Automated Analysis of Remote Sensing Data for Extensive Monitoring Tasks in the Context of Nuclear Safeguards

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***Abstract* – According to the expected technical improvements regarding the spatial and spectral resolution, satellite imagery could be more and more build the basis of complex systems in the future for recognizing and monitoring even small-scale and short-term structural features of interests within nuclear facilities, for instance construction of buildings, plant expansion, changes of the operational status, underground activities etc. A "nuclear monitoring system" for the Iran based on *eCognition Enterprise* was set up to implement and evaluate different image analysis approaches that could be relevant for nuclear safeguards applications. Regarding the necessity of automation for extensive monitoring tasks the processing aspects of standardization and transferability took the centre stage of the investigations.**

Keywords: non-proliferation treaty, nuclear safeguards, object-oriented techniques, automation.

I. Introduction

The importance of satellite imagery for monitoring and verification of multilateral agreements like the Non-Proliferation Treaty (NPT) has been effectually demonstrated by many case studies, indicating the broad potential of satellite imagery data ranging from panchromatic, multispectral, hyperspectral to radar for site description and change detection, for a comprehensive overview please see [1].

According to the expected technical improvements regarding the spatial and spectral resolution, satellite imagery could be more and more build the basis of complex systems in the future for recognizing and monitoring even small-scale and short-term structural features of interests within nuclear facilities, for instance construction of buildings, plant expansion, changes of the operational status, underground activities etc. The analysis of large volumes of multispectral satellite data from different sensors will then certainly require a high degree of automated image (pre-) processing, analysis and interpretation in order to extract the features of interest.

Though it seems to be too overconfident to replace an image analyst completely by a software system, there might me some possibilities to obtain faster and more precisely image analysis results by automated image processing procedures. In order to perform the intended processing steps on the satellite imagery stored in the database, the areas of interests are traditionally retrieved by a query on the metadata (coordinates, acquiring date, etc.) firstly and analyzed subsequently. A more advanced approach would be to realize the analysis already in the retrieval process as an image content-based query (see Fig. 1). The automation of user relevant information identification in satellite imagery by image selection on the basis of image content has already been proposed by several authors, among others by [2,3].

However, in this paper we tested the commercial image analysis environment *eCognition Enterprise* for a nuclear-safeguards related, wide-area monitoring application regarding the automation of relevant image analysis processing steps. Provided that it would be possible to implement the transferable extraction of object primitives and transferable classification models based on the object features in the given monitoring system, the users would be able to apply object extraction and classification directly to the satellite imagery in the database.

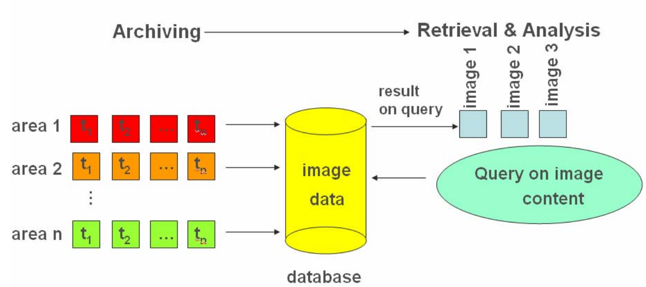

Figure 1. Image content based queries within an image database

Thus, queries like "find areas with huge construction projects", "find areas with significant changes of industrial sites between 2002 and 2004", "find all areas with industrial sites located nearby water", and others could be realized for the database image data.

II. ECOGNITION ENTERPRISE

By means of *eCognition Enterprise* an automatic workflow can be defined for data access and management, object extraction by segmentation, classification with rulebases and project handling. *eCognition Enterprise*, being a modular, multi-server, multi-user environment, consists of the following modules (see Fig. 2):

Figure 2. Modules of *eCognition Enterprise* (© Definiens Imaging)

- Developer studio, offering the same functionality as *eCognition Professional* [4];
- client(s), allowing allows the user(s) to access and manage the database, store image data in a structured manner, and process single images or groups of images with the help of rulebases;
- server and database server, carrying out the analysis of image data with the aid of *eCognition* rulebases, thus being the central elements of *eCognition Enterprise;*
- database, used to store, manage and retrieve image data, thematic information, rulebases, results, projects, and statistics in Orcale® or Microsoft Access®;
- middleware, (Java message service, JMS) being responsible for the communication between the different *eCognition Enterprise* components.

Fig. 3 shows the typical workflow within *eCognition Enterprise* and the interaction between the modules

Against the background of standardization and transferability, this study was carried out in order to determine both a fixed set of transferable segmentation parameters and number of levels and to define satisfactory and transferable object features for object classes that are relevant in terms of nuclear safeguards applications.

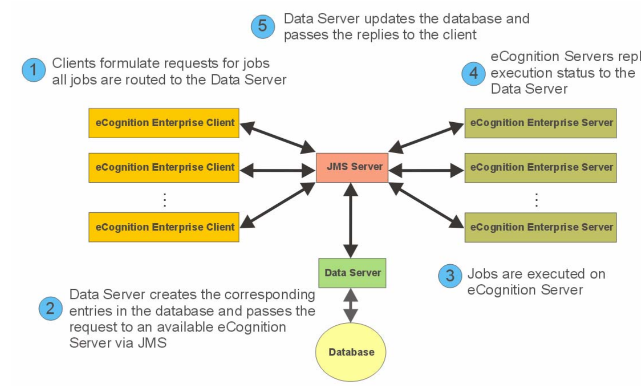

Figure 3. Workflow within *eCognition Enterprise*

III. WIDE-AREA MONITORING IRAN

Seeing the recent proliferation implications of Iran`s advanced nuclear program due to the potential of dual-use activities within uranium enrichment and reprocessing [5], a so-called nuclear monitoring system for the Iran was set up as an application (Fig. 4). In the first instance, multitemporal area-wide ASTER imagery (AST_07, surface reflectance with 15m (VNIR) and 30m (SWIR) spatial resolution) for 17 nuclear-related locations built the database for this system, accompanied by different kind of open source information and completed by high-resolution imagery from QUICKBIRD for some areas of interests. More satellite image data could be added later on demand.

Figure 4. Nuclear monitoring system for 17 nuclear-related locations in the Iran

Different image analysis approaches probably relevant for nuclear safeguards applications were implemented and evaluated. In general, a two-steps attempt was realized beginning with the wide-area monitoring on the basis of the medium-resolution ASTER data for the pre-scanning of areas of interest, i.e. significant changes within the nuclear-related locations, which then could be explicitly analyzed by analysis methods using the high-resolution QUICKBIRD image data. Regarding the necessity of automation for extensive monitoring tasks the processing aspects of standardization and transferability took the centre stage of the investigations.

IV. Investigations

A. Pre-scanning: Wide-area monitoring using medium-resolution satellite imagery

The so-called pre-scanning is intended for the detection of potential nuclear-related undeclared activities and the inspection of declared nuclear sites and their surrounding areas. ASTER imagery of the sites located at Arak, Bandar Abbas, Busheer, Esfahan and Natanz were used as training data in order to determine a fixed set of segmentation parameters for a sufficient multiresolution object extraction and to define satisfactory and transferable object features for object classes that are relevant in terms of nuclear safeguards and

For the standardization of the object extraction both solely multiresolution segmentation and a combination of chessboard and multiresolution segmentation was carried out. With respect to an acceptable computing time the latter segmentation was conducted as follows: After segmenting the image into a coarse chessboard grid, homogeneous chessboard cells with standard deviations about the VNIR mean values below a specific threshold were excluded from the further segmentation, assuming that homogenous cells defined that way are unlikely to contain small-scale heterogenic (i.e. anthropogenic) structures. The remaining cells were then divided in a finer chessboard, homogenous chessboard cells removed again on the basis of the standard deviation, the residual cells tiled into a yet finer grid and so on until reaching the defined minimum cell size. Only the pixels left thereafter were finally involved in the more time-consuming multiresolution segmentation process (Fig. 5).

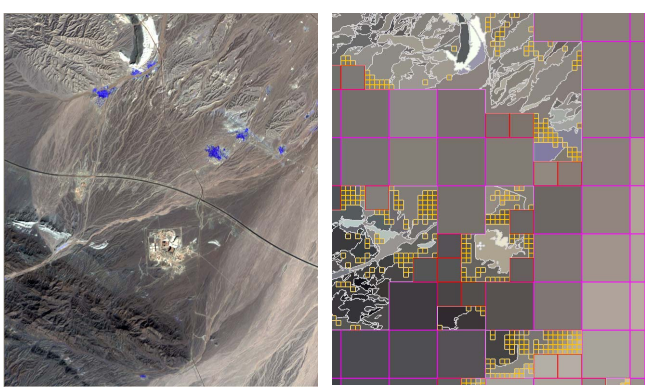

Figure 5. Extract of AST_07, green (R), red (G), NIR (B) over Natanz (left) and its chessboard/multiresolution segmentation, level 6 (right)

For the detailed object classification a standardized and transferable semantic model was meant to develop being able to perform satisfactory results for all given ASTER (AST_07) scenes. In order to avoid the likewise time-consuming "trial-and-error" practice while seeking for significant class separating object features attempts towards an automatic feature extraction were undertaken. In the given project the optimal object features and the range of its membership functions were automatically determined by a statistical procedure analyzing the separability between two classes.

The object classes had been labeled as "industrial areas", "mountainous areas", "settlements", "soils", "vegetation", "water" and "unclassified" before. By this means, a classification model was defined and applied to a number of scenes. Fig. 6 shows the classification result for the scene of Bandar Abbas. The relevant site was correctly classified as industrial area, and another one in the left range, too. Water, vegetation and settlements were indicated sufficiently aside from some misclassifications. Anyhow, without adapting the classification model for each scene, the results could be qualified as good to quickly get a general idea of the different land cover classes. The developed rulebases for the object classes can also be applied individually to the image data (Fig. 7).

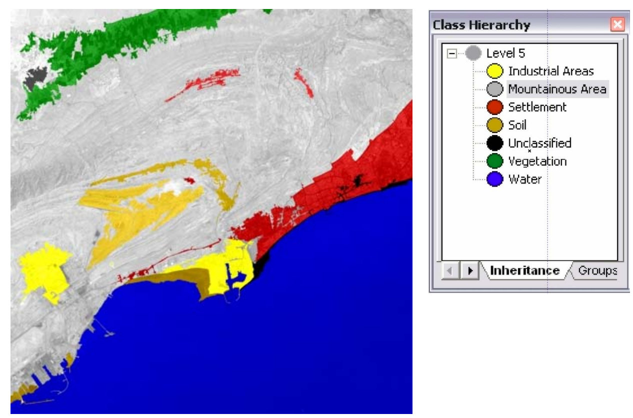

Figure 6. Application of the automated classification model to the ASTER scene of Bandar Abbas

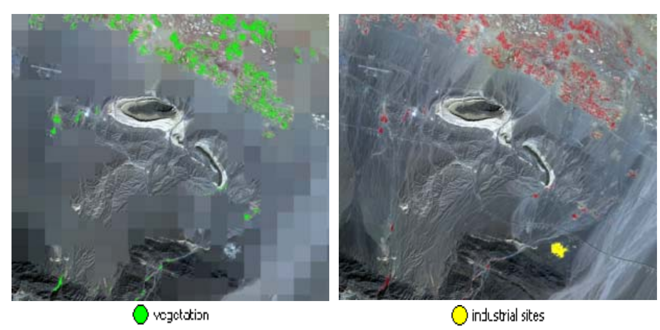

Figure 7. Classification taks for vegetation (left, indicating chessboard segmentation) and industrial sites (right) at the location of Natanz

B. Detailed analysis using high-resolution imagery

If areas with significant object features have been detected on the basis of the medium-resolution image data, they then will be analyzed in detail using high-resolution imagery. Again, investigations were conducted as to the standardization and transferability of classification models. A QUICKBIRD scene acquired over the Esfahan Nuclear Fuel Research Centre (NFRPC) in July 2002 provided the basis for automatic feature extraction for the classification model. As before, the optimal object features and the range of its membership functions were automatically determined by a statistical procedure analyzing the separability between the classes, in this case between the classes “background”, “built-up areas”, “roads”, “shadows” and “vegetation”. When applied to the image data, an overall accuracy of approximate 90% was achieved, depending on the respective segmentation level (Fig. 8). In order to check the temporal transferability the 2002 classification model was applied to another image acquired over the Esfahan Nuclear Fuel Research Centre (NFRPC) in July 2003. After minor changes of the 2002 model in reference to one single NDVI-based feature, an overall accuracy of approximate 80% was obtained (Fig. 9).

Moreover, the 2002 classification model was tested regarding the spatial transferability by applying it to another extract of the full QUICKBIRD scene (without figure).

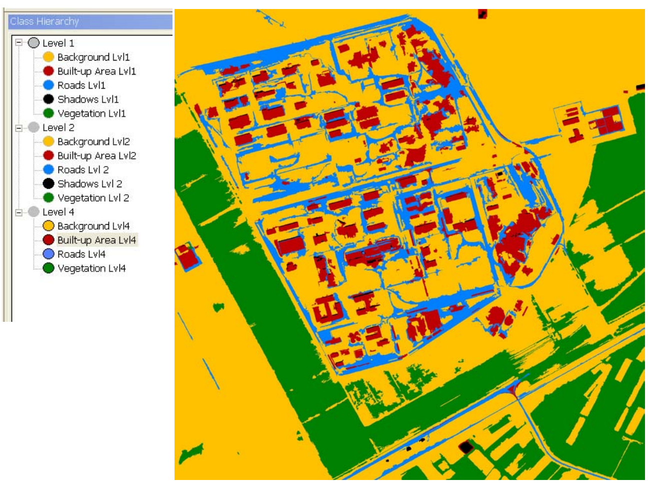

Figure 8. Object-oriented classification of the 2002 QUICKBIRD image over Esfahan Nuclear Fuel Research Centre (NFRPC)

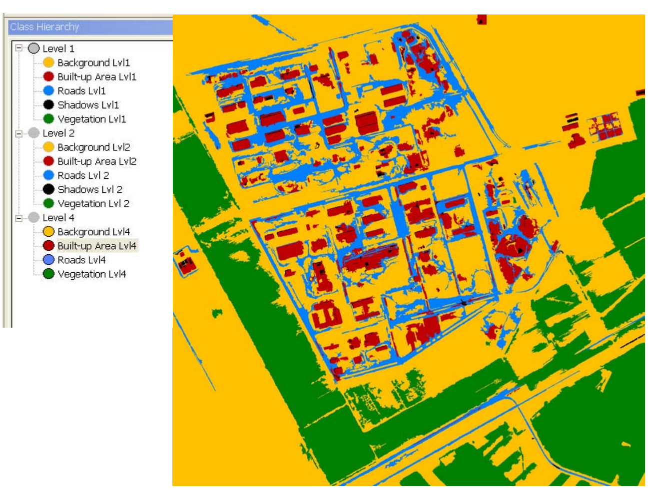

Figure 9. Object-oriented classification of the 2003 QUICKBIRD image over Esfahan Nuclear Fuel Research Centre (NFRPC)

V. CONCLUSIONS & OUTLOOK

An object-oriented monitoring system for nuclear safeguards purposes was proposed. By means by *eCognition Enterprise* some investigations on object-oriented image analysis investigations were carried out in terms of automation, thus standardization and transferability. The automation and the transferability of analysis procedures appears to be feasible to a certain extent, therewith giving rough and fast indications of areas of interest and enables the user to explicitly analyze the relevant areas.

For the advanced analysis of nuclear sites (using high-resolution imagery), a detailed classification model furthermore has to be able to differentiate between nuclear and non-nuclear industrial sites and preferably between the different types of facilities within the nuclear sites class, too. Though the preliminary results within this project and previous approaches on the automated object-oriented classification of German nuclear power plans have been somewhat promising up to now, a lot of case studies have to be performed for a comprehensive understanding of the nuclear sites signatures identifiable in satellite imagery.

Furthermore, the attempts to extract the objects features automatically have to be continued and the accuracy of the classification in terms of spatial and temporal transferability needs to be assessed in detail. Finally a measure for change has to be implemented [6].

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eCognition Enterprise is a product of Definiens Imaging (http://www.definiens-imaging.com).

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