SEMI – AUTOMATIC ASSESSMENT OF NORWAY SPRUCE (*PICEA ABIES*) IN MODERN DIGITAL AERIAL PHOTOGRAPHS

R. Seitz [a], A. Troycke [a], P. Rebhan [b], B. Grubert [b]

[a] Bavarian State Institute of Forestry, Hans-Carl-von-Carlowitz Platz 1,85354 Freising Germany - (rudolf.seitz, armin.troycke)@lwf.bayern.de
[b] GeoCreativ, Steigerwaldstraße 30, 97483 Eltmann Germany – (rebhan, grubert)@geo-creativ.de

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ABSTRACT:

In present times, forest conversion due to climate change confronts forest owners and forest administrations with great challenges if vast areas of forested surfaces are concerned by the effects of temperature rise and drought. In Bavaria, especially Norway Spruce (*Picea abies*) will lose terrain in favor of other tree species by decreasing vitality and the proliferation of bark beetle damage.
The Bavarian Forest Service is confronted with the problem, that there is only little information available about the approximately 1.6 Mio ha of nongovernmental forest property in Bavaria to fulfill its advisory tasks, because of data privacy convention.
For this reason, the Bavarian State Institute of Forestry conducted a research project focusing on possible semi-automatic approaches of anonymous information extraction from digital aerial photographs. This method mainly comprises the segmentation and object-based classification of 4-channel 16 bit aerial photographs in combination with a preceding image homogenization process.
The project showed a classification accuracy of 80% (young stands) up to more than 90% (old stands). A reliable classification (up to 80% accuracy) has even been achieved for Norway Spruce stands younger than 30 years, that cannot be interpreted by visual stereoscopic interpretation. The new methodology enables the Bavarian State Institute of Forestry to gain an identification of Norway Spruce for vast non-governmental forest areas. In a subsequent investigation, the method has to prove its cost efficiency and is to be transferred on larger areas and to other tree species of interest in the debate of environmental change.

KURZFASSUNG:

Zurzeit stellt der Waldumbau in Folge des Klimawandels die Waldbesitzer und Forstverwaltungen vor großen Herausforderungen, sobald in bedeutendem Umfang Waldflächen von den Auswirkungen des Temperaturanstiegs und zunehmender Trockenheit betroffen werden. In Bayern wird in diesem Zusammenhang vor allem die Fichte (*Picea abies*) durch verminderte Vitalität und vermehrte Borkenkäferkalamitäten Areal zu Gunsten anderer Baumarten verlieren. Aus Gründen des Datenschutzes verfügt die Bayerische Forstverwaltung über nur wenige Informationen bezüglich der ca. 1.6 Mio. ha nicht-staatlicher Wälder Bayerns, um ihre Beratungsaufgaben vor diesem Hintergrund erfüllen zu können. Aus diesem Grund führte die Bayerische Landesanstalt für Wald und Forstwirtschaft ein Forschungsprojekt mit dem Fokus auf halb-automatische Verfahren zur anonymen Informationsextraktion aus digitalen Luftbildern durch. Die dabei entwickelte Methodik umfasst in erster Linie die Segmentierung und objektbasierte Klassifizierung von 4-Kanal-Luftbildern mit einer Farbtiefe von 16 bit in Verbindung mit einem vorgeschalteten Bildhomogenisierungsprozess. Die Projektergebnisse weisen eine Klassifikationsgenauigkeit von 80 % (Jungbestände) bis über 90 % (Altbestände) auf. Eine verlässliche Klassifizierung (bis zu 80 % Trefferquote) wurde sogar für Fichtenbestände unter 30 Jahren erreicht, die nicht im Rahmen einer visuellen stereoskopischen Interpretation erfasst werden können. Die neue Methodik ermöglicht der Bayerischen Forstverwaltung somit die Identifikation von Fichtenbeständen auf den nicht-staatlichen Waldflächen Bayerns. Im Rahmen eines Folgeprojektes wird die Methodik auf ihre Kosteneffizienz hin untersucht und sowohl auf größere Flächen als auch auf weitere Baumarten ausgedehnt, die im Rahmen der Diskussion über die Umweltveränderungen von besonderem Interesse sind.

1. INTRODUCTION

1.1 Background

Climate change with all its implications is already in progress. Norway Spruce (*Picea abies*) is expected to be the tree species that will suffer most severely from it. The necessary forest conversion of Spruce-dominated forest areas means an outstanding challenge in relatively dry, warm regions of Bavaria (*Bernhart* 2007). Approximately 260.000 ha of Spruce stands are threatened momentarily in Bavarian private and communal forests (*StMELF 2008*), where the Bavarian Forest Administration disposes only little information. At the moment, the assessment of Spruce distribution within forest stands of severe conversion urgency bases commonly on the results of the second German Forest Inventory (Bundeswaldinventur (BWI) 2, *Kölling et al. 2008*). Because of the tenuous BWI inventory grid of 4x4 km however, the assessed data are insufficient for the deduction of detailed results. In order to face these challenges, remote sensing approaches seem to offer appropriate methods.
The applicability of the spectral reflection characteristics of forest trees for their assessment and identification has been investigated and described many times (for ex. in *Akça et al. 1984, Koch 1988*).
Until several years ago, optical data that can be ideally classified (this means in digital form with separated bands) have only been available from space borne sensors in a resolution inferior to that of aerial imagery.

The recent technical progress in the development of digital aerial cameras laid the foundation for approaches to distinguish tree species out of digital aerial image data. *Neubert* (2006) and *Tiede et al.* (2009) for ex. describe first approaches for the assessment of tree species composition by the use of digital aerial photographs. The Bavarian Office for Surveying and Geographic Information (Landesamt für Vermessung und Geoinformation (LVG)) conducts flight campaigns since 2008 on the basis of the latest digital camera systems. Thus, every year about one third of Bavaria's surface is covered by high resolution aerial photographs.

Against this background, the Bavarian Ministry of Food, Agriculture and Forestry financed a project of the Bavarian Institute of Forestry in cooperation with the enterprise GeoCreativ in order to investigate the potential of the actual digital aerial images for the semi-automatic assessment of Spruce. The project areas Eltmann and Gerolzhofen share more or less the same climatic conditions like the regions of western Middle Franconia and Lower Franconia that were struck by wide-spread losses of Spruce in 2005/2006. Even in this time, the observed phenomenon have been supposed to be the precursors of a development that would consider vast areas, caused by climate change (*Ammer et al. 2006*).

1.2 Objectives

Because of climate change, within short time an overview of Spruce stands that are in need of urgent conversion has to be achieved. Therefore, reliable, actual information about the dispersion of Spruce stands has to be created, using aerial photographs furnished by the LVG. In this project, by the help of modern software for image analysis and object-based classification, vast areas were supposed to be semi-automatically analyzed efficiently and in due time. At the end, a GIS-layer locating “Spruce” and “other coniferous trees” was planned to be available for the project regions.

2. BASIC INFORMATIONS

The project regions comprised of two separate areas in the „Steigerwald“ (Bavarian forest growth area 5.2 Steigerwald). One area contained the communal forest of Eltmann (ca. 2.500 ha), the second area is located within the „Bürgerwald“ Gerolzhofen (ca. 300 ha). Within the project areas grow intensively mixed deciduous and coniferous forests on vividly undulated terrain of a great variety of expositions. The Bavarian Office for Surveying and Geographic Information furnished 4-channel aerial photographs (color depth 16 bit, tiff-files; original data sets as well as ortho-rectified images). The images have been taken by the matrix camera Vexcel Ultracam-X. Ground sample distance (GSD) for the research area was 20 cm. The spectral bands green, blue, red and near infra-red are available in separated form. The flight campaign took place in August 31st, 2008.

3. METHODOLOGY

3.1 Pre-processing of image data

The original image tiles show great differences within their spectral bands, with the infra-red band possessing the least differences between the images. The transfer of classification criteria from one original image to another seemed thus to be impossible. Furthermore, the individual images partially show a distinct color drop especially at forest edges.

For the preparation of the supplied picture material, it was therefore necessary to develop a method for adjusting the four spectral channels between the individual images, to extend their histograms and to calculate new channels. For this purpose ERDAS Imagine 9.3 was used. The different algorithms have been combined with the help of the "Spatial Modeler" to an overall model. Thus, the enhancement of the individual images in each case was feasible in one single step.

The following processes have been conducted:

Step 1: Compensation of chromatic heterogeneity between images and within individual image tiles.

The color heterogeneity between the individual images could be largely offset by adjusting the individual color channels.

Exposure differences within the image tiles, particularly at the edges of forest areas however, could be corrected only to a limited extent.

Step 2: Enhancement of spectral differences between individual trees.

With the exception of forest edges with strong illumination decline, a very significant increase in visual recognition of the individual conifer species was achieved on the basis of their different colors when displayed on the screen.

The advantage of this method of image processing is a significant time reduction of the effort for the determination of training trees.

3.2 Segmentation / Classification

To classify coniferous forests covering a great area as training samples, Spruce trees and other coniferous trees were used. In this operation a probability filter has been applied, that separates coniferous and deciduous trees.

By the use of AOI's (Area of Interest) for Spruce and other coniferous tree species, 8 to 14 training trees in the best possible allocation within the individual image tile were assigned. With increasing heterogeneity of the picture, a larger amount of training trees per target class was required.

The basic settings were chosen in a way that as large as possible crown areas were recorded for each segment. The collection of several small-crown trees of the same species in a segment was deliberately taken into account, in order to improve the formation of the segment averages of the spectral bands as far as possible. The resulting polygons were attributed by their mean values and probabilities with which each segment of a species has been classified. Using a probability filter, a pre-selection of segments for all aspired classes was then conducted.

3.3 Post-processing and visualization in a GIS

Fine adjustment, post-processing and visualization of the classification results have been accomplished by ArcGIS 9.3 by ESRI. For this reason, the generated shapefiles of the segments were imported into ArcGIS. A pre-selection was achieved by the use of mean values of the reflectance (exclusion of shadows, etc.). In a next step, the generated probability limits were adjusted to enlarge the target class, while limiting misclassifications to a modest range. In this process, the necessary border values of the probabilities determined by ERDAS Imagine Objective varied considerably.

For typical training trees, a probability of 60% already proved to be sufficient for a reliable classification. For training trees with atypical radiation spectrum (e.g. along forest edges, damaged trees) a probability threshold of 90% has to be chosen in order to avoid misclassifications. In spectrally heterogeneous to very heterogeneous images, the classification had to be restricted to sufficiently homogeneous areas, since the segmentation of training trees led only in those areas to a reliable classification. As a result, in heterogeneous images, an increased number of training trees was necessary for a reliable classification, causing a much bigger effort.

4. RESULTS

4.1 Image data homogenization

As mentioned above, the heterogeneity of the image data within their spectral bands caused a major problem, with the infra-red band showing the least differences between the images. This means, that even within one flight strip adjacent images showed decisive spectral differences (figures 1 and 2).

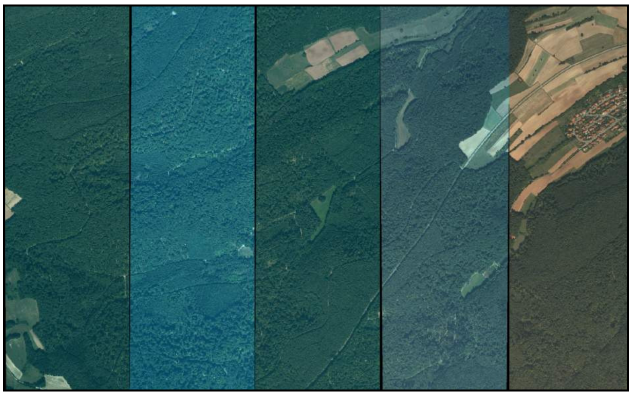

Figure 1: Example for the spectral heterogeneity of the used image data: Adjacent ortho-rectified images within one flight strip of the research area (illustration in true color without histogram stretch).

The quality control of the original image data histograms proved, that the reflection values for all spectral bands only covered about 1/3 of the possible histogram width. For this comparison, the histogram of digital image data from a flight campaign in 2006, equally using a matrix camera system, has been selected. The histograms of these images showed an almost ideal distribution over the whole possible reflection spectrum (figure 3). The shortening of the pixel-value area within the LVG image data from 2008 complicated the spectral delimitation and visual perceptibility of a tree species decisively.

As another severe quality limitation of the image data in use, spectral differences between each single spectral band of the Vexcel images have been identified. The reflection values within the spectral bands red, green and blue varied up to 15 % in one flight strip. This strong spectral differentiation between the spectral bands originally averted the transfer of the classification algorithms from one image to its neighbors. These effects necessitated a homogenization and a histogram stretching of each spectral band as an essential prerequisite to the subsequent classification. Figure 2, 4 and 5 illustrate the extent of the spectral differences between the single images and the various spectral bands within the single image as well as the efficiency of the developed methodology for the image data improvement.

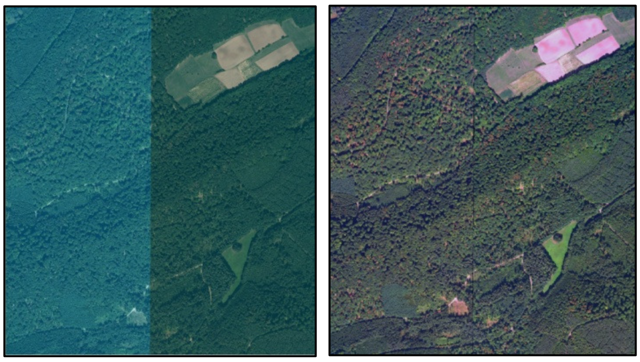

Figure 2: Detail of two adjacent images (true color illustration) within one flight strip (cf. to figure 1): left side: original image prior to pre-processing; right side: enhanced and homogenized image data.

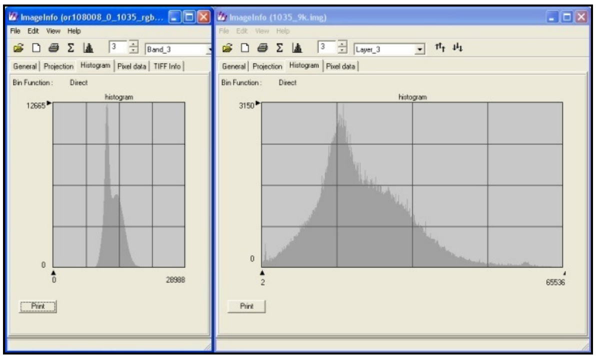

Figure 3: Histogram comparison of blue band. Left original, right after enhancement

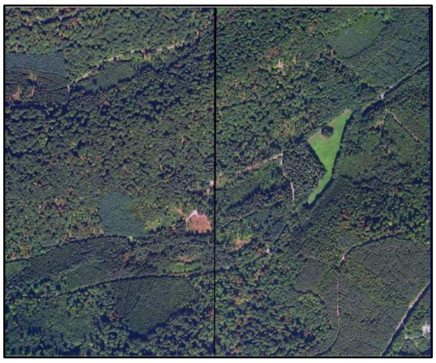

Figure 4: Two adjacent images after the pre-processing (True color illustration after pre-processing with broadened value range)

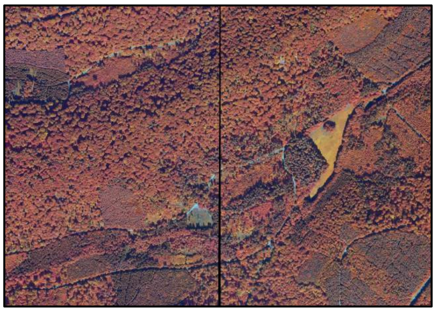

Figure 5: Two adjacent images after the pre-processing (infra-red illustration)

Only with radiometrically aligned images, a spectral respectively visual recognition of tree species is possible. Image homogenization is thus fundamental for a Spruce stands classification over large areas.
It can thus be stated conclusively, that the available Vexcel UltraCam X data required an intensive spectral enhancement and homogenization in order to prepare them for the following classification. The developed procedure for this process proved its effectiveness and reliability.

4.2 Classification of Norway Spruce

The spectral reflection of vegetation varies decisively according to the camera angle relative to the object. Within an aerial photograph, the northern part of the image represents mainly the southern, well illuminated part of the tree canopy; the southern part of the image represents the northern, shadowy parts of the canopy. This phenomenon, besides others like varying vitality status within a tree species, results in the necessity to create several classes for each tree species. For this project the following classes have been distinguished accordingly:

- Old Spruce (older than 50 years)
- Middle Old Spruce (age 30 – 50 years)
- Young Spruce (younger than 30 years)
- Spruce forest edge (up to 200 m from open country)
- Inner area of Spruce stand
- Other coniferous stands (Larix spec., Pseudotsuga spec., Pinus spec., Abies spec.)

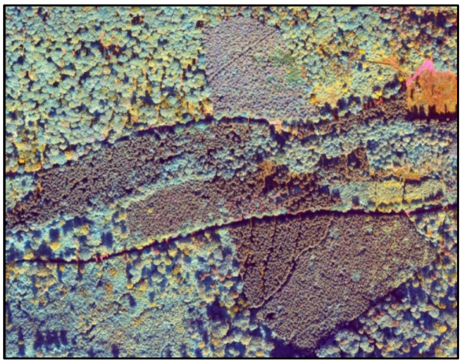

Figure 6: Processed image; scale 1:5000 with coniferous stands intensified. Grey – blue: deciduous trees blurred out.

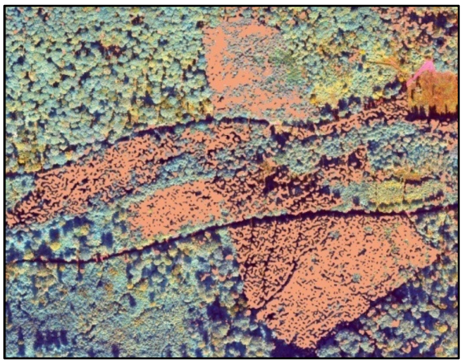

Figure 7: Classified image, scale 1:5000 with segments of coniferous classification. Grey – blue: deciduous trees blurred out.

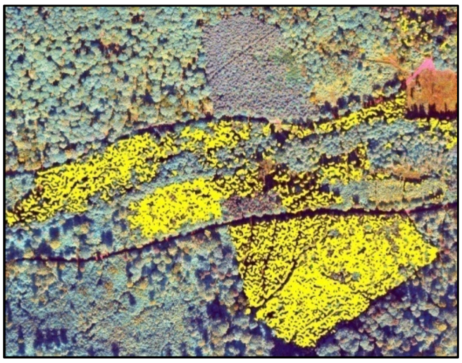

Figure 8: Classified image, scale 1:5000 with segments of Norway Spruce classification. Grey – blue: deciduous trees blurred out.

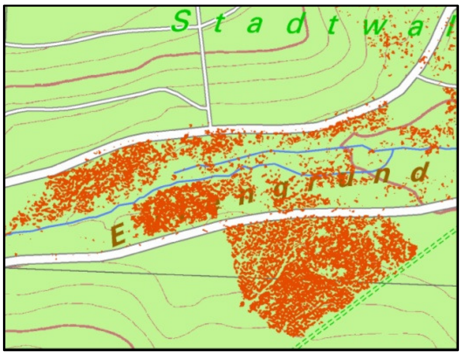

Figure 9: A topographic map, scale 1:5.000, superimposed by polygons of the Spruce classification

Figure 10: Classified Spruce in detail with sample plot (diameter 20m); scale 1:1000. Grey – blue: deciduous trees blurred out.

A total of 8 to 14 classes had to be distinguished according to the different research areas and the illumination decline at the forest edges.
As mentioned above, within the furnished Vexcel UltraCam X data, an illumination decline from forest areas towards open country areas had to be stated. The effect resulted in a decisively higher amount of work during the classification and in poorer classification accuracy for the concerned forest edges (cf. to chapter 3.1 and 3.3)

The decisive criteria for the classification step however is not the absolute likelihood value of the investigated tree species, but first of all their relative distance towards spectrally adjacent coniferous tree species.
Because of this reason, a previous classification of the totality of all coniferous trees is obligatory in order to distinguish the transitions between the single classes. Out of the initial overall classification of all coniferous trees (cf. to figures 6 and 7), division criteria for each Spruce class has been developed by the use of probabilities and mean segmentation values. Figures 6, 7, 8, 9 and 10 demonstrate the results of the various classification steps

Finally, an average hit rate of 86 % has been achieved for the classification of Spruce (cf. to chart 1).

The results in detail show a classification accuracy of more than 90% for old Spruce stands and more than 80% in middle-old stands. The classification accuracy of Spruce in mixed young stands is about 80%. In this age class especially the difficult segmentation of the individual crowns caused a higher error ratio.

4.3 Verification of results

In order to verify results, 500 randomly distributed grid-points have been created with a minimum distance of 50 m by the use of the ArcInfo tool „Create Random Points“. From these 500 points, a selection of points that were situated inside Spruce stands or inside forest stands with Spruce trees has been extracted for an accuracy validation. The selected grid points have been buffered then to sample plots between 15 and 25 m radius, according to their age and tree species composition. Inside the sample plots, the quantity of trees for each tree species has been assessed as well in the field as in an ortho-rectified aerial image. In the next step, the tree species percentage for every sample plot has been compared with the according classification results. The hit rate had to be referred exclusively to the crowns in the upper storage of the Spruce stands because of the shadow effects inside the gaps between the tree crowns (cf. to chart 1).

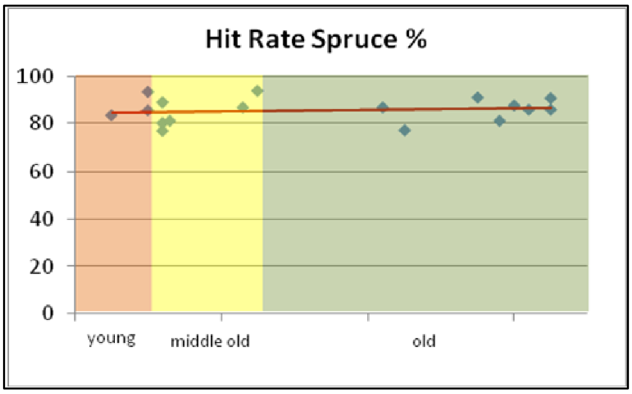

Chart 1: Hit rates for the classification of the classes young, middle old, old Spruce

5. SUMMARY AND CONCLUSION

The spectral characteristics of digital aerial image data depends decisively on the factors

- time and date of image acquisition,
- camera system,
- pre- resp. post-processing of the image data.

The image data used in the project described above was characterized by strong spectral differences between the single images within the flight strips as well as within the spectral bands within the single images. In detail, shortened histogram widths, illumination declines from forest stands towards non-forested areas and spectral heterogeneities between the several spectral bands had to be stated.
Despite the heterogeneity of the image data, the objective of the project to produce a GIS-layer locating “Spruce” and “other coniferous trees” for two test areas out of actual digital image data has been achieved. In detail, the following results have been achieved:

- The preparation of heterogeneous image data for use within the research approach
- The assessment of Spruce within the accuracy as described above
- A clear separation of deciduous from coniferous trees
- The successful transfer of the methodology on digital aerial image data of a second test region in the same flight campaign
- The semi-automatic assessment of Spruce even in young growth stands within the accuracy limitation as described above

These results outline the possibility to develop a practicable methodology for the further use of aerial imagery to gain information about the tree species composition of forested areas.

6. FUTURE PROSPECTS

6.1 Image data quality

Within the future flight campaigns of the Bavarian LVG, different camera systems are supposed to be in use. Because of the lack of standards for the image acquisition and processing of aerial imagery in common, the problematic effects as stated above are expected to turn up again in future image acquisition campaigns. This would cause negative impacts on the cost-efficiency of the methodology and thus its transferability into practice. Therefore common standards should be developed accordingly. Moreover, the stated illumination decline from forest towards open areas requires further research activities in the field of image analysis and optimization.

6.2 Segmentation/ Classification

The preparation of the image data prior to the segmentation and classification in this project as described above allowed the successful segmentation of most Spruce classes with a high accuracy. First hints lead to the conclusion that the developed methodology enables the semi-automatic assessment of even more tree species.
Further research efforts in the field of the semi-automatic tree species assessment from digital aerial imagery should therefore be conducted. The approaches should thereby concentrate on the transfer of the described results on other camera systems as well as different acquisition conditions (with concern to acquisition time, topography, illumination). Finally a focus has to be laid on the cost-efficiency of the methodology when transferred into practice on vast areas.

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