Object-based image analysis for very high resolution land cover classification in security and emergency

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Abstract. The aim of this work is to demonstrate current status of the operational object-oriented Land Cover classification and identify weak points of the approach for further technological research. The focus is put on the automation of the processing chain, while keeping standard level of product quality in the field of security and emergency. The so-called product "standards" are non-formal specifications common to GMES Services as for instance applied in RESPOND project. Object-Oriented Image Analysis was applied on the whole scene of very high resolution (VHR) image by means of fuzzy rule set created in DEFINIENS Developer. Classification nomenclature (25 classes) was defined according to the general RESPOND guidelines and experiences from other security and emergency products. The resulting Land Cover product was validated only by visual interpretation as there are missing in-situ data from the South Ossetia. The difficulties identified in the classification processing chain were mainly the extraction of road network and performance on the whole VHR scene. Performance of segmentation algorithm is a crucial point of the processing chain. Various segmentation algorithms exist with different computational complexity and demand. It is necessary to combine them in a purposive manner. Grid processing environment distributing the computation demand to different nodes may help, however other issues have to be tackled then. Another issue for the discussion on potential improvements is the shape generalization methods. Existing implemented method, mathematical morphology algorithm with possibility to define the structural element, allow great improvement of the shape appearance of the final objects, but has its limitations

Keywords: Object-based image analysis, Land Cover classification, automated classification, shape generalization, linear features

1 Introduction

GEOBIA (GEO-Object-Based Image Analysis) principals are dynamically evolving methods and tools in the last 10 years being applied widely to the Earth Observation images for various purposes. The increasing numbers of scientific papers document in a good way the progress in the application [1], [2], [4], [6].

The developed methods and tools are applied in such a way that replicate human interpretation of RS images in automated/semi-automated methods that result in increased repeatability and production, while reducing subjectivity, labor and time costs.

The security and emergency applications based on the Earth Observation image analysis is one very specific field of remote sensing. The user requirements might vary in application to application but one of the mutual features is time response. Quick product delivery to the user is an essential requirement. This leads to the use of fully automated or semi-automated image analysis. However, the product quality and content are not less important. The user requirements and product definitions are decisive for the selection of appropriate image analysis and development of the processing chain. Combination of high time response, product content and high quality of the provided information lead to the need of flexible, robust, fully automated or semi-automated image processing tools applicable to various image data inputs and various information / features to be extracted. Some of the required features to be extracted are rather a challenge for automated approaches. Frequency occurrence of such features is important information for trade-off between development of fully automated procedure and visual interpretation with object labeling. Also, the tools to be used in this field need to be flexible and robust to fulfill the producer's needs.

The objective of this case study paper is to demonstrate the operational semi-automated object-oriented Land Cover / Land Use classification and specific feature extraction. The study area of the case example is located in South Ossetia, in particular surroundings (13 x 10 km) of Tskhinvali capital.

2 Materials and Methods

The data provided for this case study consist of multi-spectral very high resolution QuickBird image together with panchromatic channel (Reference Data Set provided for test by EUSC). In addition, the Global Aster DEM was utilized as an ancillary data source (for terrain topography, contour and stream network generation).
The selection of classes was done by a visual inspection of the image, the general guidelines and experiences from other security and emergency products. The nomenclature is designed strongly according to the study area features.

<u>The selected classification nomenclature:</u>

1. **Artificial (non military areas)**
    a. Built up areas (building blocks)
        i. Damaged
        ii. Not damaged
    b. Urban green
        i. Gardens (backyards with mixed vegetation)
        ii. Grassland and commons (sparsely vegetated areas, cemeteries)
        iii. Parks (with high vegetation)
    c. Roads
        i. Bitumen roads
        ii. Consolidated / dirt roads
        iii. Path / trail
    d. Airports
    e. Construction sites
    f. Mines
    g. Dump sites
    h. Pipelines
2. **Military objects**
    a. Military areas
    b. Trenches
3. **Agricultural areas**
    a. Large and small fields, grassland fields
    b. Small vegetation landscape units (between fields)
4. **Bare soil areas** (not cultivated fields)
5. **Forests**
    a. Evergreen forests
    b. Deciduous forests
    c. Transitional woodlands
6. **Water**
    a. Rivers
    b. Lakes
    c. Canals
7. **Flooded area**

The processing chain consisted of these main steps:

a/ image pre-processing
b/ image segmentation
c/ basic land cover classes detection
d/ segmentation – main land cover classes detection
e/ specific features extraction
f/ post-classification generalization
g/ GIS post-classification analysis and feature detection
h/ visual inspection

The pre-processing image steps consisted of new pan-sharpening [5] that includes NIR channel in the resulting image (Fig. 1). Next, texture analysis [3] was performed. Mainly first order texture indices at pixel level were derived for detection of artificial classes (Fig. 2).

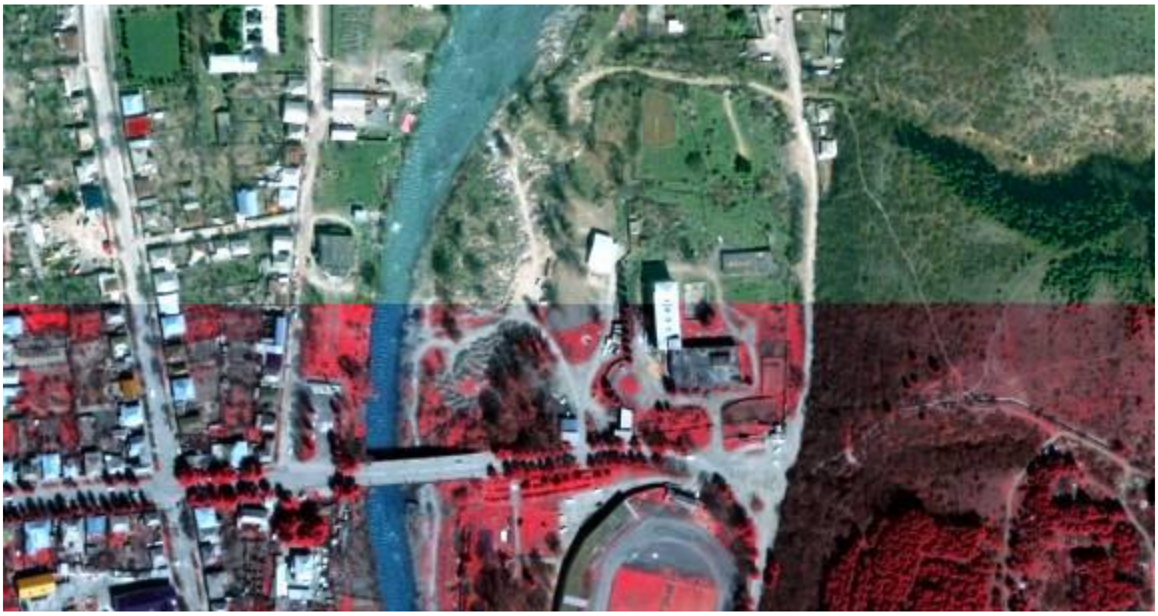
Fig.1. Pan-sharpened image including NIR channel

Beside that, visual interpretation was employed to derive the road network in the pre-processing stage. This step was done by manual editing as this component of the land cover has high importance in the product and current evaluated methods does not give a sufficient quality. Several approaches of automatic or semi-automatic were tested but did not provide reasonable result. The tested approaches included: semi-automatic so-called intelligent digitizer, feature object tool (FOX) implemented in COTS software and also fuzzy snake methodology. Improvement of methods and tools for linear feature extraction are needed. Next, main land cover classes were classified by means of contextual as well as spectro-textural classification rule ware. Semantic grouping is an important feature of the applied procedure.

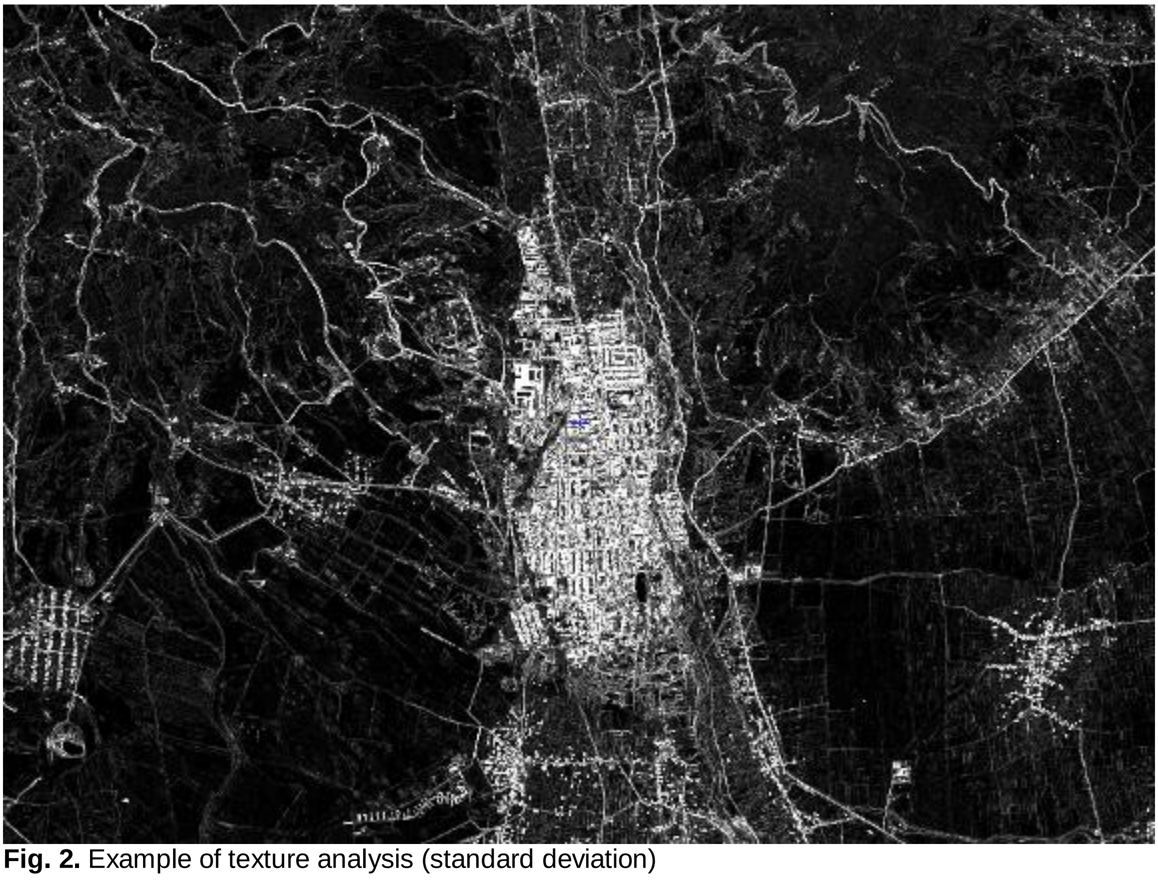
Fig. 2. Example of texture analysis (standard deviation)

Next steps (b/ to f/) were done solely in the Definiens Developer environment (version 7). Image pre-segmentation in the whole process included several main segmentation procedure including simply chessboard segmentation as well as multi-resolutional segmentation (Region Growing Algorithm). Basic land cover classes were detected by means of spectral and textural features computed at pixel or object level. Fuzzy rule set with sequential approach was used. Specific features extraction was done after the main land cover classes were fully classified as background layer. Segmentation at lower spatial layer was necessary. Fuzzy rule set with spectral, textural and contextual approach was applied.
Post-classification step consisted of size and shape generalization. Size generalization is simply applied by analysis of object area and its contextual features. Shape generalization was processed by means of mathematical morphology technique.
GIS post-classification analysis and feature detection was applied to detect specific features by means of DEM and land cover classes. At first, attempt to extract road network was performed. The approach comes up more or less from so called fuzzy snake methodology. The extraction was based on approach utilizing both optical and textural bands as an input into unsupervised ISOCLUSTER classification. The textural band selected included standard deviation, mean and kurtosis, all both for blue and green band. As an inverse classification mask was used a layer of buildings classified previously in Definiens. Subsequently, the clusters corresponding to the road surfaces were manually selected on top of the imagery and served as an input into automatic vectorization realized in ESRI ArcScan toolbox. Prior to the automatic extraction of vectors, a clean-up of input raster had to be carried out and proper vectorization parameters had to be set up. The extracted roads must be viewed as semi-product which requires further manual editing to remove spackles and false road lines, connecting of dangling lines and completing of missing segments. On the other hand, they may serve as a valuable baseline for further vectorization since they copy the feature shapes reliably and contain information on width of the road, which is derived during the process by ArcScan.
Low resolution Global ASTER DEM (30m GSD) was used as a source for terrain analysis. As a result, topographic contours with 20 m spacing and stream network were derived automatically using standard functionality in ArcGIS. It was necessary to employ further manual post-processing of obtained features and in case of contours also line smoothing to ensure proper placement and acceptable cartographic look-and-feel representation.
Quick and simple method of detection of stream crossings is based on GIS intersection of road network and stream network feature classes. Manually extracted road network was employed in this step to improve the confidence of the result. By this mean locations of bridges / fords were detected. Distinction between classes in the output layer and clean-up (addition or removal of false points) was done by interpretation for each resulting point.

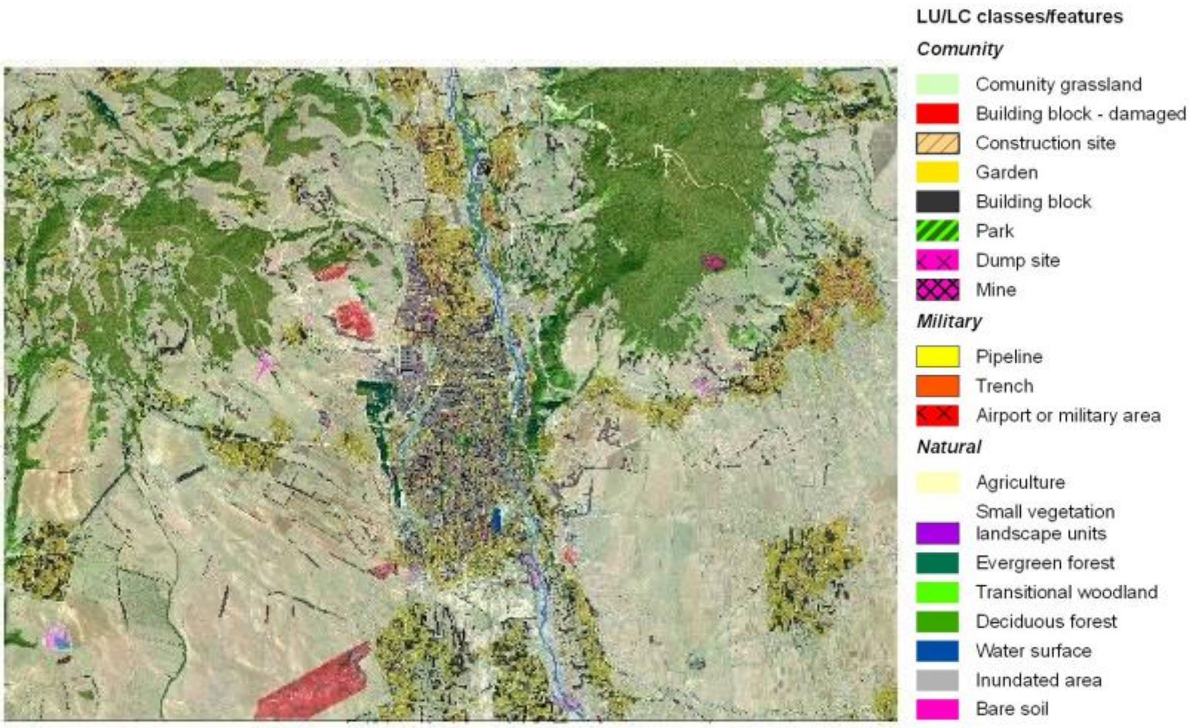

Fig. 3. Classification result of the Land Cover and Land Use database

3 Results and Discussion

The result of the Land Cover/Land Use classification and specific feature extraction is presented as a map product (Fig. 4) ready to be printed for the end user. Rule based object-oriented classification approach applied to the very high resolution image proved to be effective way of Land Cover/Land Use classification and feature extraction. Definiens Cognition Network Technology allowed rapid classification knowledge-base development with some level of transferability to other cases. One of the main distinctions of this approach is that it emulates human cognitive processes, familiar to interpreters who extract information from the image.
The importance of scale object-based mapping is enhanced in case of very high resolution imagery. These images consist of large scale as well as small scale variations that have to be combined at the same time.

Specific feature extractions, as for example linear vegetation landscape units (Fig. 4), trenches (Fig. 5) or destroyed buildings (Fig. 6) were done by fully automated procedure after the main land cover classes were classified as a background layer.

Fig. 4. Example of classification result of small vegetation landscape units

Fig. 5. Example of classification result of trenches in the agricultural landscape

Fig. 6. Example of destroyed buildings and its detection in the map

One of the difficult part in the classification processing chain is the extraction of road network by automated approach, especially in case of landscape that consists of fuzzy changes of road types and unclear borders. The other linear features as for instance trenches can be identified but since these objects are mostly spectrally heterogeneous, the shape of resulting object may be difficult to detect besides the fact that some parts of the class may be spatially disconnected. Most of these features were extracted in semi-automated way.

First, potential objects were classified using fuzzy rules including shape characteristics. Afterwards improper objects were unclassified by visual inspection on the segments level. This approach assures maintaining of segments' shapes as an output during segmentation. Other classes like airport, commercial areas, parks, etc. appear in a limited number of examples in the image. These may be identified by automation approach but it is a question how effective it is to develop dedicated rule-ware if they are identified in the whole scene only as one or two examples.

An experiment in semi-automated road extraction was done (Fig. 7) as described above. Drawback of this approach lies in utilization of built-up mask. The accuracy of the obtained road network inside urban areas increased radically. The reliability of this part is strongly influenced by previous classification results. Therefore, extraction process should be perceived as truly (semi-)automatic only outside of built-up areas. Nevertheless, it must be mentioned that if the reliable mask of buildings could be obtained without prior road delineation the method is quite promising then.

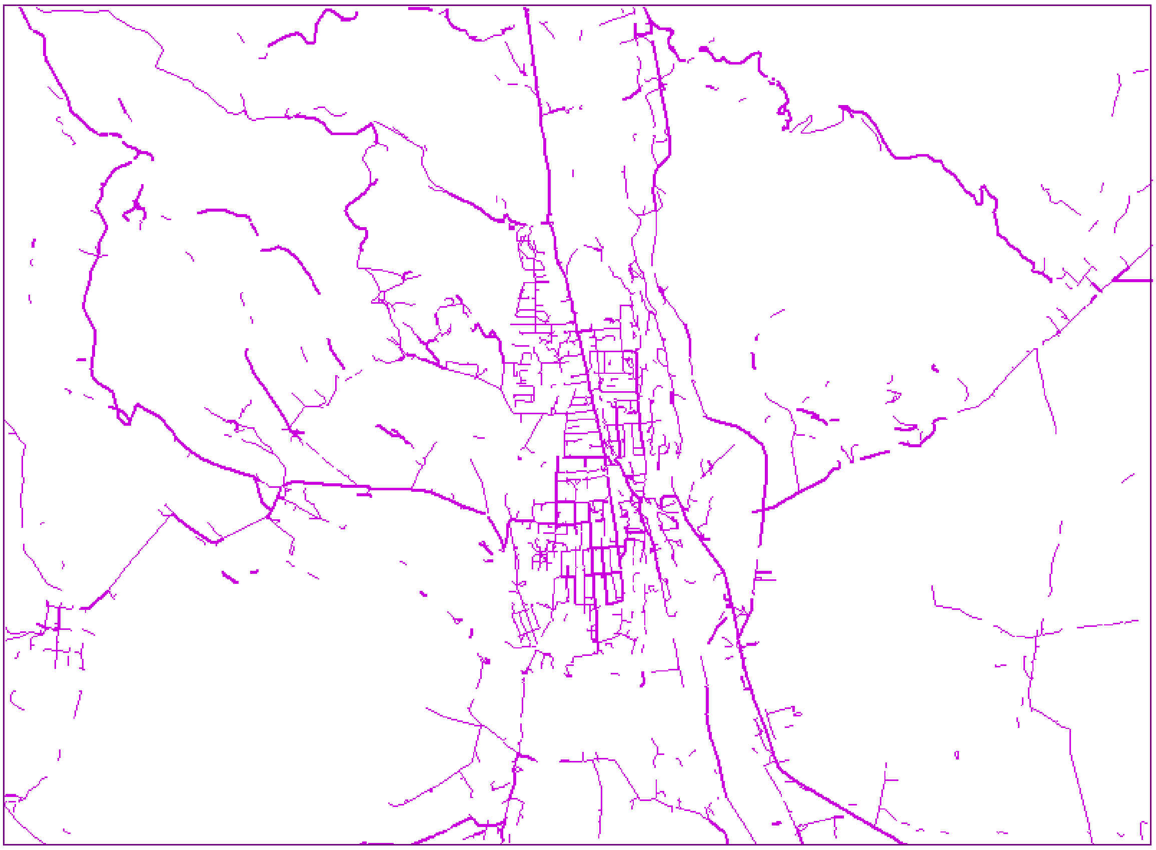

Fig. 7. Road network derived from the image derivatives by semi-automated manner

The second problematic topic of the object oriented image classification is performance in case of large very high resolution scenes. Performance of segmentation algorithm is a crucial point of the processing chain. Various segmentation algorithms exist with different computational complexity and demand. It is necessary to combine them in a purposive manner. Grid processing environment distributing the computation demand to different nodes may help, however, other issues have to be tackled then.

Another issue for the discussion on potential improvements is the shape generalization methods. Existing methods implement mathematical morphology algorithms (closing and opening) with possibility to define the structural element enabling great improvement of shape appearance of the final land cover objects, however, it has its limitations. Problematic might be linear features as roads or rivers that may be disconnected by the morphology approach. Other problematic classes are objects with complex shapes as for instance urban areas.

Fig. 8. Example of bridges detection in the map

Terrain analysis and processing methods deserve also brief discussion. Low resolution DEM is due to its resolution limited in both horizontal and vertical accuracy. As a result, this limitation transfers also on derived products. If the automatically obtained stream network is overlaid with the VHR imagery, various shifts are visible. Besides that, delineation of automatically obtained streamlines seems to be even less confident in flat areas, where the streams have been conducted from original channels into artificial ones, e.g. due to irrigation purposes. Streamlines may be corrected quite quickly manually utilizing the automatic output as a guiding skeleton. In case of wider flows such as river, whose polygon outlines should be detected by means of classification, the correct location of flow axis is obtainable in GIS as a polygon centre line.

The problematic is enhancement of DEM, derived TIN or contours using updated stream network. If we wanted to update also thalwegs in DEM in sense of positional shift and elevation correction copying the longitudinal profile of updated streamlines, each stream should have to be segmented into minimal pieces holding the elevation information. This requires further processing including manual steps. Additional topographic source that might be utilized for creation of accurate terrain representation are topographic maps. In the Caucasus area the most reliable source is former Soviet Union topographic maps in scale 1:50,000 from 1970’ and 1980’, which among others contain comprehensive elevation information including height points and contour lines. Disadvantage of solution that utilizes scanned topographic maps is a limited capability of processing automation. On the other hand it is balanced by possibility of radical improvement of terrain representation.

Since the bridge feature class was obtained (Fig. 8) as an intersection of road and stream network, both results of manual editing, they are not coincident with stream and roads demonstration outputs, which are fully automatic products. Apart from fully automated dataset outputs (before mentioned streams and roads), the output zip file contains also LU/LC classes, contours and bridges which undergone further manual interpretation and editing as described in this document.

4 Conclusions

The presented case study shows one of the examples of semi-automated processing chain designed mainly on OBIA approaches in operational environment. The focus was put on automation of the processes as much as possible. The developed methodology for the case study was done on the purpose of the user requirements. Definiens Cognition Network Technology proved to be a suitable tool for such a task, however, some parts were done outside the environment. The software allowed rapid classification knowledge-base development with potential transferability of the model to other areas of the similar landscape type. The importance of scale object-based mapping is clear when inspecting heterogeneity of the classes in the legend. Investigations of various tools for linear feature detection proves that there is an urgent need of further development tool that would suit better to producer’s demands. Also, the shape generalization methods need further development.

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