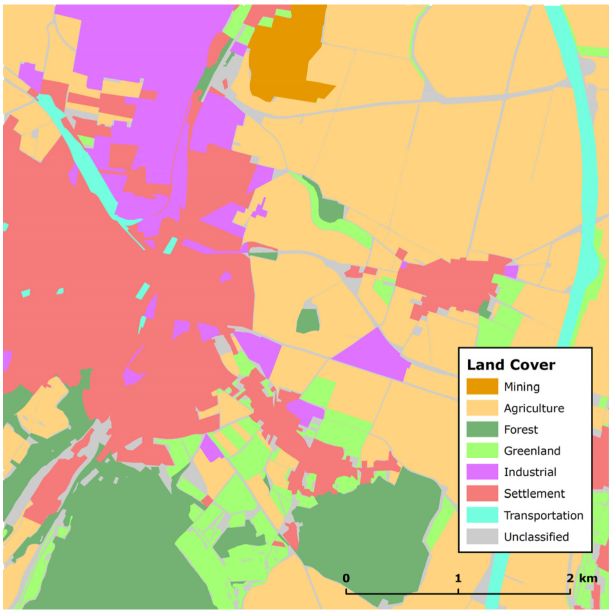

Figure 4. A sample classification result by IMALYS. Polygon borders have been smoothed and rectified in a post-processing step.

3.2 Automated change detection

To implement automated change detection the proposed approach makes use of IMALYS' way to define and use reference or training data. Reference areas are considered by IMALYS as fuzzy samples of the targeted object class. That means they are not necessarily considered to establish a fixed set of attributes and attribute combinations but instead to provide an outline of what could be typical for the currently considered class. That allows for IMALYS to cope with large and comparatively heterogeneous reference definitions as it is utilizing statistical analysis of the underlying data to extract those attributes and attribute combinations that were found to be most significant and characteristic for a given object class. Additionally there is no size limit for training data definitions, allowing for the creation of large and uninterrupted reference areas that even could cover a majority of the investigated imagery. Using this feature it is possible to provide an existing thematic dataset, such as a previously conducted land cover classification or a number of extracted objects, as reference data to IMALYS. The resulting fuzzy classification calculated by the system can then be interpreted as a probability of stability indicating whether change has taken place between the existing thematic dataset and the acquisition time of the investigated imagery.

There are a number of conditions that need to be fulfilled to make this approach feasible. It is obviously more effective when a large sample size of data – both regarding the size of an existing reference data set as well as the amount of up-to-date imagery – is utilized. Additionally the changed parts that are to be extracted must not be dominant in the reference area definition otherwise they and their attributes would be considered characteristic for the according object class. Finally, and this is a general prerequisite for all approaches that relate existing thematic data layers to imagery sources, the underlying class definition need to be not too far abstracted from the underlying imagery. This problem can eventually be reduced to the question what level of abstraction can actually be derived from imagery and needs to be addressed within a more fundamental scope.

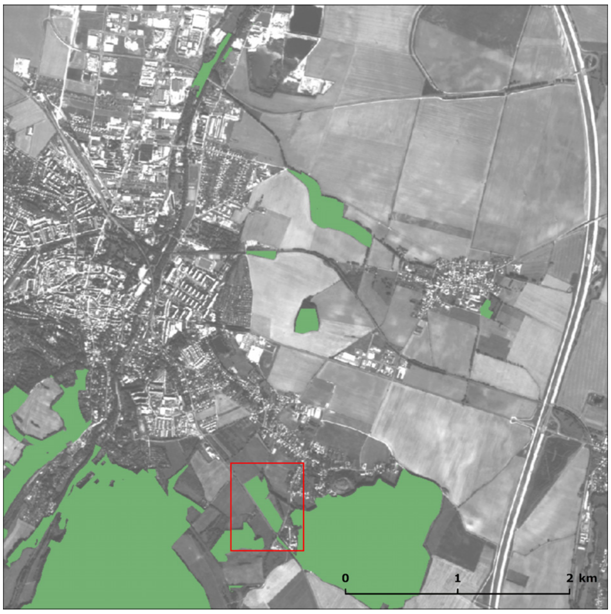

Figure 5. Thematic data layer representing forested areas superimposed on panchromatic sample scene. The simulated area of change is indicated

To exemplify the proposed methodology an existing thematic dataset representing forested areas provided by the Thuringia State Office of Surveying and Geoinformation is depicted in Figure 5. For demonstration purposes an area of assumed change has been added to the dataset by deliberately assigning it to the forest layer.

After processing using the proposed method it is possible to indicate parts of the thematic data layer that – given the investigated imagery and based on the selected image segmentation and derived attributes – are most likely to have changed. Using the reciprocal of this relation these parts correspond to the areas with the least probability of stability. An according visualization of this result is displayed in Figure 6. It is clearly visible that – among others – the simulated area of change in the lower centre part of the image has been adequately detected.

4. CURRENT DEVELOPMENT

Current development of the IMALYS system aims at enhancing its existing functions by increasing the degree of automation and portability of the provided object-based image analysis capabilities. In order to accomplish these goals it is necessary (1) to develop and implement algorithms that are able to assess features and their relevance for a considered object class in order to establish stable classification criteria that are independent of the original data, (2) to design and implement a feasible database structure to contain knowledge retrieved from the process of image analysis and (3) to further integrate the IMALYS system into a GIS environment to enhance its linkage with other modules in the underlying ILMS framework and to assure its usability and productivity.

To establish a comprehensive change analysis methodology it is further necessary to extend the presented detection approach by adding the change assessment capabilities, i.e. the possibility to indicate what kind of change has occurred.

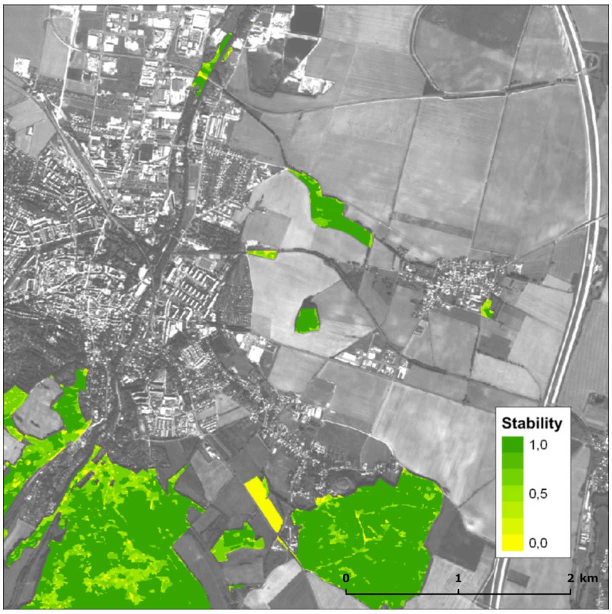

Figure 6. Result of the automated change detection approach. Areas that are less stable and more likely to have changed are shown in yellow colours.

5. CONCLUSIONS

The presented software system IMALYS provides object-based image analysis capabilities in order to identify and extract real-world objects from remotely sensed data. These capabilities include segmentation of input imagery into statistically homogeneous regions, calculation of segment-based attributes and features and a two-stage classification process consisting of an unsupervised self-organization and a supervised classification based on a context-sensitive object model.

Using these capabilities it is possible to conduct automated change detection for thematic data by using a corresponding layer as large-scale reference area. By relating the provided data layer with the given imagery IMALYS is then able to retrieve significant attributes and attribute combinations to finally result in a fuzzy classification. This fuzzy classification can be interpreted as a measure of stability within the defined reference area and indicates most likely occurrences of change between the two investigated points of time.

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ACKNOWLEDGMENTS

The authors wish to thank the German Federal Ministry of Education and Research that is funding the underlying research project ILMS in the course of the program "Entrepreneurial Regions – the BMBF Innovation Initiative for the New German Länder" under reference number 03IP514.