OBJECT ANALYSIS OF IKONOS XS AND PAN-SHARPENED IMAGERY IN COMPARISON FOR PURPOSE OF TREE SPECIES ESTIMATION

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KEY WORDS: object image classification; VHR satellite data; texture analysis; forest management

ABSTRACT:

Increasing demands on the level of accuracy, repeatability and cost are being made on large scale forest inventories during last years. The amount of terrestrial field work can be efficiently reduced by the application of traditional remote sensing methods such as manual aerial photo interpretation. However, this often requires the high level of expert knowledge and thus development of the automated classification methods is desired for operational forestry. In the same time, many studies showed that standalone optical RS techniques are insufficient for classification of complex forest structures and suggests the fusion of image data with the 3D information either from laser scanning or stereo-matching from high resolution digital surveys. Mapping of young succession stages and heterogeneous mature stands might be of particular use for such techniques.

The study proposes a deeper analysis of the optical input for the knowledge-based classification systems. It shows that for purpose of tree species identification very good results can be achieved by the combination of object-oriented approach and the topo-corrected Ikonos imagery, and with the emphasis on various image transforms derived during pre-processing phase. This involves many additional channels calculated from the original dataset such as spectral ratios and vegetation indices (NDVI), Tasseled cap and IHS transformation, low-pass filters, Sobel edge detection and GLCM texture measures. Besides, the height information from high resolution DEM needs to be used for both topographic normalisation and the classification.

In the analysis, the contribution of 15 selected features within the enlarged class signature space was assessed with stepwise Discriminant analysis and verified by the visual comparison of feature histograms. Then image segmentation and object classification were conducted on three levels of hierarchical image object network. Segments of the highest level were classified according to basic landuse types. The lower level was created only within class forest and aimed to create smaller parts regarding different succession stages at the stand level. The very detailed level assigned individual tree clusters into classes for the main forest species in the area - Quercus, Acer, Picea, Larix and Betula.

The approach based on species area coverage corresponds to the conventional technique of estimation of tree species distribution in Czech forestry. The methodology was firstly tested on 4 meter Ikonos multispectral and then applied to 1 meter resolution pan-sharpened imagery. The classification accuracy was assessed according to the GIS field reference data and the common accuracy statistics were calculated from the assembled error matrix. The results of 4-m/1-m data were compared by means of Overall accuracies and Kappa index of agreement (KIA). The developed rules based on fuzzy membership functions were found highly convertible and suitable for semi-automated application. Both data types have their benefits and should be utilised in different forest management tasks. The further research will focus on the object analysis of CIR digital aerial photos.

1. INTRODUCTION

Methods of forest state assessment using remotely sensed data have been tested for several decades, with the visual aerial photo interpretation as the main tool widely utilised in practical forestry. Nevertheless, the automated classification of such textured data is still problematic due to enormous class spectral variation (Halounová, 2003). The methods of tree species identification from satellite imagery have been also explored lately. Some studies aimed at estimation of forest species composition using moderate resolution data such as Landsat TM, Spot HRV, while the relevant studies on VHR satellite imagery such as Ikonos (Bucha, 2004) and QuickBird seem promising for the species identification at the individual tree level. As demonstrated by several authors (Brandtberg, 1999; Leckie et al., 2003), working at a tree scale has a potential to extend digital remote sensing into many new areas such as forest stand extraction, forest regeneration, logging practices, etc. In the same time, however, many studies proved the RS methods based solely on spectral classification insufficient for detailed forest mapping (Wack and Stelzl, 2005). The enhanced height information from LiDAR and its integration with the tree species estimates from optical data are nowadays in the main focus for purpose of detailed 3D stand modelling.

In the environment of the Czech forest sector, the estimation of species distribution is traditionally based on the area coverage acquired by terrestrial methods. Even manual interpretation of aerial photos never quite met the needs of forest inventories, as reported by the official authorities. Nevertheless, the increasing demands on the level of inventory precision, information resolution and repeatability call for the development of practical application based on automated image analysis to be utilised in forest management. This study deals with the automated method of tree species composition estimation from Ikonos imagery using object-oriented approach. The presented methodology was tested on both 4-meter and pan-sharpened Ikonos images with the aim to compare and describe the two datasets to meet the forestry needs. Besides, the prospect of the knowledge-based classification using VHR data in operational forestry was suggested.

2. MATERIAL AND METHODS

2.1 VHR imagery and additional input data

IKONOS

The proposed methodology was tested on VHR satellite data from sensor Ikonos-2. The sensor delivers multispectral (XS) images with spatial resolution of 4m and 1m images using panchromatic mode. The imagery acquired on 7th June 2003 was delivered in a geo-registered UTM projection (zone N33) with 11-bit radiometric resolution at Standard Geometrically Corrected processing level. The nominal Collection azimuth and elevation were 105.4862^o and 76.79404^o, the Sun angle azimuth and elevation were 155.8632^o and 61.15952^o.
The subset of 4 x 4km representing an industrial forest area close to town Žlutice (50^{o}05'N, 13^{o}12'E), Western Bohemia was selected. The predominantly flat site comprised large patches of old Norway spruce (Picea abies L.) often mixed with Scots pine (Pinus sylvestris L.), extensive mature Pedunculate oak (Quercus robur L.) forests and also Birch (Betula pendula L.), European larch (Larix decidua Mill.) and young plantations of Pine and Oak. Besides, smaller proportions of Sycamore maple (Acer pseudoplatanus L.) could be found inside forest stands and along the margins. In both areas, planted mature stands were mostly of the same age, but very heterogeneous in species composition, stocking density and canopy structure. The natural regeneration in addition to the planted trees sometimes occurred.

DTM

The digital contour map from ZABAGED® GIS database produced by the Czech Office for Surveying, Mapping and Cadastre (COSMC) in scale of 1: 10 000 were used as a source of height information. Then the DEM was created with resolution 2m/pixel (Figure 1). Lambertian Reflection Model was initially tested in order to reduce topographic effects. However, the transformed image was unsuitable to use due rapid radiometric shift and so the shade layer was instead calculated to normalise the image for varying illumination. Besides, the height information was used as an additional input during the classification phase.

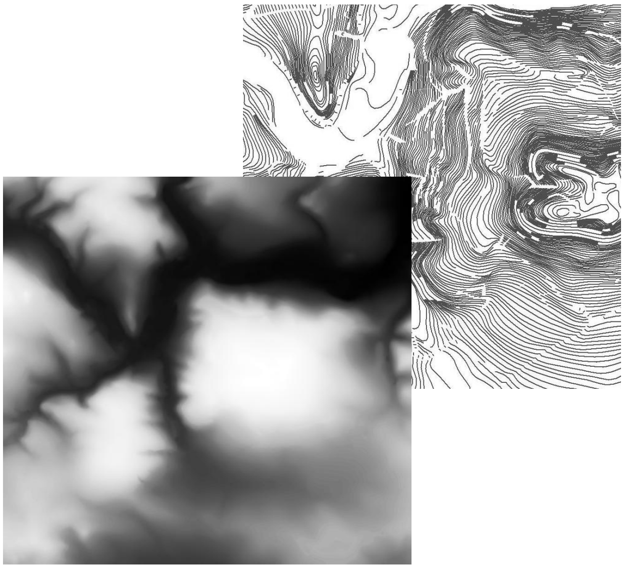

Figure 1. High resolution digital elevation model calculated from ZABAGED® (COSMC) digital contours.

FIELD GIS

Based on the previous information from forest management planning database LHPO provided by the Forest Management Institute (ÚHÚL), twenty 400m^2 plots covering areas with 100% species composition were located as a reference data. Sample plot selection put emphasis on size and class purity to provide representative basis for accuracy assessment. The boundaries of each plot were determined with differential GPS SX Blue^{TM} and PDA with ESRI ArcPad^{TM} 6.0.2 mobile GIS.

2.2 Image analysis

Object-oriented classification in software eCognition (Definiens Imaging, Germany) was the main image analysis method. This approach features an enhanced technique of multi-resolution image segmentation, complex capability in object description (spectral, geometric, textural and contextual), hierarchical image object network and fuzzy rule base classification.

SEGMENATION

Segmentation was conducted stepwise on three levels using different scales to construct the hierarchical image object network. The primary level was created using large Scale parameter and after preliminary classification was done for basic landuse classes. Other two sublevels were segmented only within the forested area using smaller Scale parameter and using classification-based segmentation (Table 1)

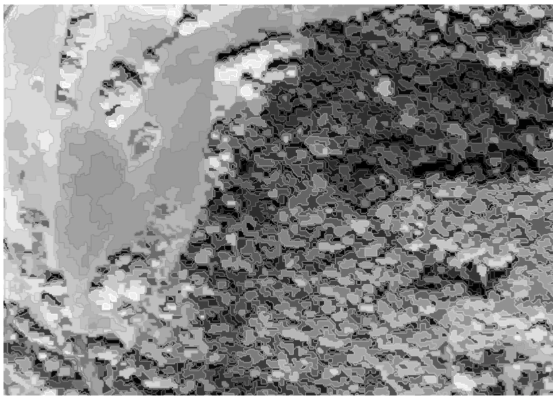

Figure 2. Detailed segmentation at the lowest level of hierarchical image object network

Segmentation	4m/pan	Homogeneity criterion			
		Color	Shape	Compact/Smooth	
Level I	25 / 60	0.8	0.2	0.5	0.5
Level II	18 / 45	0.7	0.3	0.5	0.5
Level III	5 / 12	0.7	0.3	0.7	0.3

Table 1. Segmentation parameters for analysis of Ikonos 4-m and Ikonos pan-sharpened images

SIGNATURE SPACE ENLARGEMENT AND FEATURE SELECTION

In order to enhance class separability, the signature space was enlarged by the calculation of additional channels in pre-processing phase in Erdas Imagine 8.7. Various spectral features based on original channels and also derived band rationing were calculated as "Customised features" in eCognition 4.0.6. Considering all relevant features (color, texture, and context), the dimensionality of dataset increased and therefore methods of feature selection were needed. Layers tested for the significant contribution included: spectral ratios and vegetation indices (NDVI), Tasseled cap and IHS transformation, low-pass filters, Sobel edge detection and GLCM texture measures (Haralick and Shapiro, 1992).

In each class, 30 sample objects were manually classified based and the reference field data and then the visual and statistical techniques of feature contribution were tested. Discriminant analysis (Rencher, 2002) was used to find optimal variables for distinction of different stand structures. The assessment was based on comparison of coefficients a_r , $r = 1, 2, \ldots, p$, in the discriminant function

$$z = \mathrm{a}'\mathrm{y} = a_1 y_1 + a_2 y_2 + \ldots + a_p y_p \qquad (1)$$

where $a_1 \ldots a_p$ = discriminant function coefficients

$y_1 \ldots y_p$ = classification variables

Mean observation vectors **y** for 15 selected variables were calculated and the discriminant function coefficient vectors **a** were derived from variance-covariance matrix $\mathbf{S}_{\mathrm{pl}}$ as

$$\mathbf{a} = \mathbf{S}_{\mathrm{pl}}^{-1}\left(\bar{\mathbf{y}}_1 - \bar{\mathbf{y}}_2\right) \qquad (2)$$

where $\mathbf{S}_{\mathrm{pl}}$ = variance-covariance matrix

$\bar{\mathbf{y}}$ = mean observation vectors

Since the y's were not commensurate, coefficients applicable to standardised variables **a*** had to be calculated. The relative contribution to separation of the analysed classes was then assessed by comparison of absolute values of coefficients standardized by square roots of the diagonal elements of $\mathbf{S}_{\mathrm{pl}}$:

$$\mathbf{a}^* = \left(\mathrm{diag}\ \mathbf{S}_{\mathrm{pl}}\right)^{1/2}\mathbf{a} \qquad (3)$$

where $\mathbf{a}^*$ = standardised DF coefficients

$\mathbf{S}_{\mathrm{pl}}$ = variance-covariance matrix

Further, the result of the statistical analysis was reviewed using the visual assessment of the feature distribution comparing histograms of two selected classes at the time. The significant contribution to class separation was found for these features:

- Mean spectral values of visible Green and NIR Ikonos bands together with the Customized features such as NIR/Red, Green/NIR, NDVI ratios and their derivatives normalized by Shade layer were predominantly used for the classification of tree species based on spectral information
- Sobel Edge layer calculated for IR Ikonos band, 2nd (saturation) channel of IHS transformation and GLCM texture feature Variance of window size 3 x 3 were applied to separate agriculture and vegetation areas of different textures and to differentiate forested areas, regenerating areas and clearcuts
- DEM values served to separate forest/agriculture bare soil areas

Besides the classification stage, channel of Median filter with kernel 3 x 3 was tested and used during initial segmentation of highly textured pan sharpened data.

FUZZY RULE-BASED CLASSIFICATION

The classification process was controlled by a rule base describing characteristics of individual classes by means of fuzzy membership functions (Baatz et al., 2003). Each class description consisted of a set of fuzzy expressions allowing the evaluation of specific features and their logical operation.

The three levels of hierarchical image object network were used to delimit classes (Figure 3). Level 3 comprised basic "Landuse" types – Water, Urban, Fields and Forest. This served to mask all non-forest areas. The lower level 2 "Forest" aimed at separation of forest regions into areas of bare ground, mature stands and young stands, where classes "plantation (transition)" and young stages of conifers, broadleaves and other were further distinguished. "Other" young forests were mostly consisted of Larch and Birch trees. The detailed level 1 "Stand" was set to distinguish four main forest species in the area - Quercus, Acer, Picea, Larix and Betula. Further, structures of shadows and bare ground were classified on this level. All classes of "Forest" level were also recognised at the lower "Stand" level for purpose of post classification improvement.

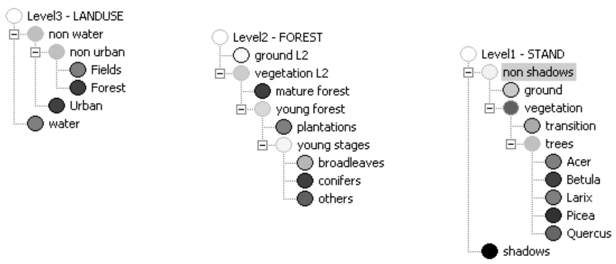

Figure 3. Classification rule-base of image analysis at three levels

3. RESULTS

The knowledge base initially created for 4m image was also applied with minor threshold modifications to the pan-sharpened data, so the comparative results were achieved. Then 20 samples for each class of the "Forest" and "Stand" classification levels were selected in accordance with the GIS field reference data and the common accuracy statistics were calculated from the assembled error matrix.

The overall classification results at the lowest "Stand" level were very similar for both tested datasets. As deduced from the accuracy assessment (Table 2), there is no crucial difference between 4-meter and pan-sharpened Ikonos imagery in ability of identifying tree species composition in terms of area coverage. The very good result of more than 90% was obtained for classes Acer and Picea, and class ground with approx. 80 %. The lower agreement (around 75%) was achieved for Betula and Larix and for the class transition (60%). Besides, some differences linked the image resolution occurred. This was most evident for shadows, where pan Ikonos gained nearly 30% in accuracy for over 4-m image.

Species / Stats	Acer	Querc	Picea	Betula	Larix
KIA class (4m)	0.92	0.92	0.92	0.70	0.77
KIA class (pan)	1.00	0.77	0.94	0.82	0.61
Overall (4m/pan)	0.83 / 0.83				
KIA (4m/pan)	0.80 / 0.81				

Table 2. Selected accuracy measures for "Stand" level of Ikonos 4m / pan classification. The statistics were derived per class, Overall Accuracy and the Kappa index of agreement from aggregated results

Figure 4. Pan-sharpened Ikonos image ©European Space Imaging Germany, 2003

The result of classification at the "Forest" level was also evaluated and the datasets of 4m/1m spatial resolution compared. The statistical measures (Table 3) indicate the overall accuracy improvement of nearly 10% when analysing pan sharpened Ikonos data. This was especially evident for delineation of the stand boundaries of young forest stages (conifers, broadleaves, other). Classes ground and plantation (transition), on the other hand, were better identified in 4-meter data. The fact is possibly connected to the different influence of textural information, as it was substantial for classification at this level.

Cover/ Stats	ground	plant	Yconif	Ydecid	Yother
KIA class(4m)	0.63	0.64	0.36	0.30	0.76
KIA class(pan)	0.48	0.36	0.61	0.88	0.82
Overall(4m/pan)	0.63 / 0.71				
KIA (4m/pan)	0.57 / 0.66				

Table 3. Selected accuracy measures for "Forest" level of Ikonos 4m / pan classification. The statistics were derived per class, and as aggregated results.

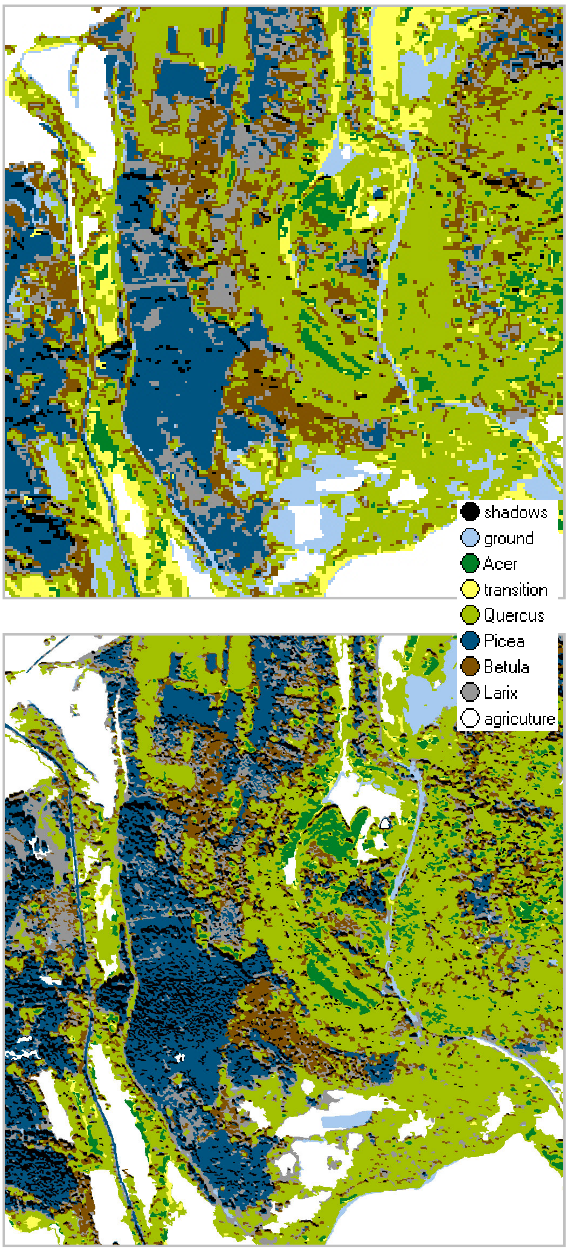

Figure 5. Forest species classification from Ikonos 4m vs. pan-sharpened imagery

4. DISCUSSION

As showed in several previous studies, the standalone optical RS methods are insufficient for classification of complex forest structures. This is particularly true for young succession stages and heterogeneous mature stands. For purpose of tree species identification, however, very good results can be achieved by the combination of object-oriented approach and the topo-corrected VHR (both 4m and pan) Ikonos data with derived image transforms. The OO classification rules based on fuzzy membership functions are highly convertible and the knowledge-base can be transferred and applied to other data by means of recorded protocols. Among the calculated layers contributing to the classification, ratios of Green and NIR bands, Sobel edge and GLCM Variance are the most significant. The spectral signatures normalised with the high resolution DEM can further enhance the classification. Besides, the segmentation of pan-sharpened images can benefit from the use of median filtering. The ability of delineation of young stands is dependent on the amount of texture information, thus the analysis of 1-m spatial resolution imagery is suggested. Such data require careful determination of object scale with the perspective of broader context. However, the higher amount of detail brings the new opportunities in object description, where the multilevel mutual relations are of special advantage.

5. CONCLUSIONS

This study aimed at comparing of classification results of 4-m and 1-m resolution Ikonos imagery. Both data types have their benefits and should be utilised in different forest management tasks with respect to the price. As reported by Hájek (2005), the 4-m Ikonos imagery allows to estimate percentage distribution of the tree species at sufficient scale. The pan-sharpened data has further potential to expose detailed structures within forest stands but also canopies of individual trees. Classification of tree species composition with such high level of detail and accuracy would be suitable to combine with LiDAR data for advanced 3D stand modelling. Still, the prospect of the method utilisation is dependant on the existence of capable knowledge-based system, sufficiently robust for high level of automation. The further research will focus on object analysis of CIR digital aerial photos.

6. ACKNOWLEDGEMENTS

This study was supported by Grant Project No. QG50097/2004 funded by the National Agency for Agricultural Research (NAZV) under the research program MZe 2005-2009.

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