The examination and utilisation of connection between spectral, spatial and temporal dimensions in the classification of digital satellite images

Theses of PhD Dissertation

István László

Supervisor: Dr István Fekete

Eötvös Loránd University
Faculty of Informatics

Doctoral School of Informatics
Prof. András Benczúr, D.Sc.

Doctoral Program of Information Systems
Prof. András Benczúr, D.Sc.

Budapest, 2013

1 Introduction

In my dissertation I introduce my results regarding the analysis of remote sensing images. My professional work in the last years covered research and development, applied problem solution, education and curriculum development.

My research and development activity focuses on two major areas. One of them is the classification of image content, especially segment-based classification and object-based image analysis. However, I have separated these two connected fields in the introduction and in theses. Results presented here can be bound to an intellectual workshop that has been working for several years in the framework of collaboration between Eötvös Loránd University (ELTE) and the Institute of Geodesy, Cartography and Remote Sensing (FÖMI).

The other major topic, the joint utilisation of multi-source data (shortly: data fusion) became my field of interest in connection with tasks at FÖMI. These two topics meet in our work, as the delineation and classification on satellite images became more efficient with data integration.

A part of my results is connected to the operational applications of remote sensing. Regarding the tasks arising in my workplace, at FÖMI, I have found solutions that are theoretically valuable and can be published. These tasks are predominantly area survey projects that are executed on a yearly basis. The results mainly came from the appropriate utilisation of the above mentioned segmentation, classification and data fusion. I would like to emphasize Control with Remote Sensing of EU Area-based Agricultural Subsidies, which is the delegated task of the department lead by me.

My dissertation also covers the teaching of remote sensing. I will introduce the activity regarding curriculum development and writing lecture notes , which I am continuously doing at ELTE, Faculty of Informatics (IK) in order to keep my lectures on remote sensing up to date.

In the field of remote sensing, having strong practical applications, research is usually carried out in creative communities, as is also in my case. Therefore in the forthcoming review I have always tried to delineate my own contribution to results.

Part I of my dissertation contains a survey on the principal theoretical and practical concepts of remote sensing, therefore no external source is necessary to understand research results. However, I have not detailed these principles in this review.

2 Segment-based classification of remote sensing images

The starting point regarding the research on this topic was a mainframe software system carrying out segment-based classification of satellite images in a collaboration between ELTE and FÖMI (1983-1984, see [3]). The accuracy of its results has globally superseded those of pixel-based classification, but it gave coarser results at certain places of images with fine details.

After the mainframe system I have reimplemented the complete system of pixel-based and segment-based classification in Sun and PC environment using the C language. I have developed further the functionality of modules. Using the segment-based classification implemented, the global accuracy could reach 95-97%, which supersedes the pixel-based results by 2-3%. We have reported the milestones of research in several publications ([6], [7], [8] and [5]).

The incorporation of segmentation into the process of classification enables the effect of context in the assignment of each pixel. The outlier points of an area with homogeneous coverage is "brought along" by its neighbourhood into the proper land cover category. Experience shows that this effect yields correct results in the majority of cases.

I have improved the segmentation algorithm originally proposed by Kettig and Landgrebe several times. Regarding the linking possibilities of homogeneous cells the length of forward looking has become arbitrarily long. Among the linking possibilities at a certain place the best one is taken into account instead of the first one. This way the quality of segmentation has been significantly improved, while the running time has only slightly increased.

Clustering is a determining step of the classification process developed by me. It is supported by a deeper theoretical consideration. Clusters are linked to land cover categories using the study areas. This way the spectral subclasses of thematic categories are formed on the basis of the whole image. With this procedure we get statistical distributions better fitting to the image than what would be available solely on the basis of small study areas. Using this approach, the assignment of pixels and segments became more stable and reliable. Theoretical background is supported by the proven assumption stating that the intensity values of real land cover categories can be described by a normal distribution or can be approximated by the composition of several normal distributions.

The methodology developed incorporates the two classification methods into a unified framework. Using this approach, the classification of a segmented image is analogous to pixel-based assignment; the difference is that segments are the determining objects of each step. It was necessary to interpret the usual notions of pixel-based classification to segments, which required a stronger mathematical background.

Clusters of pixels or segments resulting from the first step of procedure are regarded as the initial values of spectral subclasses of thematic categories. Final subclasses are formed by a compound method involving the cutting and abandonment of clusters. Pixels or segments are finally assigned to these subclasses. Segment-based classification is amended by the step of pixel-wise re-examination. The procedure is finished by accuracy assessment using the test areas of ground truth data.

Classification procedure has been mostly used in the creation of crop maps. An important condition of reliable result is the joint utilisation of images taken at appropriate dates. The spectral behaviour of arable crops may be very similar in certain time periods, but these categories may be distinguished using multi-temporal stack of images.

I have also participated in another branch of research. Together with my research fellows we have chosen six further segmentation algorithms, and we have elaborated them with complete algorithmic details. We have introduced several distance measures into research. Using my experience in remote sensing, I have guided the directions of development with the selection of study areas and with the evaluation of running results ([4], [2] és [1]).

Thesis 1. I have developed a robust and efficient segment-based procedure for the classification of remote sensing images that is able to map land cover categories with high accuracy, superseding the results of pixel-based classification. I have incorporated the pixel-based and the segment-based procedures into a uniform framework. Clustering is a determining step of my method, which is the basis of establishing the spectral subclasses of thematic land cover categories. The procedure relies on the general knowledge on the statistical distribution of land cover classes. In my procedure there is a good balance between clustering, classification and the effect of statistical check. I have corrected the statistically necessary misclassification of segmentation by pixel-wise re-examination. The accuracy of classification has been increased by the utilisation of multi-source (multi-temporal and different resolution) data. I have improved the segmentation algorithm used in my development several times. I have participated in the selection and detailed algorithmic implementation of six further segmentation algorithms. My contribution also included the selection of appropriate study areas and the evaluation of running results.

3 Object-based Image Analysis

In the past years we have faced a shift of paradigm in remote sensing, including out institutional tasks ([10], [13]). The Very High Resolution (VHR) images have become widely available, and the role of ortho-photos with high spatial resolution has further increased. In the novel tasks the individual pixels can be hardly interpreted by themselves. The size of searched or examined objects in the images is often smaller, they have irregular border or their intensity is inhomogeneous (in contrast with large, regular and homogeneous parcels).

These tasks cannot be solved with pixel-wise evaluation. Segmentation is necessary in order to utilise contextual information. The involvement of further statistical, geometric and textural properties into evaluation is also often necessary. These are conceptually bound to objects; this approach is called Object-based Image Analysis (OBIA). Software products supporting OBIA appeared in the market. In FÖMI eCognition is used, which contains several segmentation methods as part of its rich toolbox. The procedures of such a professional system cannot be efficiently used without theoretical knowledge and practical skills. Using the practice I have gained with segmentation I could successfully participate in several applications.

The methodology of OBIA was first used in Land Parcel Identification System, in the delineation of eligible and ineligible areas. A typical case is the detection of ineligible solitary trees, tree groups and bushes within the eligible pastures. The objects of these two categories can be hardly differentiated solely on the basis of spectral properties. The difference between tree species is often larger than that between trees and other species. Therefore the texture of categories and the properties of object shape have also been taken into account.

This task has been solved by eCognition. Multi-source input data have been used: beside colour infrared (CIR) ortho-photos very high resolution satellite images have also been used. The final output of delimitation is a vectorial file containing polygons.

Having acquainted with the task, we have established a four-step segmentation procedure, using cut-based and merge-based methods. Geometric and textural properties have also been taken into account because of spectral difficulties. The homogeneity of texture of objects has been measured by Gray Level Co-occurrence Matrix (GLCM) and entropy. Classification has been refined by geometric properties.

OBIA has been used in connection with *the need to quickly survey the effect of a regrettable industrial disaster, the red mud spill happened in 2010.* It was necessary to use object-based methods, as the reliable distinction between inundated and intact areas could only be accomplished using geometric and textural properties. Three categories have been introduced during processing: open red mud surface, inundated soil and inundated vegetation. The final goal was the delimitation of inundated area.

Segmentation consisted of three parts, using the procedures of eCognition. Segments have been formed with the consecutive application of merge-based and cut-based segmentation steps and with the calculation of NDVI-like indices utilising red, red-edge and near-infrared bands. Maximum likelihood method has been used for classification.

Geometric features have also been taken into account during classification, because the spectral and textural properties of bare soil and moderately spilt surface are rather similar. The differentiation between them has been done by smoothing, taking into account the neighbouring objects.

The mapping of buildings differs pretty much from traditional applications, as it primarily requires the built-in urban environment. The necessity of object-based methods was obvious, which has been confirmed by the fact that no NDVI-like indices can be introduced for the infrastructure of built-in areas to support classification. The image data source of examinations consists of ortho-photos with spatial resolution of 0.5 m or better. They are amended with elevation data, which yields much better recognition accuracy.

Segmentation was a four-step process, using the procedures of eCognition. The utilisation of geometric properties has been proven to be subservient. The density measure gave good results in the case of roads and buildings. However, sometimes this was still insufficient; for example, the roof of long blocks of flats and sections of concrete roads can be differentiated by taking into account height data.

Thesis 2. In connection with applications and research regarding object-based image analysis I have relied on the theoretical knowledge of and the experience gained with segmentation. I have participated in several operational applications with the design of image analysis processes, the selection and parametrisation of segmentation and classification methods, the determination of appropriate geometric and textural features, the organisation of functions and commands into Rule Sets and the evaluation of results. Certain steps of image analysis have been carried out by my colleagues in a part of tasks.

4 The integrated utilisation of multi-source data

My research contains two main directions in the field of data integration. The first one is the examination of connection between the spatial, spectral and temporal dimensions of remotely sensed data, the fusion, joint utilisation of images of different kinds. The second one is the research into the possibilities of involving other geospatial data into remote sensing applications.

Different data sources may mean the spectral bands of a sensor, different sensors of a carrier, vectorial delimitations, maps, in-the-field measurement results. Integration can be an algorithmic procedure to calculate the merged data set or an informal method relying on human decisions. The merging realised by data fusion can be accomplished at different phases of processing.

The most frequent application of data fusion on remote sensing is *the pixel-based fusion of images*. It covers the improvement of spatial properties of a multispectral image by the merge with a higher spatial resolution image. The following has been stated during the usage of this approach:

The result of pixel-based fusion with VHR images is strongly influenced by the spectral coverage of bands and the system correction. It would be more advantageous in the quantitative processing to use only nearest neighbour re-sampling method during pre-processing. But in order for the visual interpretation to be efficient smoothing re-sampling (bilinear interpolation, cubic convolution) must be used already in the geometric correction.

When carrying out pixel-based fusion between multispectral and panchromatic bands of Landsat 7 ETM+ sensor, the pixel size of multispectral image was not a multiple of that of panchromatic pixel size. However, with the proper use of geo-location data this does not cause problems.

Among the fusion procedures applied for Landsat 7 ETM+ the Principal Component Analysis (PCA), the High-pass Filter (HPF) and the UNB Pansharpen, strongly taking into account the spectral coverage of bands, give the most favourable results when RGB 453 band combination was examined.

The looser interpretation of data fusion contains *the general merging of spatial, temporal and spectral dimensions of images* (see [16]). In our applications we have integrated images with better spatial or spectral resolution, but infrequent acquisition and those with frequent revisit, but weaker spatial or spectral resolution several times. For example, in agricultural applications winter and summer crops can be accomplished with just one or two satellite images. But for the more exact determination of crop species several images are needed from certain periods of the year that show the developed crops.

The CROPMON project used a two-level data fusion method. The first level consisted of the combination of satellite images taken at different dates within the period of winter and summer crops. At the second level the thematic synthesis of crop maps obtained in the two periods took place. We have settled that the status and temporal development of vegetation can be monitored more smoothly with the usage of medium resolution images than with the more frequent low resolution ones, because the pixels are less mixed. The best results can be obtained with the combined use of the two kinds of images.

The general interpretation of data fusion allows the integration of different GIS data sets with remote sensing data, which can be used in the refinement of delineations and in the definition of elementary processing units. However, the accuracy of vectorial delineation and remotely sensed data must be taken into account. Field measurements can also be considered as a case of data integration. It can be carried out before (ground truth data collection), during (rapid field visit) or after (follow-up inspection) remote sensing control. In our applications the usage of slope category map calculated from digital elevation model and the height of objects is also important. In the case of former one delineations on raster data are vectorised before usage.

We have also examined *the relationship between segment-based classification and data fusion.* Our segment-based classification method can be prepared to use satellite images with different pixel size. Further data available in raster or vector form can also be incorporated. A further important relationship can be settled between OBIA and data integration: in both approaches we can build rule sets for partial results gained in the phases of evaluation and intermediate thematic classifications. They are motivated by visual interpretation, highly building on human thinking.

Thesis 3. I have introduced and improved pixel-based merge and, taking into account the general meaning of data fusion, the advantageous integration of spatial, temporal and spectral properties of remotely sensed images in several applications. I have participated in the refinement of development monitoring of certain rare arable crops with the usage of medium resolution images. In practical applications I took significant part in the establishment of methods of integrating different geospatial data, like field measurements and digital elevation model. Our research into data fusion determined the way of further development of the established segment-based classification methodology (images with different resolution, joint usage of vector data), which has been partially realised with the introduction of OBIA.

5 Applications in the field of remote sensing

In my workplace I have contributed to several projects with my research and development activity. In the following I will mostly refer to the appearance of my main research topics. Segmentation can be primarily used in thematic classification tasks where the groups of pixels falling into the same category represent the objects of real world (e.g. agricultural parcels). However, this approach has been proven useful also in other cases (e.g. mapping of red mud). Our applications highly build on the integration of images of different kinds. Time dimension is especially important in the distinction between land cover categories and in crop development assessment.

Crop Monitoring and Production Forecast System (CROPMON): The aim of CROPMON (1997-2003) was the determination of area of eight main crops at county and country level and the prediction of expectable yields. Images of different resolutions and dates have been used in an integrated way in the continuously developing image processing procedures.

Because of its task, CROPMON was in the tightest relationship with my research topics. The majority of questions of segment-based classification has already appeared here; its results have been incorporated into the project. Besides, I have built in the radiometric correction of four new sensor into yield forecasting system. I have established the Tasseled Cap transformation, calculating certain indices, for Landsat 7 ETM+ sensor, with tracing back to Landsat 5 TM sensor. I have developed and implemented a semi-automatic cloud and cloud shadow filter procedure using this transformation.

Control with Remote Sensing of Area-based Subsidies (CwRS): Farmers submit about 180 thousand applications for EU agricultural subsidies. 5-9% of them are subject of on-the-spot control, which means the remote sensing control of 60-80 thousand parcels regarding cultivated crop, area, and the compliance to Good Agricultural and Environmental Conditions. The system, which is mainly based on visual interpretation, incorporates significant professional knowledge from the field of law, process management, agriculture, geographical information systems, remote sensing, data integration and classification. A strict error threshold is valid against the accuracy of methodology: error rate of 1% would already be dangerous.

As the methodological and process responsible of this project, my tasks include inland and international liaisons and accurate process development. From the professional side I contribute to the successful implementation of the yearly campaign with the selection and pre-processing of remote sensing images, the complex application of methodology of GIS, data integration and classification, database development and data processing tasks ([14], [15]).

Land Parcel Identification System (LPIS) is the exclusive GIS identification system of EU agricultural subsidies. It is based on ortho-photos. It provides the frame for identification and area measurement of parcels. It contains several thematic layers (e.g. Natura 2000). Satellite images are also used for the updating of physical blocks (refinement of land cover, identification of stable elements). I have developed a program doing pixel-based fusion for used satellite images at country level. With my leading participation the statistical and object-based classification became the part of updating ([10]).

Disaster monitoring: Flood, waterlog and drought monitoring requires three different remote sensing approach, but they are similar in the wide spectrum of satellite images and in the importance of general data fusion and temporal dimension. Primarily I have participated in drought monitoring, where the radiometric correction, inter-calibration and the calculation of vegetation indices are also important beyond the above mentioned aspects. I have developed models and programmes to the pre-processing and inter-calibration of images and to the calculation of maximum composites of vegetation indices for decades. With their usage I have derived drought maps for several time periods and I have evaluated the results.

Ragweed monitoring with remote sensing: In the project of protection against ragweed significant innovation has been realised to handle the irregular spatial and temporal behaviour of this crop, where data integration and OBIA is also involved. As my own result, I have elaborated a method for the GIS processing of ragweed spots resulted from remote sensing survey. Its aim is to filter out errors caused by local noise from the official procedure. I have established a method to the classification of infection of physical blocks and settlements, based on the results of remote sensing and field control.

Thesis 4. In the important fields of remote sensing I was or I am participating in the implementation of seven country-wide project, leading one of them. They together cover almost the whole spectrum of image analysis. My major results: process development (in EU-harmonic way), the elaboration of methodology, image pre-processing (geometric and radiometric correction, cloud filtering), data fusion (pixel-based merge, inter-calibration), the application of OBIA methods (with geometric and textural properties and indices), incorporation of geospatial data models (elevation model) and the quantitative ranking and qualitative interpretation of results.

6 The education of remote sensing

The Geoinformatics educational module started in 2004 at ELTE Faculty of Informatics as a part of software engineer education. It contains the course Analysis of Remote Sensing Images, which is maintained together by the staff of ELTE and FÖMI. Lectures are currently given by me, but I am also taking part in the practices with the demonstration of some important procedures. We have reported about education results at a conference and in a journal ([5]).

The curriculum of this course with more than 400 slides is near to the level of lecture notes. This is confirmed by the prize gained in 2011 in the tender for lecture notes of Faculty of Informatics. It has been placed in the digital library of the Faculty ([11]). In the near future a textbook, supported by the tender TÁMOP-3.1.4, will be completed by me and my co-authors.

A formal mathematical description of thematic classification (e.g. digital image, feature space, clustering, refinement of subclasses, segmentation) has been inspired by education. Parts I and II of my dissertation is highly based on this description. The exact notion has proven to be a useful tool in the algorithmic design during research and development.

I regularly undertake the supervision of MSc theses on practical problems. The methods elaborated in the latest thesis have been involved into the operational projects of FÖMI, and serve as the basis of professional solutions ([5], [13]).

I help the education in the frame of Geoinformatics Laboratory with consultations. In the laboratory project the AEGIS open source GIS framework has great importance. I support its development and application from the practical side ([5], [12]).

Up to now several hundred students have completed the Geoinformatics educational module including the course Analysis of Remote Sensing Images. Many of them began their professional work in this field, some of them in the FÖMI itself. Therefore my students has become my colleagues.

Result. I have been participating in the education of remote sensing at ELTE Faculty of Informatics for 8 years, currently as the lecturer of the course. The textbook based on about 400 slides will be issued in 2013. The formal mathematical description has been proven to be usable generally, not only in eduacation. I regularly publish practical MSc thesis topics. I support with consultations the project work of student laboratory.

References

[1] Dezső B.: Optimization methods in remote sensing and geoinformatics. Ph.D. Dissertation (Supervisor: Dr. István Fekete), Eötvös Loránd University, Faculty of Informatics, Doctoral School of Informatics, Budapest, 2012.

[2] Dezső B., Giachetta R., László I., Fekete I.: Experimental study on graph-based image segmentation methods in the classification of satellite images. EARSeL eProceedings, Vol. 11, 2012. (pp. 12–24.)

[3] Fekete I., Farkasfalvy J.: Automatic segmentation of multispectral digital images. In: *5th Conference of Program Designers,* ELTE, Budapest, 1989.

[4] Fekete I., Dezső B., László I., Ócsai K.: A szegmentálás szerepe az űrfelvételek tematikus osztályozásában (The role of segmentation in the thematic classification of satellite images). In: Informatika a felsőoktatásban (Informatics in Higher Education) 2008, Debrecen 2008.

[5] Giachetta R., László I., Elek I., Fekete I., Gera D.: Térinformatikai oktatás és kutatás-fejlesztés az ELTE Informatikai Karán (GIS Education and Research at Eötvös Loránd University, Faculty of Informatics). Agrárinformatika Folyóirat. 2011. 2. évfolyam 1. szám (Journal of Agricultural Informatics. 2011 Vol. 2, No. 1)

[6] László I., Nádor G., Fekete I., Csornai G., Kocsis A.: A segment-based classification method for satellite images. In: 5th International Conference on Applied Informatics, Eger, 2001.

[7] László I., Pröhle T., Fekete I., Csornai G.: A method for classifying satellite images using segments. In: *Annales Univ. Sci. Budapest., Sectio Computatorica*, 23 (2004) 163–178.

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

[9] G. Csornai, I. László, G. Mikus, G. Nádor, I. Hubik, K. Lipták, M. Antal, K. Ócsai, I. Fekete, D. Gera: The Possibilities of New Satellite Image Types in the Control of Area-based Subsidies and in Ragweed Monitoring System. *Remote Sensing for Science, Education, and Natural and Cultural Heritage – Proceedings of the 30th Symposium of EARSeL* (ISBN 978-3-00-033435-1), EARSeL, 2010 (pp. 699-706)

[10] László I., Ócsai K., Gera D., Giachetta R., Fekete I.: Object-Based Image Analysis of Pasture with Trees and Red Mud Spill. In: In: L. Halounová (Ed.): Remote Sensing and Geoinformation not only for Scientific Cooperation - Proceedings of the 31st Symposium of EARSeL, (ISBN 978-80-01-04868-9), EARSeL 2011. (pp. 423-431)

[11] László I., Csornai G.: Távérzékelt felvételek elemzése (Analysis of Remote Sensing Images). Slides of university lecture. Availability on the homepage of ELTE IK: http://www.inf.elte.hu/karunkrol/digitkonyv/Lapok/2011jegyzettamogatas.aspx
On the homepage of course responsible:
http://people.inf.elte.hu/fekete/taverzekeles/eloadasok_2013/

[12] R. Giachetta, I. László and Cs. L. Bálint: Towards the new open source GIS platform AEGIS. In: Degbelo, A. et al. (eds.): GI Zeitgeist 2012 – Proceedings of the Young Researchers Forum on Geographic Information Science, 11-22, 2012.

[13] László I., Dezső B., I. Fekete, Gera D., Roberto G., László I.: Object-based Image Analysis in Remote Sensing Applications Using Various Segmentation Techniques. Annales Univ. Sci. Budapest, Sectio Computatorica Vol. 37 (2012) 103–120. Selected papers of 9th Joint Conference on Mathematics and Computer Science (MaCS) 2012 February 9-12, 2012, Siófok, Hungary

[14] I. László: The integration of remote sensing and GIS data in the control of agricultural subsidies in Hungary. Előadás, 33^rd EARSeL Symposium, Matera, Olaszország, 2013. június 3-6. (A cikk megjelenés alatt a konferencia kiadványában.)

[15] G. Nádor, I. László: Comparative analysis of Pleiades and other VHR images in quantitative and visual evaluation. Előadás, 33^rd EARSeL Symposium, Matera, Olaszország, 2013. június 3-6. (A cikk megjelenés alatt a konferencia kiadványában.)

[16] Wald, L.: *Data Fusion: Definitions and Architectures - Fusion of images of different spatial resolutions.* L'Ecole des Mines de Paris, 2002.