Pixel-based and object-oriented change detection analysis using high-resolution imagery

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Abstract

The high spatial resolution of state-of-the-art commercial satellite imagery provides a good basis for recognising and monitoring even small-scale structural changes within nuclear facilities and for planning of routine and/or challenge inspections of nuclear sites. Despite the advantages of the improved spatial resolution some problems exist that may make the interpretation of the changes more difficult: Firstly, the results of the change analysis can be very complex and unclear at a glance. Secondly, shadow formation and off-nadir images due to different sensor and solar conditions at the acquisition times can cause false signals or overlap real changes.
In view to the fast-growing amount of data from different sensor types there are then some requirements of an effective change detection procedure for safeguards purposes: i. The techniques involved should possess a certain amount of robustness in terms of small misregistration errors, different atmospheric conditions at the acquiring dates, off-nadir angles. ii. Given large multisensor data sets it would be necessary that the procedure operates as automatically as possible. Iii. The procedure has to imply techniques to initially pinpoint out those parts of a scene in which significant changes have taken place. iv. All image areas indicating changes then should be subject to a detailed classification and interpretation procedure.
We have already investigated some pixel-based change detection for the routine nuclear verification, based on recently published visualisation and change detection algorithms: canonical correlation analysis (MAD transformation) to enhance the change information in the difference images and bayesian techniques for the automatic determination of significant thresholds. Some steps have been taken by combining pixel- and object-oriented approaches, i.e. MAD transformation of the image data and object-oriented post-classification of the changes and object extraction for the image data or MAD transformation of the objects and post-classification of the change objects. Another approach implies a solely object-oriented change detection technique: Object extraction, semantic classification and post-classification comparison by means of a change matrix.
The object-oriented change analysis procedures are carried out with a relatively new technology for image analysis, eCognition (http://www.definiens-imaging.com).

Keywords: change detection; pixel-based techniques; object-oriented approaches; high-resolution satellite imagery; safeguards purposes;

1. Introduction

Change detection procedures intend to find and, where appropriate, to interpret the alterations of objects or phenomenon between the different acquiring times t_1, t_2 ... t_n. When using multitemporal remote sensing image data, the value of an image pixel or object at time t_1 can be compared with the value of the corresponding image pixel or object at time t_2 in order to determine the degree of change.
Many different procedures have been developed within the last 30 years, depending on the given spatial, spectral and temporal resolution of the available imagery and the computer capacities in regard to digital image processing. Reviews of change detection techniques are given in [1-4].
At the same time, the variety of change detection applications has increased. Whereas the first change detection studies particularly focused on large-scale and possibly long-term changes of land use and land cover, i.e. vegetation, forest, agriculture, water, urban areas, recent procedures

may also realise small-scale and short-term changes within urban areas or ecosystems. The improvements in spatial and spectral resolution bring with them new applications in new fields, for example the verification of international treaties on nuclear disarmament and non-proliferation. Now, the high spatial resolution satellite imagery from state-of-the-art commercial satellites IKONOS and QUICKBIRD provides a good basis for recognising and monitoring even small-scale structural changes within nuclear facilities and for planning of routine and/or challenge inspections of nuclear sites.

2. Methodology

A comprehensive change detection system for nuclear verification purposes has to imply pixel-based techniques for geometric registration, radiometric normalisation, image fusion/sharpening and statistical change-/no-change-analysis of medium- or high-resolution imagery. Statistical change detection techniques may calculate the change of the spectral or texture pixel values (by arithmetic procedures, regression, change vector), may estimate the change of transformed pixel values (by principal component analysis, canonical correlation analysis) or may identify the change of class memberships of the pixels (by comparison of classifications, multitemporal classifications). For the specific application of nuclear monitoring the most satisfactory results were carried out by canonical correlation analysis [5] to enhance the change information in the difference images and bayesian techniques [6] for the automatic determination of significant thresholds [7-10].

Significant changes can then explicitly be analysed and interpreted by object-oriented approaches using high-resolution satellite imagery. Analysing satellite image data in an object-oriented way generally gives the possibility to involve specific knowledge in the classification or recognition process. Specific features can be defined by membership functions in a semantic model. Preliminary results [11] indicate that the analysis and interpretation of changes within nuclear plants can be more precisely and reliably if the change detection procedure makes use of the characteristic features of facility objects and changes (e.g. compared to other industrial sites). The change detection procedure then may analyse the changes the mean object features (spectral colour, form), may compare the relations between the objects (distance between objects, location of sub-objects within super-objects, existence of neighbouring objects) or the class memberships of the objects.

The software solution for an object-oriented change analysis is given by a relatively new technology for image analysis, eCognition (http://www.definiens-imaging.com). This system shows some fundamental differences compared to other more conventional (pixel-based) techniques for image analysis. A basic part of the system is a new patented technique for the knowledge free extraction of image object primitives at different resolutions, the so-called multiresolution segmentation. The segmentation operates as a heuristic optimization procedure which minimizes the average heterogeneity of image objects for a given resolution over the whole scene. The objective is to construct a hierarchical net of image objects, in which fine objects are sub-objects of coarser structures. Due to the hierarchical structure, the image data are simultaneously represented in different resolutions. Each object “knows” its context, its neighbourhood and its sub-objects. Thus, it is possible to define relations between the objects. The defined local object-oriented context information can then be used together with other (spectral, form, texture) features of the image objects for classification.

3. Investigations

A change detection analysis procedure was carried out for two IKONOS-2 images acquired over the Pickering Nuclear Power Generating Station (Ontario, Canada) in July 2000 and July 2001 (Figure 1). The visual comparison of the images points out some of the problems related to high-resolution satellite imagery: Due to different sensor and solar conditions at both acquisition times the objects are mismatched and form different shadows.

Thus, a pixel-based change detection analysis may bring out a lot of false signals. The results of the pixel-based changed detection analysis by mutivariate alteration detection [5] are given in Figure 2. As expected, the results of the change analysis are very complex and unclear at a glance.

Fig. 1: IKONOS-2 images over Pickering Nuclear Power Generating Station, Canada, July 2000 (left) and July 2001 (right). On the left image, major changes and problems due to different off-nadir and sun angels are indicated

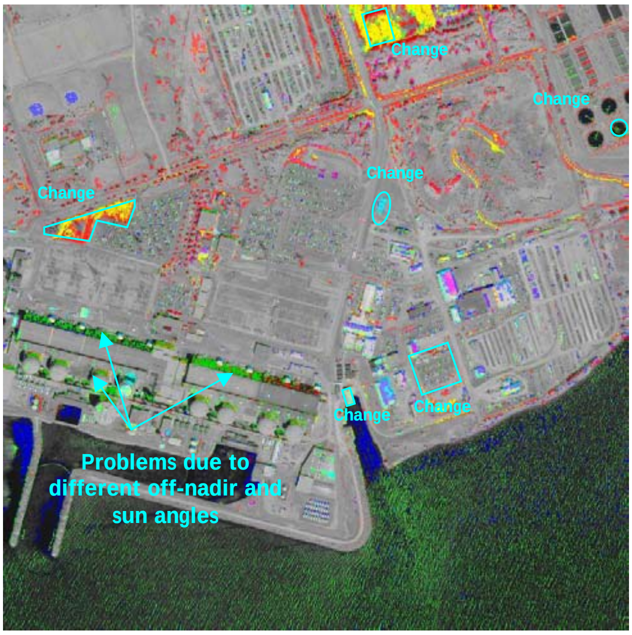

Fig. 2: Multivariate Alteration Detection (MAD): MAD component 1 in red, MAD component 2 in green, MAD component 3 in blue

Assuming that an object-oriented approach could improve the results, we implemented a second procedure (see figure 3). As input data, we used the four change components carried out with the MAD transformation of the two IKONOS-2 images. In addition, we used the original panchromatic and multispectral IKONOS-2 data of July 2001 in order have the possibility to extract real objects. The segmentation was realised on the basis of the original IKONOS-2 data in different scales, so that the individual objects of the nuclear plant are extracted in a fine level In order to extract fine objects we weight the panchromatic channel by a factor of 10. By increasing the scale parameter the objects become coarser, until the different parts of the site are included in one object (without figure). Four change classes were defined: “changes DN-“ for objects with decreased grey values, “changes DN+“ in case of increased grey values, “changes vegetation-“ for degraded vegetation and “changes vegetation+“ for accumulated vegetation. A class for water areas was added to the set of classes. The membership functions for the object description were defined in terms of standard deviations of the MAD components, some mean object values and object relations. Figure 4 shows the results of the change classification. This time, we received a very rough indication of changes

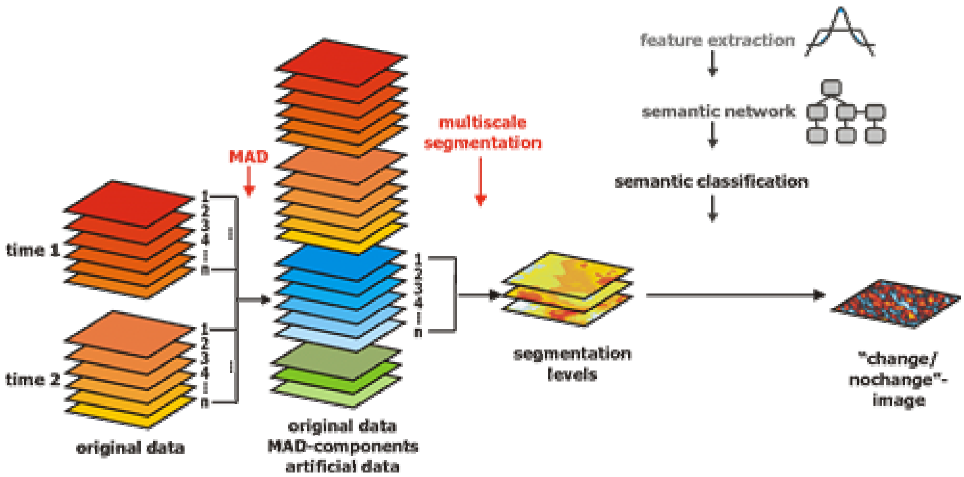

Fig. 3: Object-oriented change detection using MAD components

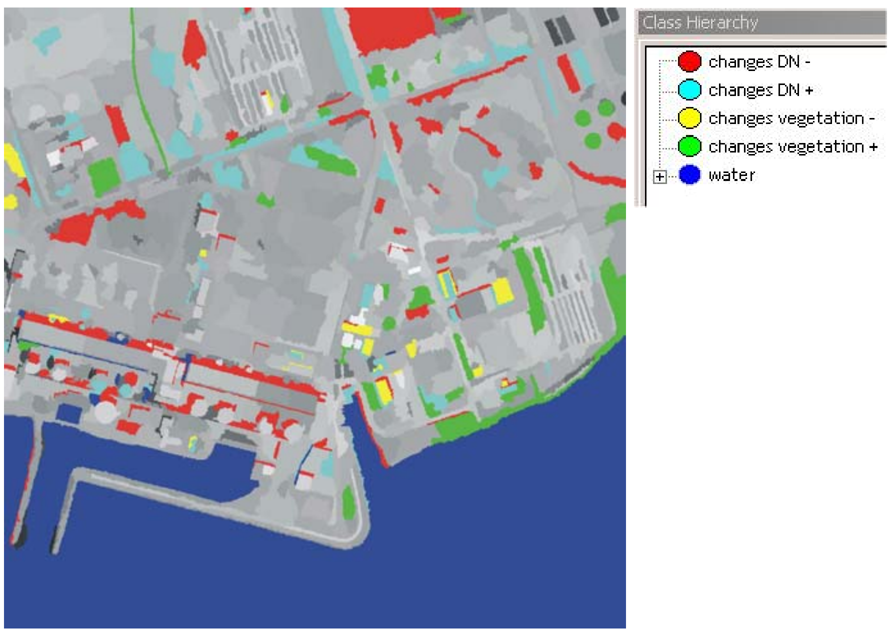

Fig. 4: Classification result for the object-oriented change detection using MAD components

4 Conclusions and Outlook

Pixel-based techniques are suitable for change-/no change-analysis of medium-resolution imagery while object-oriented approaches (with *eCognition*) seem to expand the possibilities to detect and interpret changes using high-resolution satellite imagery.

The next step should involve a solely object-oriented change detection scheme as shown in figure 5. Both images should be classified individually and then be compared by a change detection-matrix. At the moment, many “unsolved problems” in the remote sensing research community exist as to the object-oriented analysis of high-resolution image data in general, especially in terms of change detection procedures.

Recent problems are connected to the question, how to compare segmentation levels with different object boundaries in (the usual) case of different off-nadir angels. Parameters have to be found in order to quantify and qualify an object’s change between two acquisitions times. An optimal set of input image (original, normalized, artificial) and GIS (topographic maps, site diagrams etc.) layer has to be defined. Relevant classes have to be defined by objects features and class relations and the change matrix has to be specified.

For a comprehensive change detection and interpretation system signatures for different facility types in different geographical/ political areas are urgently needed. Thus, the features of the different elements of the nuclear fuel cycle - mining/milling, uranium enrichment, fuel fabrication, reactor (civil power plant), reprocessing plant, waste storage facility have to be analysed and utilised for image processing.

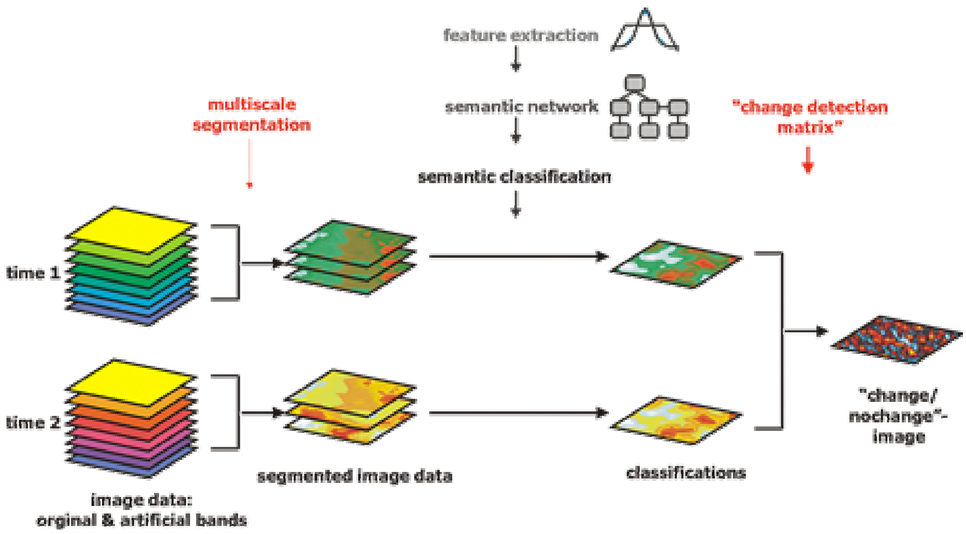

Fig. 4: Object-oriented change detection using a change detection matrix

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