Object-Based Image Analysis of Pasture with Trees and Red Mud Spill

István László[1], Katalin Ócsai[1], Dávid Gera[1], Roberto Giachetta[2] and István Fekete[2]
Institute of Geodesy, Cartography and Remote Sensing (FÖMI),Remote Sensing Directorate, Budapest, Hungary; {laszlo.istvan, ocsai.katalin, gera.david}@fomi.hu
Eötvös Loránd University (ELTE), Faculty of Informatics, Budapest, Hungary;
{groberto, fekete.istvan}@inf.elte.hu

Abstract. This article shows the possibilities of object-based analysis of very high resolution satellite and aerial images in three applications from the areas of agriculture and disaster monitoring: the detection of scattered trees and bushes on pasture (eligibility issues in Land Parcel Identification System), the delineation of industrial red sludge spill and ragweed monitoring (mapping of ragweed spots in agricultural areas). To achieve proper results, we need to create image objects fitting land cover objects and classify them to predefined classes. The key step of object-based approach is segmentation, that is, the division of image to contiguous sets of spectrally similar pixels. Beside implementing and examining different segmentation algorithms, the authors have used the Definiens / eCognition software in operational applications. The results achieved justify that the accuracy of object-based classification is comparable to pixel-based one, and the analysis of textural and shape properties can further increase accuracy and appropriateness of procedures.

Keywords. Segmentation, object-based image analysis, Land Parcel Identification System, toxic spill, ragweed monitoring

1. Introduction

The Instutute of Geodesy, Cartography and Remote Sensing (FÖMI) is carrying out several country-level agricultural remote sensing applications, which require different approaches. In the majority of projects, the combination of visual and quantitative methods is used. Although FÖMI is efficient in completing large volumes of visual work in GIS, there is always an attempt to automatise the tasks as much as possible. In the past months successful results have been achieved in the introduction of object-oriented image analysis into several projects. Beside large-scale country-level applications – namely, the maintenance of Land Parcel Identification System and Ragweed Monitoring – the surveying of a recent industrial disaster was in focus. Among these three projects, ragweed monitoring is an outlier with respect to methodology, and it was not a definite goal of former experiments to use object-based methods in it, but by the time of writing this article promising results have been achieved, which are therefore included below.

2. Collaboration between ELTE and FÖMI

Within FÖMI, Remote Sensing Directorate (TÁI) is responsible for the research and development of technologies in remote sensing, mainly in the areas of agriculture and environmental protection. This includes the operation of Land Parcel Identification System (LPIS-Hu) and Control with Remote Sensing of Area-based Subsidies (CwRS), which play important role in the system of agricultural payments in the EU. Continuous improvement of image analysis methods has always been an important part of operational projects, in which FÖMI works together with the Eötvös Loránd University, Faculty of Informatics (ELTE IK). This collaboration began in the early 80's, with the joint development of a software system evaluating satellite images. From 1985 to 2002 several occasional collaborations took place, their results were jointly published. Common fields include segment-based processing of satellite images and data fusion methods. In 1999 and 2005 segment-based classification appeared in PhD projects.

The other side of this connection is education. Within ELTE, Faculty on Informatics has been established in 2003. This has given further movement to joint research projects. Since 2004, ELTE IK grants home to a Geospatial Information Systems educational module, including the course *Analysis of Remote Sensing Images,* which is taught by the scientists of FÖMI TÁI. Besides, students with interest in this field may complete their professional practice at FÖMI in the frame of *Cooperative Education.* Since 2006, twelve students have participated in this kind of training.

3. Segment-based classification

In the thematic classifications of remote sensing images, it is always a key question to find the link between objects of "real world" and those of images. To achieve proper detection of features in mapping applications, image objects need to be delineated that fit land cover objects, and they must be classified into predefined classes. Since the birth of Earth observation by remote sensing the rich spectral content of satellite images has been showing its strength in the differentiation of land cover classes. But it is not always enough to utilise only spectral information. Traditional pixel-based classification methods completely disregard spatial relations. To overcome this drawback, segmentation was introduced with the aim of extracting neighbourhood information and preserving natural homogeneity. Segment is a contiguous set of spectrally similar pixels. Segments do not overlap, and they completely cover the given image, that is, segmentation forms a complete disjoint coverage.

Within the wide range of segmentation methods, the authors predominantly deal with region-based segmentation methods. The segments in different iteration steps of an algorithm can be organised into a hierarchical system. The following methods were implemented and analysed:

1. *Merge-based, "bottom-up" methods* start from pixels: in the beginning, every pixel of the image form an individual segment. During the iterations of algorithm, several segments are merged.
    a. *Sequential linking* deals with the statistical homogeneity of segments. In a preparatory step, small groups of pixels (for example, 2 by 2 squares) are joined into cells. The iteration consists of rowwise traversing through cells, and an attempt is made to join current cell to a segment. Because of sequential traversing, the time the algorithm requires is linear with respect to image size. But a serious drawback is that the resulting segments are strongly influenced by the traverse order.
    b. *Best merge* algorithm overcomes the above mentioned strict traverse order: it chooses any two neighbouring segments over the image if their contraction is optimal with respect to certain criteria.
    c. The idea of *graph-based merge* comes from graph theory. Segments are characterised by their heterogeneity, which is formally defined using graph notation. The general introduction of graph-based representation of images and segmentation algorithm is given below.
2. *Cut-based, "top-down" methods* behave the opposite way. In the beginning, the whole image is considered as one large segment. In each iteration of the algorithm an appropriately chosen segment is cut into two smaller ones. All the cut-based methods the authors dealt with are developed and implemented on the basis of graph representation.

a. In the *Minimum mean cut* algorithm the edge weights are proportional to the spectral difference between segments that are represented by the respective subgraph.
b. *Minimum ratio cut* algorithm is an improved, generalised variant of minimum mean cut. Two weight functions are used, and criteria are defined with their ratio.
c. *Normalized cut* algorithm is also derived from minimum mean cut, using its weight function. This algorithm is NP-hard, but it can be well approximated in the range of real numbers.

Images and segmentation algorithms can be represented by undirected graphs. Vertices correspond to pixels. Vertices of neighbouring pixels are connected by edges. Weights of edges are assigned according to the relation between pixels they are connecting. Within the graph, segments can be described by sub-graphs. Both merge-based and cut-based segmentation algorithms can be described by graph algorithms. Cut means the subdivision of edge set into disjoint subsets. This way only those edges remain in the graph that connect pixels within segments.

Several samples areas were selected for the development and testing of algorithms. Fig. 1 shows the time series taken from one of the sample areas of processing.

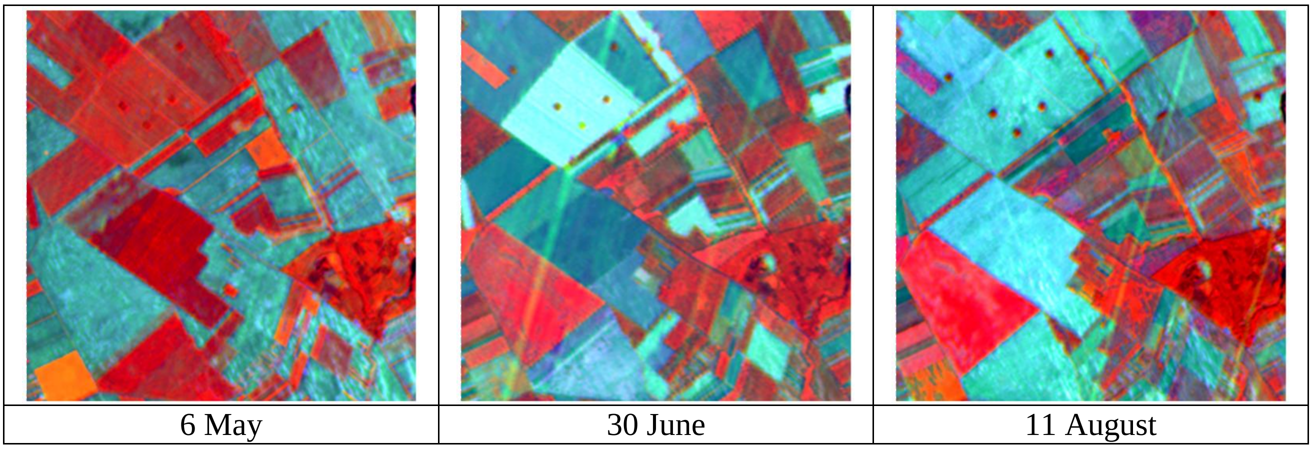


Figure 1: The time series of one sample areas of processing.

The result of *segmentation* is a thematic image containing the numbers of segment the pixel belongs to. The segment map of three methods are shown in the images of Fig. 2.

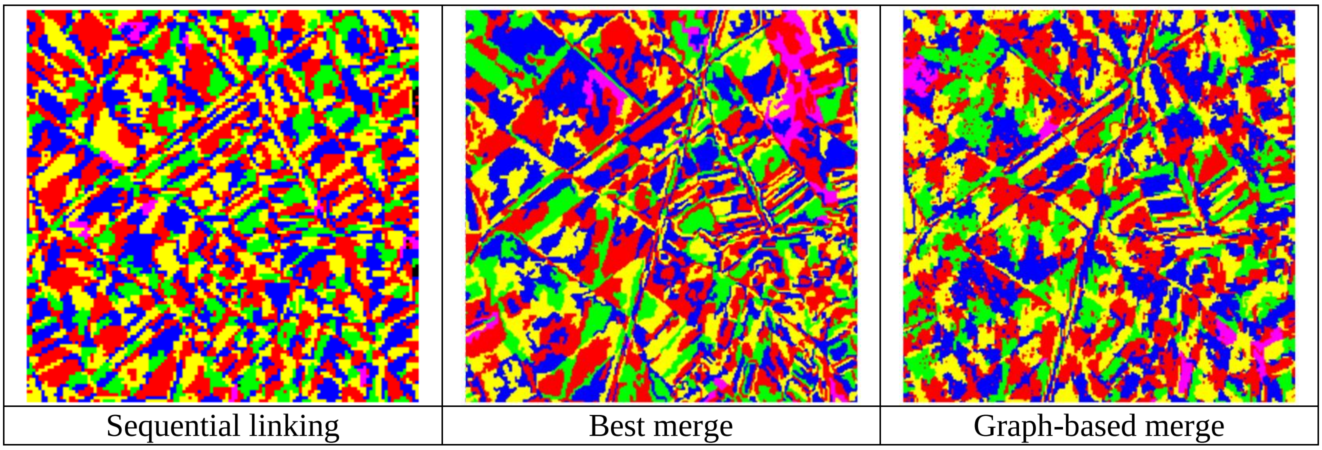
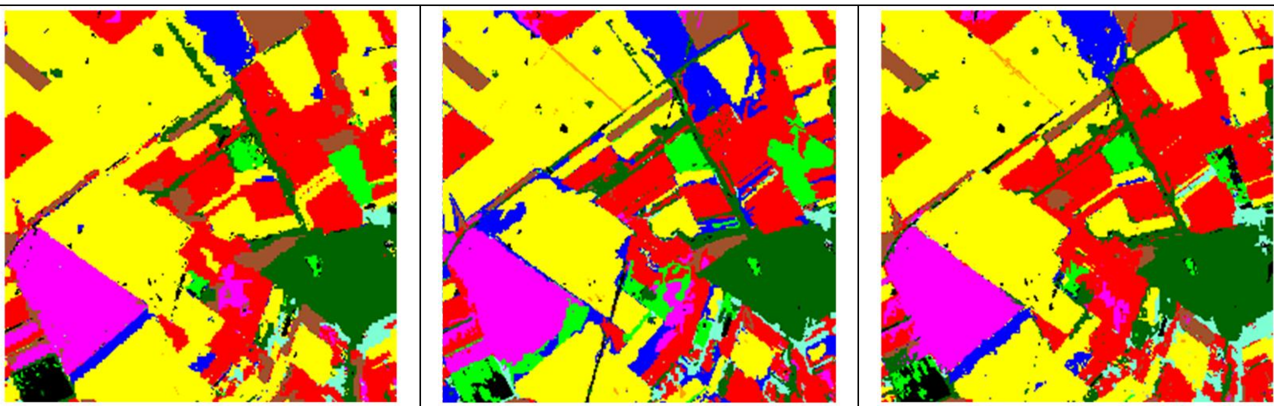


Figure 2: The result of segmentation with three methods.

As a result of earlier research and development, a fully segment-based classification algorithm has been developed. The steps of pixel-based classification have been adapted to segments. Segmentation is followed by *clustering*, and then the final *classification* is carried out. The result of classification after the three classification methods can be seen in Fig. 3.



Sequential linking	Best merge	Graph-based merge

Figure 3: The result of classification after three segmentation methods.

With the introduction of fully segment-based classification, the thematic accuracy grew to 91-95%, about 2% more than that of pixel-based method. Procedures are sensitive to parameters, but they less depend on the segmentation algorithm chosen. Run-time has dramatically decreased, as the number of objects to be dealt with is less by magnitudes. The results achieved entitle us to run these procedures operationally.

4. Applications: object-based image analysis

In this section three applications are shown where task is solved by object-based image processing, using the Definiens / eCognition software suite. The applications are linked to running projects of FÖMI; the difference is that the classification part of projects are solved in an alternative way, but the aim is not to completely replace existing methods.

The segmentation algorithms used in these practical applications are not the same that were presented in the last section. But the theoretical knowledge of segmentation and the experience gained with their implementation greatly helps in the proper use of this software suite. When processing large images, eCognition is able to apply the “divide et conquer” approach: the image is split into smaller, equal-sized tiles, which may be processed in parallel, finally the results of tiles are “stitched” together.

Input consists of raster images: primarily ortho-photos or very high resolution satellite images. The main output is a thematic vector (shapefile) with the classification results, which can be used in other GIS programs. The eCognition suite provides plenty of procedures built from elementary algorithms. Their choice and parametrisation requires the theoretical knowledge of segmentation and photogrammetry. Fine-tuning of parameters was done by testing and experimentation.

The software eCognition deals with a hierarchical system of images and image objects. Segmentation and classification steps are executed to derive objects from the level of pixels. Segmentation is followed by the classification of objects. Based on the complexity of task, it may consist of several steps. For this purpose, commands and functions are organized into so-called Rule Sets. The built-in segmentation algorithms include, for example, Chessboard, Quadtree, Contrast split, Multi-resolution, Spectral Difference and Multi-resolution segmentation methods. Classification takes segments as input. A plentiful system of sophisticated criteria is used for classification. Beyond usual statistical measures, geometrical and textural features, membership functions in class hierarchy and statistical distributions are available.

4.1. The delineation of tree groups

One of the largest tasks of FÖMI is the operation and updating of Land Parcel Identification System (LPIS). This is the exclusive reference system of area-based EU subsidies, in which all the agricultural parcels can be identified. The basic areal unit is physical block, which is bounded by borders stable in time. However, cultivation structure continuously changes; therefore LPIS must be regularly updated to reflect changes. The basis is the ortho-photo coverage, which is renewed in every year for about one fourth or one third of the country.

In Land Parcel Identification System, an important property of areas is whether they are subsidised (eligible for agricultural payments). The goal of application is to automatically *delineate (ineligible) scattered trees and bushes appearing on (otherwise eligible) pastures.* This task can not be correctly solved with pixel-based classification, as the land cover units are larger than pixels. The half meter spatial resolution of ortho-photos provides great geometrical accuracy. However, local spectral properties make classification harder, as it is difficult to distinguish between objects belonging to tree groups and similar segments actually belonging to other types of land cover. In some cases the question cannot be decided even by visual interpretation. Segment-based classification was proven to be appropriate in the majority of cases examined. For the delineation of scattered trees, colour infrared ortho-photos with submeter resolution were applied.

A difficulty of ortho-photos is that their radiometric properties are heterogeneous over large areas (e.g., a whole county of Hungary), due to the technological limits of acquisition. Besides, due to some misleading details in the images, their fully automated processing can not be achieved. An example of ortho-photo is seen in Fig. 4, while Fig. 5 shows the results of the following steps:

- Segmentation is done using three elementary algorithms, with emphasised role of edge tracking.
- After detaching shadows, objects are categorized into nine classes that are defined with sampling. To overcome differences in ortho-photos taken from different areas, several rule sets have been elaborated to fit local properties (e.g., time of day, lighting, shadows, relief, soil type). Differences over various areas are completely handled by several rule sets, that is, the segmentation algorithm remains the same in all cases.
- Refinement of object boundaries is carried out by the known morphological operations “shrinking” and “growing”. This way the original scattered border is smoothed.

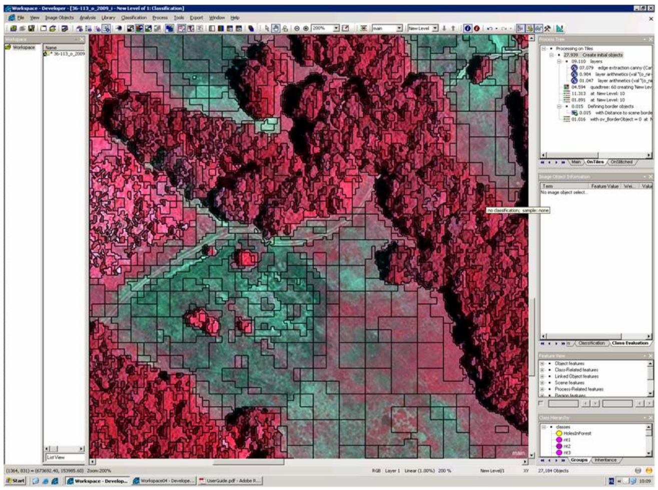


Figure 4: An example of colour infrared ortho-photo used in classification.

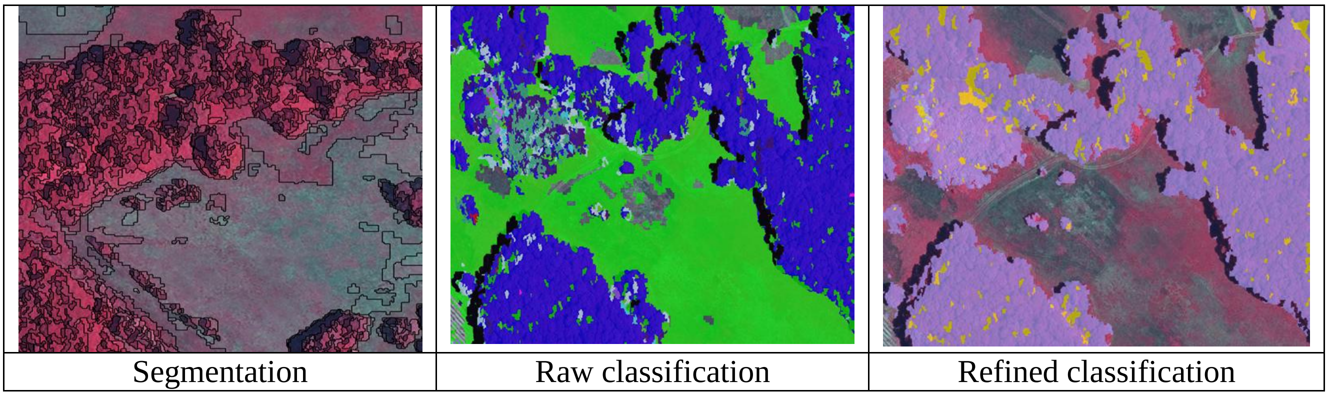


Figure 5: The intermediate results of classification steps.

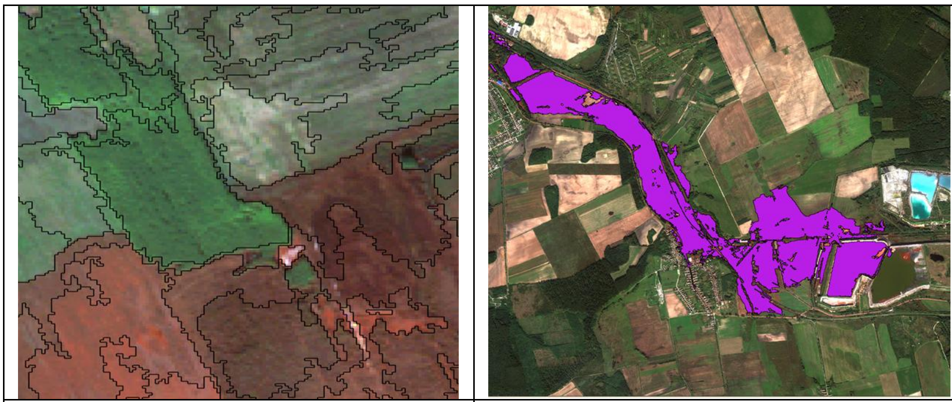
The accuracy of this procedure is satisfactory, but it could be further improved if images of several dates were available. Parameters are refined so that the ratio of first-order and second-order errors is optimal with respect to the goals of processing LPIS. The accuracy reached is acceptable; visual interpretation cannot be completely replaced, but this method makes it much easier.

4.2. The surveying of red mud spill

An important task of remote sensing is the surveying of environmental and industrial disasters. The second application is the detection and documentation of area affected by red sludge (red mud). On 4 October 2010, industrial *red sludge spill* caused serious environmental damage in the surrounding of Ajka town (North-Western Hungary). It was important to urgently deliver map information of spilt areas to help the assessment of damage and salvage. Five-band RapidEye images (with spatial resolution of 5 meters) and eight-band WorldView-2 images (2 meters) were used to monitor red mud spill. These images provided the possibility to exploit several different spectral features.

Classification was performed with sample selection and Maximum Likelihood method. The final goal is to delineate inundated area. But in the intermediate steps of processing three classes were defined: open sludge surface, inundated soil and inundated vegetation. As the availability of on-the-spot reference data was limited, the training of classification was based on the difference seen in the images. These three classes are statistically described with the combination of some (few) sub-classes, which are not completely disjoint, but their overlap is minimal. Original band values, vegetation indices and their standard deviation were used in the classification, taking into account red,

red-edge and near infrared bands. Fig. 6 shows the result of segmentation and classification run on WorldView-2 image.



Segmentation	Classification

Figure 6: Segmentation and classification result of WorldView-2 image.

RapidEye image was processed with a similar, but somewhat simpler method than the one used in the case of WorldView-2. The spectral bands used in the processing of WorldView-2 image are available in RapidEye as well, but the variations stemming from different spatial resolution have to be taken into account. The ToA-reflectance image was not available for RapidEye, which is not a serious problem in our case, but in case of time series analysis it would be unevitable.

4.3. Ragweed monitoring

Among invasive alien species, *ragweed* causes serious problems in Hungary, because of the allergenic effect of its pollen. Since 2005, remote sensing highly supports its exemption. As a third application, the segment-based approach of *ragweed monitoring* is shown. Traditionally, remote sensing detection of ragweed is carried out by the pixel-based processing of high resolution (HR) satellite image time series. Classical field controls are used to collect reference data and for validation. As an experimental research project, very high resolution (VHR) satellite images were processed with a segment-based method. The matching between results of segment-based and pixel-based processing is about 90%, which is illustrated in Fig. 7.

Ragweed recognition differs from the “traditional” arable land mapping tasks in the sense that both spatial and temporal behaviour of ragweed is very irregular. The basis of recognition is the identification of differences from arable land crops and the textural changes caused by the appearance of ragweed. Ground reference data collected in the field near to the date of satellite images were necessary to the derivation of training and test areas.

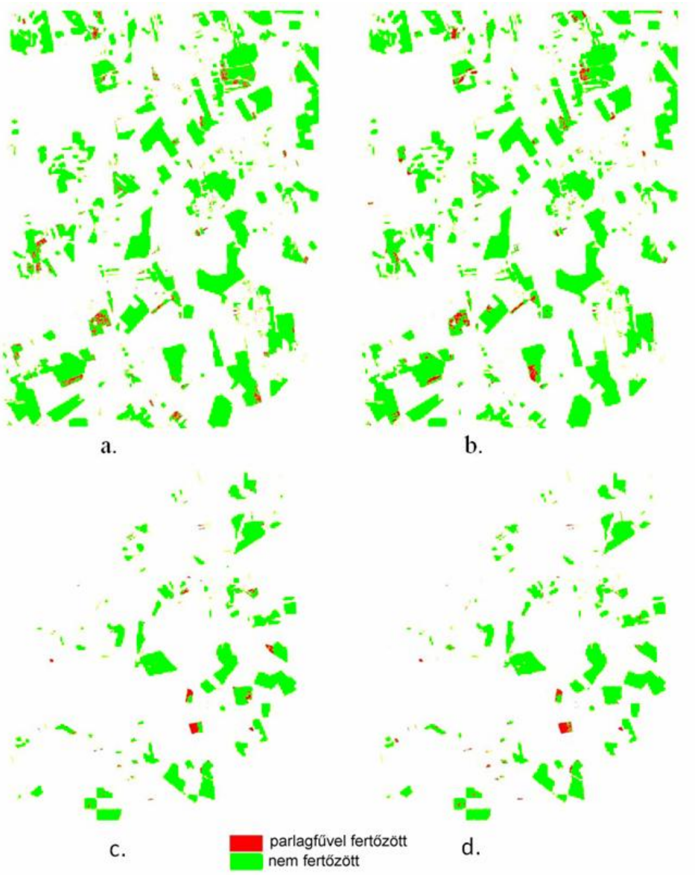
5. Conclusions

As segments form the base objects representing land cover objects, choosing appropriate segmentation algorithms and suitable parameters is a crucial point in the accuracy of classification results. Therefore we propose to thoroughly analyze textural and shape properties forming the base of segmentation algorithms and combining them efficiently.

Studying the literature, it can be observed that instead of theoretical research and implementation of algorithms, using “off-the-shelf” flexible algorithms provided by commercial software comes to the front. However, the choice, parameterization and combination of algorithms is still far from being trivial, and prior theoretical knowledge of segmentation greatly helps in the successful usage of object-based image analysis software products.

Acknowledgements

Research projects presented in this article are supported by the European Union and co-financed by the European Social Fund (grant agreement no. TÁMOP 4.2.1./B-09/1/KMR-2010-0003). Operational projects carried out by FÖMI and serving as the basis of research are financed by the Ministry of Agriculture and Rural Development (MARD) and the Agricultural and Rural Development Agency (ARDA). The WorldView-2 satellite images were provided in the frame of "8 Band Research Challenge" of DigitalGlobe.



a. Pixel-based, cereal stubble	b. Object-based, cereal stubble
c. Pixel-based, soybean	d. Object-based, soybean

Figure 7: The matching between results of segment-based and pixel-based processing.

References

[1] Kettig, R. L., Landgrebe, D. A., 1976. *Classification of Multisprectral Image Data by Extraction and Classification of Homogeneous Object.* In: IEEE Transaction on Geoscience Electronics, 14(1):19-26, 1976.

[2] Pal, N.R., Pal, S.K., 1993. *A Review on Image Segmentation Techniques.* Pattern Recognition, Volume 26, Issue 9, September 1993, 1277-1294.

[3] Hay, G. J., Castilla, G., 2006. *Object-based Image Analysis: Strengths, Weaknesses, Opportunities and Threaths (Swot).* 1st International Conference on Object-based Image Analysis (OBIA 2006), 4-5, July, 2006, Salzburg, Austria.

[4] László I., Pröhle T., Fekete I., Csornai G., 2004. *A Method for Classifying Satellite Images Using Segments.* Annales Univ. Sci. Budapest, Sectio Computatorica 23, 2004. (pp. 163-178)

[5] László I., Dezső B., Fekete I., Pröhle T., 2009. *A Fully Segment-based Method for the Classification of Satellite Images.* Annales Univ. Sci. Budapest, Sectio Computatorica 30, 2009. (pp. 157-174)

[6] *Definiens eCognition Developer 8, Reference Book*. Definiens AG, München, 2009.

[7] *Definiens eCognition Developer 8, User Guide.* Definiens AG, München, 2009.

[8] Csornai G., László I., Mikus G., Nádor G., Hubik I., Lipták K., Antal M., Ócsai K., Fekete I., Gera D., 2010. *The Possibilities of New Satellite Image Types in the Control of Area-based Subsidies and in Ragweed Monitoring System.* 30th EARSeL Symposium "Remote Sensing for Science, Education, and Natural and Cultural Heritage", UNESCO, Paris, 31 May - 4 June 2010. - Proceedings of EARSeL Symposium 2010, ISBN 978-3-00-033435-1