MAPPING PROTECTION FORESTS IN THE PROVINCE OF SALZBURG USING REMOTE SENSING

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ABSTRACT

Natural and anthropogenic influences such as catastrophic storm damage, the resultant - and enduring - bark beetle problem, and global climatic changes have weakened the resilience of alpine forests. Far-sighted management of protection forests at regional and national levels is necessary to ensure that appropriate preventive measures can be implemented by forestry and agricultural authorities. The success of such measures is crucially dependent on the availability of information about the status of alpine forests. Until now, however, recent and realistic information on the spatial distribution of forest condition on regional scale has not been available. The Forestry Management Department of the Province of Salzburg therefore commissioned a project whose aim is to map forests throughout the province using remote sensing for the retrieval of the most important forest parameters. The results of this project presented in this paper demonstrate that most of these parameters can be derived from SPOT IV MS and PAN data with satisfactory accuracy. The achievement of satisfactory mapping results depends to a great extent on precise image calibration, such as topographic and radiometric calibration of the satellite data. The methods developed in the project are currently being improved and made operational within the EU Integrated Project GEOLAND.

Keywords: Alpine protection forest, SPOT IV data, radiometric and topographic calibration

1 INTRODUCTION

The Forestry Management Department of the Province of Salzburg needs detailed information about the composition and state of the forests at provincial level in order to be able to co-ordinate plans for the maintenance of protective forests and to develop framework guidelines for forest management strategies. The most important forest parameters are timber line and type of forest (spruce, larch, mixed spruce/larch, deciduous forests, mixed deciduous/coniferous forests, dwarf pine and green alder). Other important parameters for planning decisions include the age of the forest stands and the density of the forest canopy.

Most cartographic techniques employed by forestry management departments for the mapping of forests to date have relied on aerial photography and ground-based surveys. The majority of inventories were produced at large scales and infrequent intervals. Because of the high cost involved, these inventories were restricted to smaller forest sites and did not cover larger regions and provinces. For this reason, information at provincial level is mainly derived from sample data of the Austrian Forest Inventory. While providing key statistical data on larger regions, these surveys do not allow the derivation of data on the regional distribution of the various forest parameters. It is precisely this kind of comprehensive information, however, that is needed for many planning procedures and analytical studies.

The Forestry Management Department therefore commissioned a project whose aim is to map forests throughout the province using remote sensing for the retrieval of the most important forest parameters. Another reason why the Department opted for the use of satellite data was the improved geometric resolution, which enables a more efficient use of remote sensing data for forest cartography projects and allows the production of 1:50,000 to 1:25,000 scale maps for the first time. Data provided by the SPOT-IV/V sensor systems are particularly useful for this purpose [1].

The following factors have been considered as potential key advantages by the Forest Management Department: Analysis and interpretation of data extracted from satellite images are available for large areas and therefore permit a synoptic overview with regard to the composition and state of the forest. The collection of similarly detailed data for larger areas using aerial photographs or ground based methodologies would be far more labour intensive and costly. Another advantage of satellite data based inventories is that surveys can be repeated at shorter intervals as large amounts of data can be retrieved quickly and at relatively low cost. A further advantage of the exploitation of satellite data for forest mapping is that the interpretation results can be easily integrated into forestry information systems which are being increasingly used by forestry management departments. In short, remote sensing technology can provide the kind of information that was previously not available to forestry management departments or which was not available on a scale appropriate for comprehensive analyses and planning projects.

The methods applied and results achieved will be outlined and evaluated in the following chapters.

2 DATA

The forest maps were produced using panchromatic and multispectral SPOT IV data. A total of four SPOT IV scenes were needed to cover 6 of 7 districts of the province of Salzburg. Black/white and CIR aerial photos were purchased for large parts of the province to support the selection of training areas and the visual interpretation of the forest line. Additionally, a digital terrain model was made available by the Salzburg Forestry Management Department as a basis for geocoding and topographic normalisation.

3 DATA PREPROCESSING

Emphasis was put on data pre-processing, as strong relief effects influence both the geometry and radiometry of the satellite data. These effects, therefore, necessitate precise parametric geocoding and topographic normalisation of the satellite images.

3.1. GEOCODING

Displacement errors caused by topographic relief must be removed to optimise the absolute geometric location accuracy of the geocoded image data [2]. In the course of geocoding, these errors were removed through the integration of a digital elevation model (DEM), i.e., the consideration of terrain relief information. Geocoding was performed with the RSG software (Remote Sensing Software Package Graz) of Joanneum Research .

3.2. TOPOGRAPHIC NORMALISATION

An ideal slope-aspect correction removes all topographically induced illumination variations so that two objects having the same reflectance properties showing the same digital number despite their different orientation to the sun's position. As a visible consequence, the three-dimensional relief impression of a scene disappears and the image looks flat. In order to achieve this result, several radiometric correction procedures have been developed. Besides empirical approaches, such as image ratioing, which do not take into account the physical behaviour of scene elements, early correction methods were based on the Lambertian assumption, i.e. the satellite images are normalised according to the cosine of the effective illumination angle [3]. However, most objects on the Earth’s surface show non-Lambertian reflectance characteristics [4]. The cosine correction had thus to be extended by introducing parameters simulating the non-Lambertian behaviour of the surface [5, 6]. The estimation of these parameters is generally based on a linear regression between the radiometrically distorted bands and a shaded terrain model. A comparison between four correction methods, including the non-parametric cosine correction, confirms a significant improvement in classification results when applying the parametric models [4]. In this mapping project, the parametric Minnaert correction was used for topographic normalisation, as this method has been proven to achieve satisfactory results [7, 8].

3.3. IMAGE CALIBRATION AND MOSAICKING

The four neighbouring satellite images were radiometrically calibrated to allow classification of all four scenes with the same statistical parameters (derived from one set of reference data). This processing step is required for operational application, as acquisition of reference/ground truth data for classification constitutes the main effort in mapping projects. The independent classification of the satellite scenes using different complete sets of training areas would thus significantly increase the work and costs involved. Radiometric calibration is a critical processing step, however, since even small differences in radiometry can lead to mis-classification of forest parameters. Scenes within one track, which are acquired at the same time need not be calibrated and can be appended directly. Two different approaches were evaluated for radiometric adaptation of the two tracks: firstly, absolute calibration with coefficients provided by Spot-Image, and secondly, relative calibration with linear regression.

Absolute calibration:

For absolute calibration the calibration parameters given in the leader file of the Spot data are applied. The accuracy of the calibration results was analysed within the overlap area, where a region mainly covered with forest was selected and radiance within this region compared (Table 1). To allow direct comparison with results derived from relative calibration, the results of the absolute calibration were transformed back to DN of the reference scene.

Table 1. Results of absolute calibration (transformed back to digital numbers of the reference scene) in overlap area, mainly covered with forest.

Band	mean ref.scene	stdv ref.scene	mean cal. scene	stdv cal. scene	grey-value difference
1	71.4	8.7	72.7	8.7	- 1.3
2	51.4	10.6	50.4	10.4	1.0
3	67.5	21.1	67.7	21.4	- 0.2
4	62.4	19.0	58.7	17.9	3.7

The results show that absolute calibration of bands 1 to 3 provided satisfactory results, as the grey-value difference is in the order of the expected uncertainty of signatures derived with reference data. Absolute calibration of band 4 cannot be recommended, however, because of the remaining high grey-value difference of 3.7 in the calibrated images, which would lead to mis-classification of forest parameters.

Relative calibration:

A region covered with forest/rocks/agricultural fields in the overlap area of the left and right tracks was selected for relative calibration. As geometrical shifts in the order of one pixel size remain between the two geo-referenced image tracks, aggregation within 7x7 pixel windows based on mean values was applied, which leads to a more stable regression as shown in Figure 1 [9, 10].

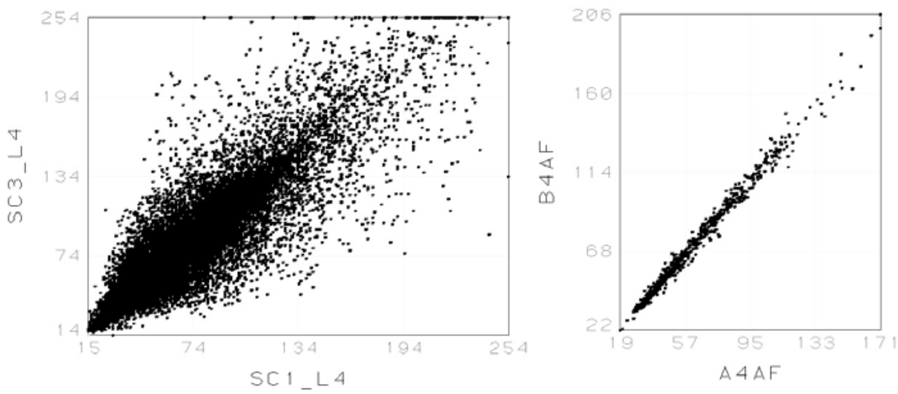

Figure 1. Scattergram of band 4 between left and right track in overlap region. Left, original (not aggregated) pixel values, right, aggregated within 7 x 7 pixel windows with mean value.

The right scattergram in Figure 1 shows that 1st order regression is suited for relative calibration. The calibration results depicted in Table 2 were analysed in the same region as above for absolute calibration.

Table 2. Results of relative calibration for region mainly covered with forest.

Band	mean ref.scene	stdv ref.scene	Mean cal. scene	stdv cal. scene	grey-value difference
1	71.4	8.7	71.7	8.6	- 0.3
2	51.4	10.6	51.3	10.3	0.1
3	67.5	21.1	67.7	21.3	- 0.2
4	62.4	19.0	61.6	18.5	0.8

The values in Table 2 show that mean grey-value differences are below 1 DN in all bands. All bands are, therefore, suited for classification, as signature uncertainties are expected to be at the same or above that level. As all bands show lower grey-value differences for linear regression as for absolute calibration linear regression was performed with the parameters given in Table 3.

Table 3. Parameters for relative calibration of left track imagery to right track reference imagery.

Band	Offset	gain
1	-0.34	1.052
2	1.17	1.031
3	0.50	0.968
4	0.92	1.136

During the preparatory phase, the satellite images were topographically normalised and parametrically geocoded using digital elevation model data made available by the Salzburg Provincial Government. The scenes were subsequently radiometrically adjusted and mosaicked. Radiometric calibration was applied for left track and right track scenes with the right track serving as the reference scene. After radiometric adjustment of the images all four scenes could be classified using one set of training data, which significantly facilitated the collection of ground truth data.

4 SETUP OF NOMENCLATURE

The following parameters to be classified were defined together with the Forestry Management Department of the Province of Salzburg in a very detailed manner. Merging of classes should be performed later, based on the classification results according to the accuracies achievable for the classes listed below.

A. FOREST DEFINITION (FOREST MASK):

Crown closure of forest:	>30 %
Crown closure of forest in the transition zone:	10 – 30%
Minimum mapping unit (MMU) of forest gaps:	500m² - 1000m²
Dwarf mountain pine:	crown closure > 50% and MMU > 3000m²
Green alder:	crown closure > 50% and MMU > 3000m²

B. FOREST TYPES

1. Pure coniferous: if coniferous	**90-100%**
spruce and firs	[spruce + firs ≥ 90 %]
larch	[larch > 90 %]
larch / spruce	[larch 60-90%]
larch / spruce	[larch 30-60%]
spruce / larch	[larch 10-30%]
spruce / larch / pine	[larch or pine 10-30%]
pine	[pine > 90 %]
pine / spruce	[pine 60-90%]
spruce / pine	[pine 30-60%]
spruce / pine	[pine 10-30%]
dwarf mountain pine	[density > 50%]
other coniferous	[e.g. mixture of larch / spruce and dwarf mountain pine]

2. Mixed coniferous / deciduous forest:
76 - 89% coniferous; 51 - 75% coniferous; 26 - 50% coniferous; 11 - 25% coniferous

3. Pure deciduous forest: 0 - 10% coniferous
deciduous forest of the colline to mountainous height zone

C. CROWN CLOSURE IN %:
up to 30, 31 – 50, 51 – 60, 61 – 80, 81 - 100

D. NATURAL AGE CLASSES
1. Clear Cuts; 2. Culture; 3. Thickets; 4. Pole Timber; 5. Timber; 6. Strong / Old Timber

5. CLASSIFICATION / VISUAL INTERPRETATION

The SPOT IV data were evaluated in two different steps:

1. Step: Visual delineation along the alpine forest line
2. Step: Supervised classification (maximum likelihood) of the forest categories within the forest mask interpreted visually

The digital classification of both the forest line and open dispersed forests at sub-alpine altitudes is problematic because such forests tend to be inhomogeneous and open, resulting in the overlapping of the tree and ground reflectance spectral portions. The following problems resulting from automated digital classification methods were identified:

- Open stands below 30% crown coverage are often classified as alpine meadows.
- Dwarf pine and stone pine cannot be distinguished.
- The classification of dwarf pine is not possible using only spectral characteristics.
- Dwarf pines present in the second layer produce higher canopy density data for spruce stands.
- The identification of green alder stands is difficult if they are surrounded by meadowland.
- Tree lines proved difficult to be identified where forests gradually grow less dense at higher altitudes.

Figure 2 demonstrate the complex spatial forest distribution along the alpine forest line

5.1. VISUAL INTERPRETATION ALONG THE ALPINE FOREST LINE

Because of the restrictions mentioned above visual interpretation was performed on the alpine forest line (forest mask), on larch and spruce stands with canopy densities generally below 30% and on green alder and dwarf pine stands. The visual interpretation was based on orthophotographs made available by the Salzburg Provincial Government and the multispectral SPOT IV data that were also used for digital classification. The results of the visual interpretation are exemplarily shown in Fig. 2.

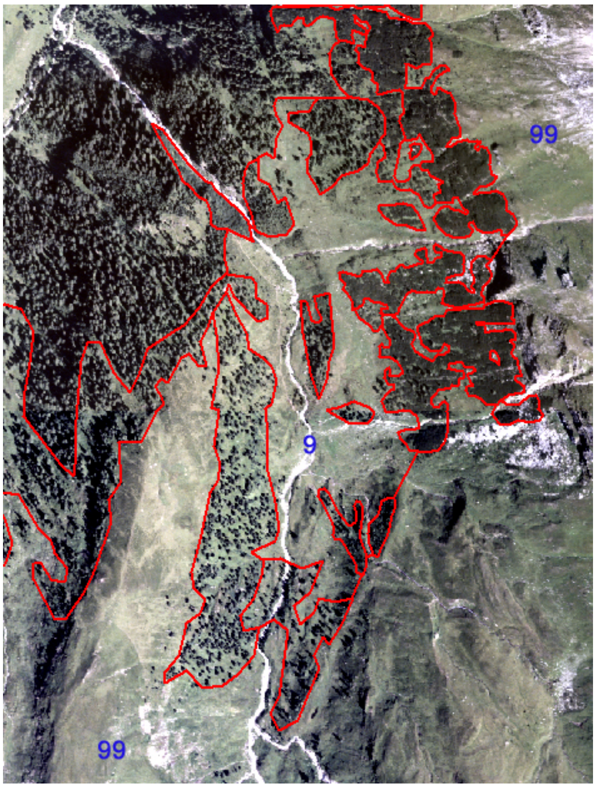

Figure 2. Sub-area illustrating the visually interpreted forest line, open forest and areas covered by dwarf mountain pines and green alder.

5.2 DIGITAL CLASSIFICATION WITHIN THE FOREST MASK

Selection of training areas

The training areas required for supervised classification were selected on the basis of CIR aerial photographs from different data sources and acquisition times. The different image qualities, scales and acquisition periods had to be taken into account in the evaluation. The reference areas were mapped from CIR aerial photographs and some of these areas were additionally spot-checked in the field, which included a plausibility check and subsequent correction where necessary. Field surveys were carried out with the support of the Salzburg Government, Department for Agriculture and Forestry.

Classification

Following signature analysis, the classification was carried out with selected signatures using the maximum likelihood method. A detailed evaluation of several classification runs based on different parameter settings and combinations of training areas resulted in the following "best practice procedure":

1. *Classification according to altitude*: the classification was carried out separately for areas above and below 1500 m, the results being subsequently combined into an overall result to account for the altitude effect.

2. *Weighted classification*: the "probability values" were reduced for uncertain training areas that were difficult to evaluate.

3. *Classification for the derivation of tree species*: the error probability increases for stands below 50% crown closure due to the strong influence of the ground vegetation. Only training areas with a crown closure of more than 50% were therefore selected for tree species classification.

4. Dwarf mountain pine and green alder stands were excluded for determining the *even-aged forest below 1500m altitude*.

5. For age class determination, ideal clusters were generated in the feature space and integrated into the training data set.

6 RESULTS

An assessment of the results based on an analysis of selected reference areas as well as several field surveys and comparisons with aerial photographs performed by the Forestry Management Department have shown that the forest parameters mentioned above can basically be determined using SPOT4 data. However, the following problems were identified on the basis of the above assessments and experiences from previous classifications, which were partly corroborated:

- Old timber is sometimes classified as thicket or pole timber in deciduous and deciduous/mixed classes.
- Older classes dominate the classification in multi-layer stands.
- Pine was difficult to classify, mainly because the number of reference areas was too small and many of the pine stands were affected by pine dieback. The results for pine are currently being evaluated.
- Deciduous forest is often classified in open areas such as forest gaps if the undergrowth consists of dense and higher vegetation, such as ferns, caccinium, rhododendron or the like. Since these stands are frequently found along the alpine forest line and more rarely at lower altitudes, this error is largely avoided by visual interpretation.
- Open stands, especially those with a crown closure below 50%, are often classified as deciduous (alder), Rhododendron or pine stands (stone and dwarf pine) with higher canopy density. This error can also be kept within limits by visual interpretation, since stands with a low crown density are also usually found along the forest line.

Figure 3 exemplarily shows the classification of a image section into different forest types.

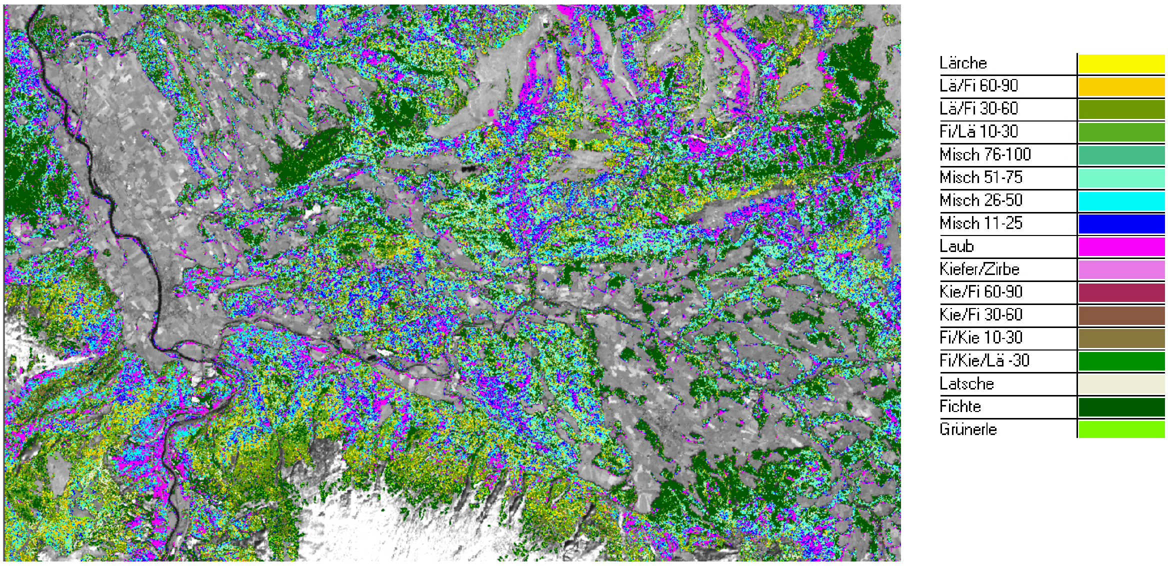

Figure 3. Classification of an image section according to different stand types.

CONCLUSION

The project results have shown that satellite remote sensing is a suitable method for gathering spatial information required for the monitoring and management of protection forests. The SPOT IV data used in this study provide much better classification results than Landsat Thematic Mapper data. This is due not only to the improved geometric resolution but also to the excellent radiometric properties of the SPOT IV data. It was also shown that sophisticated pre-processing steps can significantly increase the accuracy of the classification results. Further research in this context is required in the fields of topographic normalisation and radiometric adaptation of neighbouring satellite images. The latter method is of special interest for inventories covering several regions or even the entire Alpine area and which thus necessitate the use of several satellite images. The project has also shown that an automatic computer-based classification cannot determine all parameters with sufficient accuracy. This is especially the case with inhomogeneous forest structures and small-scale changes in crown closure, age classes and tree species. Small-scale structures can only be mapped with high-resolution satellite data (e.g. IKONOS or QUICKBIRD), which are still very expensive. In addition, special evaluation algorithms suitable for the mapping of complex forest structures must be developed. This may well be an area meriting further research.

LITERATURE

1 Granica, K., Schardt, M. and Gallaun, H. (2000): Monitoring of Protection Forests by Means of SPOT4 Satellite Data, 20th EARSeL Symposium, 14th – 16th June, 2000, Dresden, Germany, to be published

2 Raggam H., Almer A., Strobl D. & Buchroithner M.F. (1991): RSG - State-of-the-Art Geometric Treatment of Remote Sensing Data. In Proc. of 11'th EARSeL Symposium: Europe: From Sea Level to Alpine Peaks, from Iceland to the Urals, pp. 111-120, Graz, Austria, July 3-5 1991.

3 Smith J.A., Tzeu Lie Lin & Ranson K.J. (1980): The lambertian assumption and Landsat data. Photogrammetric Engineering and Remote Sensing, Vol. 46, No. 9, pp. 1183-1189.

4 Meyer P., Itten K.I., Kellenberger T., Sandmeier S. & Sandmeier R. (1993): Radiometric correction of topographically induced effects on Landsat TM data in an alpine environment. ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 48, No. 4, pp. 17-28.

5 Civco D.L. (1991): Topographic normalisation of Landsat Thematic Mapper digital imagery. Photogrammetric Engineering and Remote Sensing, Vol. 55, No. 9, pp. 1303-1309.

6 Colby J.D. (1991): Topographic normalisation in rugged terrain. Photogrammetric Engineering and Remote Sensing, Vol. 57, No. 5, pp. 531-537.

7 Schardt, M.; Granica, K.; Schmitt, U. & Gallaun, H. (2000): Monitoring of Protection Forests in alpine Regions. Proceedings of the 4.02.05 Group Session „Remote Sensing and World Forest Monitoring“, IUFRO XXI World

Congress, 7-12 August 2000, Kuala Lumpur, Malaysia, 2000 (edited by the Institute of Geodesy and Cartography in Warsaw).

8 Schardt, M. & Schmitt, U. (2001): Inventory of Alpine Relevant Parameters for an Alpine Monitoring System Using Remote Sensing Data. Proceedings of the International Workshop on „Geo-Spatial Knowledge Processing for Natural Resource Management, University of Insubria, Varese, Italy, June 28-29, 2001.

9 Schardt, M.; Gallaun, H. & Häusler, T. (1998): Monitoring of Environmental Parameters in the Alpine Regions by Means of Satellite Remote Sensing. Proceedings of the International ISPRS-Symposium on "Resource and Environmenal Monitoring, Local, Regional, Global, Commission VII, September 7-4, 1998, Budapest, Hungary.

10 Gallaun H., Schardt M., Granica K., Flaschberger G. (2001): Monitoring von Schutzwäldern mit Satelliten-Fernerkundung. VGI - Österr. Zeitschr. für Vermessung & Geoinformation.