University of West Hungary
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Spatio-Temporal Analysis of Vegetation Habitats in Riparian Wetlands

Theses of doctoral (PhD) dissertation

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Sopron, 2014

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Abbreviations

Á-NÉR	*Hu.*__Á__ltalános **N**emzeti **É**lőhelyosztályozási **R**endszer (botanical vegetation classification system in Hungary)
ASV	**Ásv**ányráró test site
CDBF	**C**lass **D**escription **B**ased **F**uzzy (algorithm)
CIR	**C**olour-**i**nfra**r**ed
DK	**D**una**k**iliti test site
DR	**D**una**r**emete test site
DT	**D**ecision **T**ree (classification algorithm)
FATI1	*Hu.*Az **1. fa**állomány **tí**pus kódja (*En.*FST)
FÖMI	**Fö**ld**m**érési és Távérzékelési **I**ntézet, Budapest (Institute of Geodesy, Cartography and Remote Sensing)
FST	**F**orest **S**tand **T**ype
GLCM	**G**rey **L**evel **C**o-occurrrence **M**atrix
GLDV	**G**rey **L**evel **D**ifference **V**ector
JM	**J**effries-**M**atusita (statistical separability analysis)
NDVI	**N**ormalized **D**ifference **V**egetation **I**ndex
NNY	*Hu.*__N__emes **ny**áras (hybrid poplar)
OA	**O**verall **a**ccuracy
OBIA	**O**bject-**B**ased **I**mage **A**nalysis
STDEV	**St**andard **dev**iation

Background and aims

The loss of natural and semi-natural ecosystems and hereby induced negative change in the biological diversity are among the most actual problems nowadays. For the objective monitoring of changes and their effective management, an appropriate analysis method is needed. Wetland ecosystems came into the focus of interest, since they are the most productive ecosystems in the Earth, and reached a vulnerable status due to the recent changes. In these ecosystems, e.g., in riparian floodplains, traditional field survey is often problematic because of inundation and they could not give updated information for an extended site. The manual interpretation of remote sensing data (satellite and aerial imagery) is also subjective and time consuming like the field work. Since an ever increasing amount of remote sensing data is being produced in these days, (semi-)automated image analysis techniques became crucial, coinciding with the increasing computation power. Therefore, the automated analysis of available aerial images provide a potential solution for ecosystem-monitoring and hereby giving a basis for future restauration strategies.
The main aim of the dissertation is to develop a vegetation habitat mapping method based on high spatial resolution aerial imagery, using automated digital image analysis techniques.

1. In the first step the automated classification method is to be worked out for a selected test site in the Szigetköz Danubian floodplain (Hungary), using aerial images from different years.

2. After that it is aimed at developing such an image analysis method,

which is automatically applicable to other areas outside the training area, in the same riparian wetland.

3. In the next step an appropriate image analysis method is sought for the detection of similar vegetation in distinct years, based on a selected test site.

4. In the end it is aimed at working out a universally applicable method in space and time, applied to aerial images with the same spectral and geometric resolution, where forested and non-forested wetlands can be automatically separated based on the training image.

Materials and methods

Three test sites have been selected in the Szigetköz floodplain near to the villages Dunakiliti (DK), Dunaremete (DR) and Ásványráró (ASV). The applied true colour and colour-infrared (CIR) aerial images are available at the Institute of Geodesy, Cartography and Remote Sensing (FÖMI, Budapest) and in the archives of the University of West Hungary, covering around 2-3 km^2 area in each case. The ground spatial resolution of the images is 1.25 m/pixel after the resampling of the 2008 and 2005 images, based on the original resolution of the 1999 orthophoto. The target classes for the vegetation mapping are based on botanical inventory (from the National Park of Fertő-Hanság): habitat map with the Á-NÉR classification system (*Hu.*Általános Nemzeti Élőhelyosztályozási Rendszer, general national habitat classification system) and silvicultural data (Forest Stand Type, FST) from the National Forest Inventory (Szombathely). Besides that, separability of vegetation classes by visual image interpretation was considered. Since detailed botanical inventory within the framework of National Biodiversity Monitoring System with the Á-NÉR classification system was only worked out for a selected site in the floodplain, the development of image analysis techniques was principally based on the overlap area: DR.

The application of pixel-based image analysis algorithms is often problematic in case of high spatial resolution (under 5 m/pixel) imagery with a high level of detail, but in contrast, applying OBIA (object-based image analysis) is advantageous, where the first step of the analysis is image segmentation. For the most commonly applied multi-resolution (MR) segmentation the so-called homogeneity criterion has to be set for the target segments, which consists of a colour and a shape value. Based on this segmentation, water bodies can be accurately classified, where the colour information is significant. Contrary to that different vegetation habitats cannot be detected based on the spectral information only.
Instead of analysing the average radiometric value (e.g., for the different bands, also for the first principal component), geostatistical descriptors, like textural parameters from the GLCM (Grey Level Co-occurrence Matrix) can be computed for the image segments. GLCM describes the probability that radiometric values of each pair of pixels from a grey-scale image (image segment) co-occur in a given direction and at a certain lag distance. Different measures calculated from the matrix help in the characterization of image texture. For a unique anal-

ysis of textures chessboard segmentation was applied instead of MR segmentation, where the significance of the segmentation type was emphasized based on accuracy assessment. After chessboard segmentation the image is divided into regular squares, where the optimal square size was defined after semivariogram analysis based on a training sample set for the target classes.

Jeffries-Matusita (JM) statistical separability analysis was applied for the evaluation of significant textural parameters and the analysis of vegetation class separability.

Afterwards the classification of objects into thematic classes was based on the class description based fuzzy (CDBF) algorithm, which is one of the supervised classification type in OBIA. The other classification type applied in the dissertation is hierarchical, where an optimal decision tree (DT) is computed based on the input parameters: the target classes (with training areas) and the spectral and textural parameters.

For accuracy assessment overall accuracy (OA) and Kappa index were calculated, based on reference areas selected after visual interpretation, not overlapping with the original training samples.

Besides using ERDAS Imagine, ArcGIS and R statistical software, the most part of the applications were worked out in the object-based image analysis software eCognition Developer.

Results

Firstly vegetation mapping was worked out for the principal test site (DR), separately applied to true colour and CIR aerial imagery from three different years (2008, 2005, 1999). It was proved that the combination of spectral descriptor (vegetation index) and GLCM textural parameters after the JM separability analysis give the best vegetation classification result applied as input parameter set in the CDBF algorithm, contrary to the sole use of spectral or textural parameters. The classification was based on 20 m×20 m square image segments, giving better accuracies (OA was between 82% and 87%) in comparison with the MR-segment-basis (where OA was between 61% and 78%) for all the analysed images. The here applied "simple" vegetation classification scheme was concentrated on selected habitats. However, the scheme was extended for the definition of the unclassified area remained. The "extended" scheme was worked out for the same test site (DR) with the analysis of the 2008 image, where the overall accuracy was 88%. Nevertheless, unclassified image objects still remained.

Analysing DR test site (2008) with another image classification algorithm, the decision tree, no unclassified area remained and the overall accuracy of the classification was 90% with the extended classification scheme. Beyond that, the training image based decision tree was applied to two other test areas (DK, ASV) in the floodplain, where the detection of Hybrid poplar class gave a user's and producer's accuracy higher than 85%. Further analysis proved, that the Hybrid poplar vegetation class can be automatically classified in other sites (ASV) as well, based on a training image based decision tree, but it requires that the training samples only include the Hybrid poplar FST (*Hu.*FATI1 code: NNY).

By applying JM separability analysis to different year CIR aerial imagery (respectively to a sample data set taken from the images), GLCM standard deviation (STDEV) was proved to be a stable parameter, which is applicable to detect similar (like low vegetation) and different vegetation patterns (like Hybrid poplar) in the distinct years. Afterwards a generalized classification scheme with low and high vegetation classes was analysed and it was proved, that the decision tree computed with GLCM STDEV and a spectral descriptor (vegetation index) applied to the 2008 image is automatically applicable to the earlier CIR image (1999). Nevertheless, the GLCM STDEV is sufficient as a single descriptor applied to the 1999 scene with NIR-R-G spectral band combination for the separation of low and high vegetation.

Transferring the training-image based decision tree classification was proved to be feasible for the separation of high (forested) and low vegetation (non-forested wetlands) applied to other site (DK). Thus the classification approach is automatically transferable in space and time. Besides the earlier applied chessboard segmentation with 20 m$\times$20 m image objects, MR-segments were tested for classification performance and in comparison with the chessboard-basis, they proved to give lower overall accuracies, but still $\geq 87\%$ for each test site.

Conclusions and future prospects

High resolution aerial imagery based automated image analysis provides an objective method for vegetation mapping compared to the field investigation based vegetation monitoring. Therefore, the developed image classification methods can help botanical and silvicultural surveyors to produce and update vegetation and forest habitat maps.
Based on the applied imagery (1.25 m/pixel) with the available botanical and silvicultural data significant target vegetation classes were identified, however, the reliability of the vegetation classification scheme could be problematic due to the time differences for the images and the ancillary data.
The significance of applying CIR aerial imagery was proved by the use of vegetation indices which provide concrete separability between water bodies and vegetation, and beyond that, enhance vegetation habitat separabilities, including the automated detection of Hybrid poplar stands.
Decision tree transfer methods applied to CIR aerial imagery firstly provide a rapid assessment technique for the detection of Hybrid poplar vegetation cover, if images come from the same image acquisition, secondly, offer an automated solution for separating high and low vegetation for spatio-temporal monitoring purposes. The Jeffries-Matusita separability analysis is vital for the selection of significant parameters in a one-year and in a multi-temporal image analysis.
The necessity of a specific accuracy assessment technique in future applications became crucial for the evaluation of vegetation habitat borders in MR-segment-based classifications.

For future research, analysing most recent aerial imagery and reference information from the same time would have the potential for applying a more accurate vegetation classification scheme and a more reliable accuracy assessment. Beyond that, detailed silvicultural data would ensure the analysis of a combined mapping focusing on species composition and age structure.

Based on an analogue NIR-R-G aerial image (1999) textural parameter was found as a more significant parameter than spectral parameter for the separation of high and low vegetation, in contrast to the recent digital imagery with the NIR-G-B spectral band combination (2008). Nevertheless, the analysis of further imagery is needed for the verification of this assumption.

Automated image analysis techniques developed in the current research could complement a recent research activity, the INMEIN ("Innovative methods for monitoring and inventory of Danube floodplain forests based on 3D technologies of remote sensing"), a Hungarian-Slovakian Cross-border Cooperation project, where the image classification of recent aerial photography (2013) is to be potentially combined with the analysis of airborne laser scanning data.

The universal applicability of the here applied vegetation mapping methods is to be tested to other riparian wetlands and areas with similar vegetation cover.

Theses of the dissertation

1. The class description based fuzzy algorithm as a supervised image classifier, applied to segmented aerial images from different years, provides the best vegetation classification result, if the input parameter set includes spectral and textural parameters, not only spectral or only textural features. Based on the accuracy analysis in the present research, the following parameters provide the best results: GLCM (Grey Level Co-occurrence Matrix) standard deviation, GLCM contrast, GLCM mean, GLDV (Grey Level Difference Vector) entropy, vegetation index.

2. It was proved, that a decision tree classifier with a spectral-textural parameter set, developed on a segmented CIR aerial image for the detection of the Hybrid poplar class, can be transferred spatially to other areas. The transfer can be successful only, if the training samples belong entirely to the Hybrid poplar Forest Stand Type (FST, FATI1 code in the *Hu.* silvicultural classification scheme, FATI1: NNY). Using other mixed FSTs as training samples, e.g., Domestic poplar-Hybrid poplar (FATI1: NNY-HNY), although being predominantly populated with Hybrid poplar species (*Populus x euramericana 'Pannonia'*), leads to classification errors. The developed method can be used for rapid forest inventories using CIR aerial imagery, focusing on the assessment of Hybrid poplar stands.

3. Based on a systematic Jeffries-Matusita class separability analysis, the GLCM standard deviation was found to be a stable

textural parameter, applicable for the 20m$\times$ 20m (16$\times$16 pixel) square sample-based evaluation of vegetation pattern similarities and differences in CIR aerial images acquired in different years with different techniques but having the same geometric resolution (1.25 m/pixel).

4. Accuracy analysis of image processing results proved that a decision tree classifier with its spectral-textural parameter set, developed on a most recent CIR aerial image, can be transferred for the analysis of an older image of the same area for the separation of high and low vegetation. The images need to have the same spatial resolution and include the near-infrared band.

5. It was proved that the use of GLCM standard deviation as a textural parameter is sufficient for the separation of high and low vegetation classes based on aerial imagery with the NIR-R-G spectral band combination.

6. On segmented CIR aerial imagery with common spatial resolution, but from different years and sites of the same wetland it was proved that vegetation can be automatically classified into forested and non-forested areas with a most recent training image-based decision tree classifier. This method provides a rapid assessment technique based on object-based aerial image analysis, which is spatially and temporally transferable, in order to map the cover of high and low vegetation areas often required in environmental modelling and monitoring studies.

Publications

Articles in peer-reviewed journals

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Acknowledgements:

Trimble Geospatial Munich, Germany
University of West Hungary,
Faculty of Geoinformatics, Székesfehérvár, Hungary
University of Twente, ITC
(Faculty of Geo-Information Science and Earth Observation),
Enschede, the Netherlands
Technical University of Dortmund, Faculty of Spatial Planning,
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