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An Approach to the Spectral Signature Analysis and Supervised Classification for Forest Damages

– An Assessment of Low Altitude Airborne MSS Data –

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Abstract

This paper discusses the capabilities of airborne remotely sensed data to detect and classify forest damages. In this work the AMS (Aircraft Multiband Scanner) was used to obtain digital imagery at 300m altitude for forest damage inventory in the Black Forest of Germany. MSS (Multispectral Scanner) digital numbers were converted to spectral emittance and radiance values in 8 spectral bands from the visible to the thermal infrared and submitted to a maximum-likelihood classification for : (1) tree species ; and, (2) damage classes. As expected, the results of MSS data with high spatial resolution 0.75m × 0.75m enabled the detection and identification of single trees with different damages and were nearly equivalent to the truth information of ground checked data.

I. Introduction

The increasingly widespread forest decline is attributed to the effects of air pollution or acid rain as reported in Germany. Since the late 1970's detailed information about a regional decline was requirements of the forest service. Aerial photo interpretation and field sampling of large areas have been used to register countrywide forest damage inventories. Besides these conventional methods the project was started in 1984, with the potential use of airborne MSS data for such inventories at the department of Photogrammetry and Remote Sensing, University of Freiburg i. Br., which was funded by the state of Baden-Württenberg and the European Community. MSS data were collected in July 1984, August 1985 and July 1986 on test areas in the Black

Forest. The spectral signature analysis of single tree crowns provided basis for verification of the computer aided classification and could enhance better accuracy for forest damage assessment of satellite data.

Ⅱ. Material and Methods

Ⅱ. 1. Technical Data

The MSS data from approximately 300m above groundlevel were acquired from the test area of Marzell in the South Black Forest on July 21st, 1984 about 12 o'clock middle european time. The data were taken in a line-and columnwise geometry, using the Bendix M^2S scanner which had been modified and remotely sensed data were calibrated by DFVLR(Deutsche Forschungs-und Versuchsanstalt für Luft-und Raumfahrt=German Research and Experiment Station for Air and Space Travel). To determine the incident radiation, reference panels were placed along the flying strip in size 200 sqm. The technical specification of the employed sensor are given in Table 1. The spatial resolution has 0.75 by 0.75m at 300m altitude.

Table 1. Bendix M^2S Specification

Spectral Band	Wavelength Interval(μm)	Filter-position 4; Calibrated rate 85(Hz)
3	0.49～0.54	1.91
4	0.54～0.58	2.34
5	0.58～0.62	2.77
6	0.62～0.66	3.50
7	0.66～0.70	3.52
8	0.70～0.74	3.83
9	0.76～0.86	5.07
11	8.00～13.00	*NE⊿T=0.1℃
Internal reference source:	2(low and high) black body, lamp, skylight(solar port)	
Quantization levels:	8 bit precision(0～255)	
Pixel per scan line:	803	
Total field of view:	100°	

* Temperature resolution.

Ⅱ. 2. Forest Conditions of Test Site

The test site is located at Egerten between Badenweiler and Marzell in the South Black Forest and situated at west exposure. The forest type is an old remaining stand. Forest picture shows mountainous and ideal mixed mountain forest which contains 2/3 coniferous trees(spruse and fir) and deciduous trees(beech).

Ⅱ. 3. Ground Truth Data

Each tree was given a number and their crown was evaluated through binoculars according to damage classification used throughout West Germany. The forest damage classification is characterized as follows:

0 = healthy	loss of leaves or needles	0～10%
Ⅰ = sickly	loss of leaves or needles	11～25%
Ⅱ = damaged	loss of leaves or needles	26～60%
Ⅲ = severely damaged	loss of leaves or needles	>60%

Most of the trees in the test area were damaged to sickly (Ⅰ) or damaged degree (Ⅱ).

Ⅱ. 4. Background

Irradiance differences causes different spectral signature which depends on elevation, aspect, slope, mixture of species and natural variability within the species. Distinct differences in the signature of healthy and damaged trees are found in the reflective portion of the spectrum by the diversity of leaf pigments and water content. The reflected energy is equal to the incident energy reduced by the energy which is either absorbed or transmitted. Generally in the visible— and middle infrared wavelengths the reflectance of damage trees increases compared with the reflectance of healthy ones. This reaction can be explained by chlorophyll—and waterabsorption. In the near—infrared portions of the spectrum the reflectance of damaged trees decreases compared with the reflectance of the healthy ones. In this region the incident energy is almost reflected and very little is absorbed by the internal structure of the leaves. In the thermal(emissive) infrared region discrimination between damaged—and healthy trees will be simply referred to the energy exchange for a leaf through evapotranspiration. This hypothesis can be discussed with the fact, that according to GATE(1963) the transmissivity of deciduous leaves at infrared wavelengths beyond 3μm is less than 1% and the absorptivity of deciduous leaves at thermal infrared wavelengths is 96 to 98%. Hence the emissivity is between 96% to 98%. Since the thermal band of the scanner collects the thermal effluent by the crown surface which is equal to $\varepsilon\delta T$,* it is apparent that the inference of surface temperature depends upon the water content of leaves. Water has the greatest specific heat.

II. 5. Methodology

The airborne MSS data were processed with the program system FIPS(Freiburg Image Processing), a modular system which has been implemented at the UNIVAC-1108 computer of the University of Freiburg and connects PDP-11/73 by designing of the RSX-11M operating system in Dept. of Phtogrammetry and Remote Sensing. These allow interactively to process and analyze image data reguired for this work. The following procedures were in use.

- reading MSS data from CCT(Computer Compatible Tape) and transformig them into direct access image
- control of data quality of the internal calibration sources(Fig. 1)
- definition of training areas for damage degree by using false color composite image on the display(Fig. 2)
- computation of statistics of the defined areas(means, min-and maxvalues, standard deviation, correlation and covariance matrix) and plotting
- computation of the internal calibration source values
- computation of the spectral reflectance according to formula (1) and radiation temperature according to formula (2)

$$(1)\ L_{\lambda,i}=\frac{(D_{\lambda,i}-D_{\lambda,bb1})L_{\lambda,c1}}{(D_{\lambda,c1}-D_{\lambda,bb1})\Delta\lambda}\ [W/m^2\cdot sr\cdot nm]$$

$L_{\lambda,i}$=Spectral radiance reflected from object i in the spectra band λ

$D_{\lambda,i}$=Intensity value of the object i

* ε : emissivity
  δ : Stefan-Boltzmann constant
  T : surface temperature

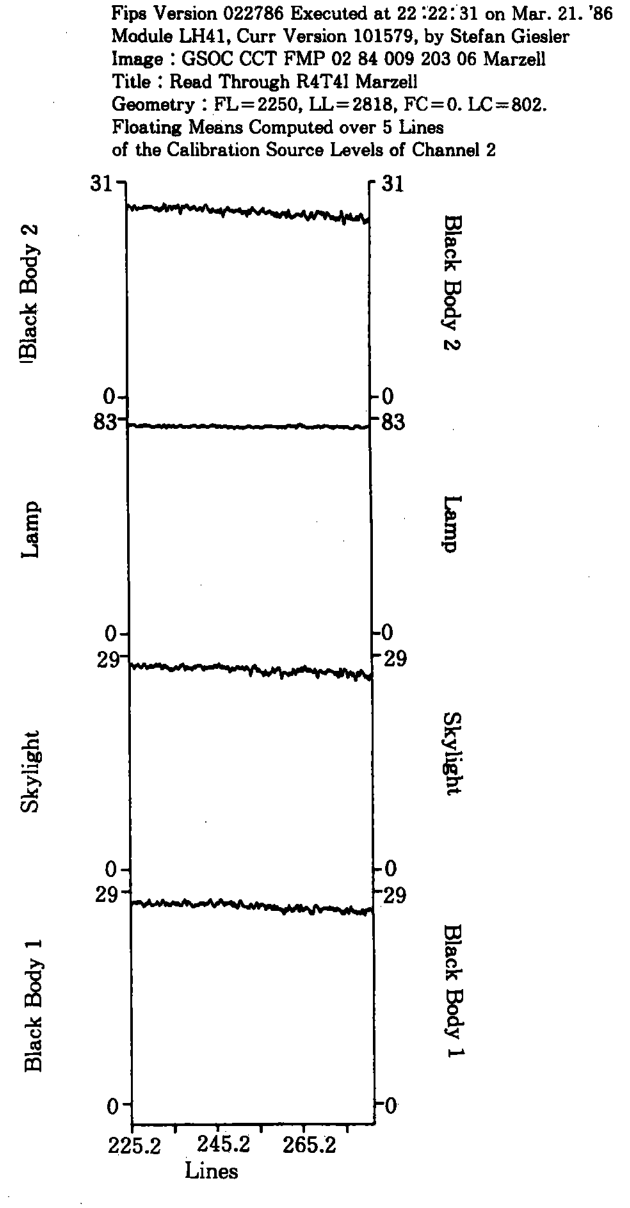

Fig. 1. X-axis : values of indicated calibration
Y-axis : scan line number

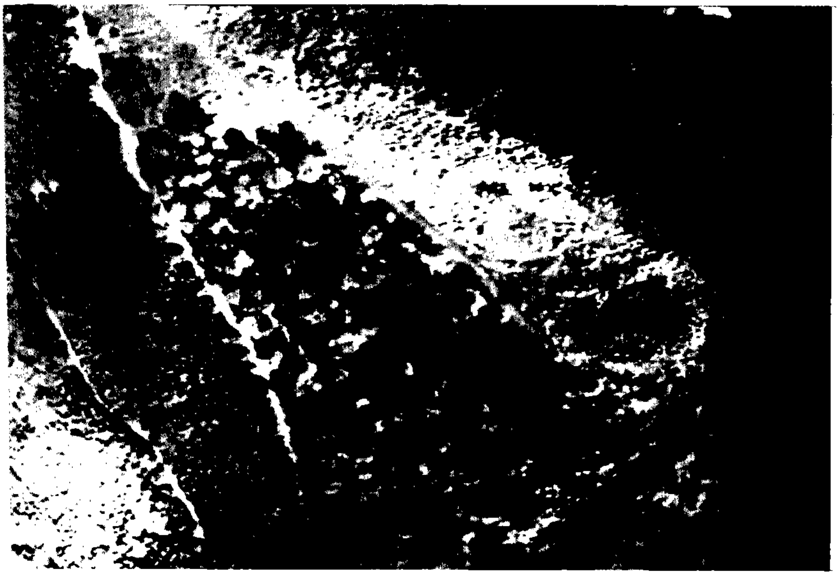

Fig. 2. Tree band(B4, B6, B9) color composition over test area, the very clear separation between coniferous and beech tree.

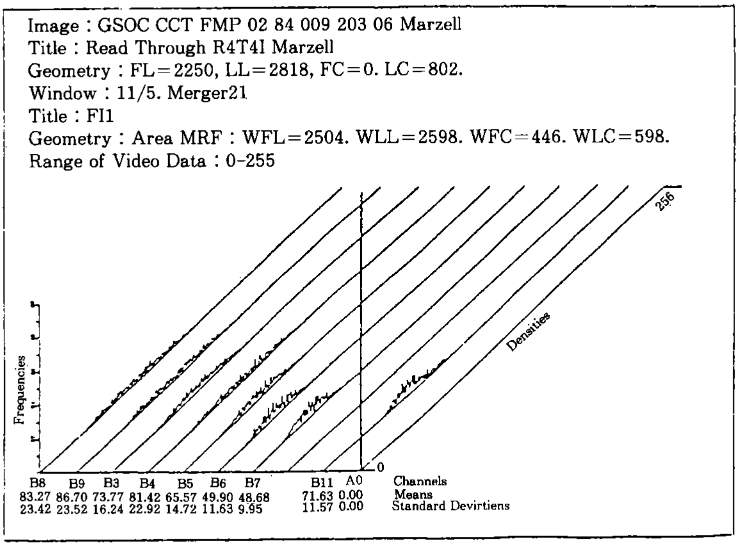

Fig. 3. Frequency distribution of reflectance—and emittance values(density) of sickly spruce crown.

$D_{\lambda, bbl}$ = Intensity value of the blackbody low

$D_{\lambda, cl}$ = Intensity value of the blackbody high

*1) $L_{\lambda, cl}$ = Spectral radiance of the calibration lamp

$$(2)\ T_i = T_{bbl} + \frac{(D_i - D_{bbl})}{(D_{bbh} - D_{bbl})}(T_{bbh} - T_{bbl})\ [^\circ C]$$

T_i = Rediation temperature emitted from the object i

*2)T_{bbl} = Temperature of black body low [℃]

*2)T_{bbh} = Temperature of black body high [℃]

D_i = Intensity value of the object i

D_{bbl} = Intensity value of balckbody low [℃]

D_{bbh} = Intensity value of blackbody high [℃]

－ computer aided clssification of the test area by using maximum likelihood algorithm : This supervised clssification is a flexible and complex system which offers the user facilities to include additional information such as terrain-model, environmental condition(soil type, climate etc.). Futhermore it is possible to change classification parameters and to control the classification process.

－ producing of clssified images:
In our pseudo-color processing system there is an 8 bit refresh memory, namely the 256 discrete grey level which is appointed to 18 different hue values.

Ⅲ. Signature Analysis of Different Forest Damage

Instead of the calculation of the spectral reflectance factor R(λ) the spectral reflectance in this investigation was applied. Because in-situ-measurements were not performed simultaneously, the atmospheric effect could not be evaluated.

1) In this case the given data are the calibration factor which was measured by DFVLR

2) The given data were calibrated with externe Blackbody in the laboratory of DFVLR

Ⅲ. 1. Spectral Reflectance of Beech

Spectral reflectance values in the 0.49 to 0.65μm wavelengths increase from healthy to sickly to damage for beech. This trend, as expected, is reversed in the 0.70 to 0.86μm region. The confidence interval of reflectance values generally increases as the degree of damage increases.

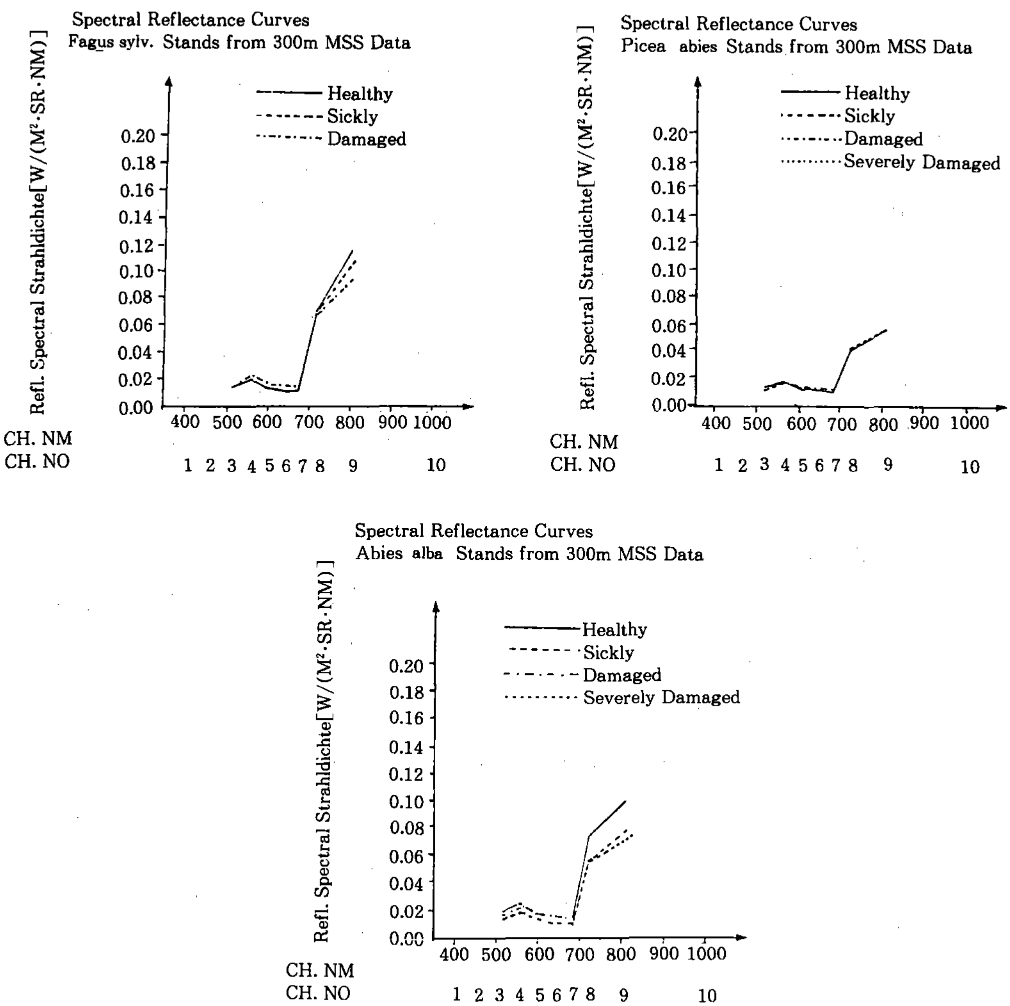

Fig. 4. Reflected spectral radiance on different damage beechs(upper left), spruces (upper right) and firs(below) in old remaining forest stand.

This phenomenon can be explained with the interpretation of radiation temperature plot over different damaged trees together(Fig. 5).

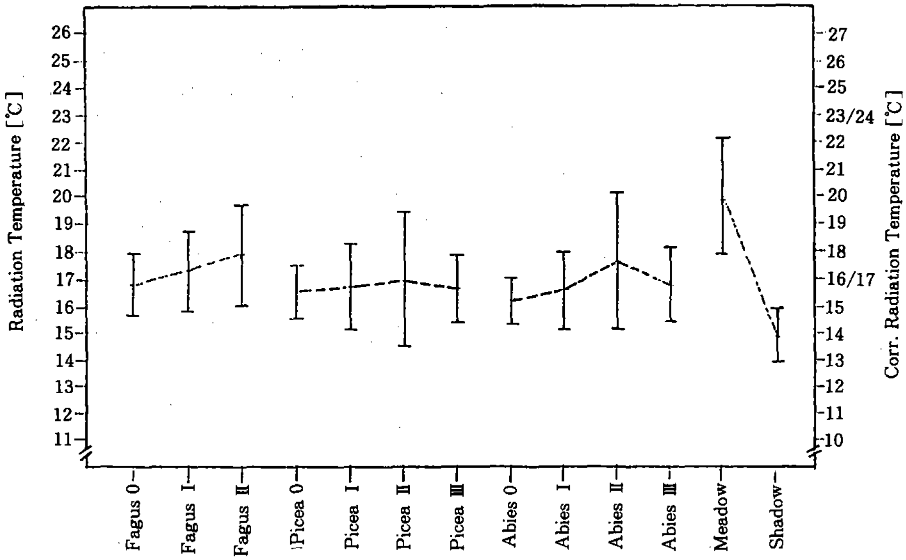

Fig. 5. Radiation(Surface) temperature, right of Y axis : corrected rad. temperature by the diagram for influence of atmospheric absorption and emission of LORENZ(1973), plot of different tree species and shadow.

Ⅲ.2. Spectral Reflectance of Spruce

Reflectance values in the visible and near-infrared are nearly the same for all damage classes of spruce although damaged and severely damaged spruce show slightly higher values in the 0.54 to 0.58μm region(Fig. 4, Fig. 6 and Fig. 7). This lack of difference maybe partially explained by the heavy influence of shadow within a narrow, pointed spruce crown. Another is angle effected which shows a typical increase of spectral reflectance with a flatter observation angle. The confidence intervals in the visible region are quite distinctive but not so in the near-infrared region where spruce generally reflects less infrared radiation than beech or fir.

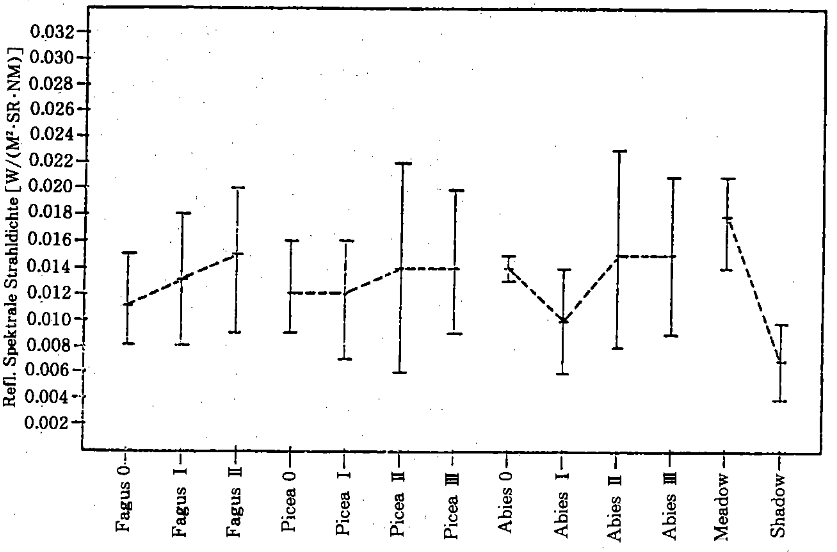

Fig. 6. A detailed spectral reflectance of band 4(0.54~0.58μm)

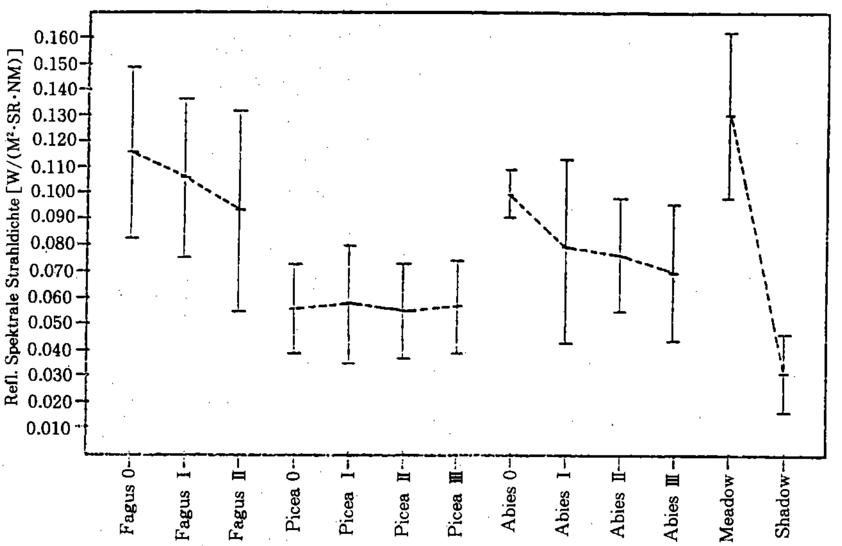

Fig. 7. A detailed spectral reflectance of band 9(0.76~0.86μm)

Ⅲ. 3. Spectral Reflectance of Fir

The trand for fir is similar to beech in the near-infrared, i.e., reflectance increases from severely damaged to healthy. A similar trend is not notes in the visible where only the sickly fir category shows a lower reflectance than the other three categories, which are equal and compare closely to spruce. There are many possible factors which could explain this, but the most important cause could be the change of morphological form according to water sprouts(KIM, 1987).

Ⅲ. 4. Radiation Temperature of All Species

As shown in Fig. 5, in wavelengths from 8 to 13μm it can be observed that the radiation temperatures of healthy trees are remarkably below those of damaged trees but increase steadily to damage degree (Ⅱ). The values of severely damaged (Ⅱ) trees are lower than the other ones, and the confidence interval of damage degree (Ⅲ) is also shorter than the other ones. This leads to the influence of the understory vegetation(see the value of shadow temperature). The ranges of the confidence increase significantly in accordance with the degree of damage(just until damage Ⅱ). This fact will be simply referred to as possessor phenomenon of leaf sorts of all 3 different damage degree. This can be even found by the classification images(Fig. 8 and Fig. 9). Whereas airborne thermal scan data can be evaluated for damage detection almost independently of the observation angle, it can be very difficult to define the object and the selection of the training area for the computer aided classification. This problem can be alleviated by matching other band false color composites(Fig. 2) with the thermal band for locational purpose.

Ⅳ. Forest Damage Classification

A supervised classification based on single trees which were specified in the training area was determined separately from ground truth data and subdivided into 16 categories. The following images of forest damage classification were made from visual display units and pixel counts classified to determine the area of damage class.

Ⅳ. 1. Thermal Infrared Classification

From the results as seen in table 2, class Fagus 0(healthy beech), Picea 0(healthy spruce) and Abies Ⅲ(severely damaged fir) were represented. Their discrimination problem, which was tested by classified cluster in Figure 5 in accordance with the size of confidence range was evident. Their coverages in ground are inferior to 1%. Figure 8 shows one dimensional classification of thermal band (11). Even small areas could be well demonstrated and the shadows as an individual class was emphasized.

Fig. 8. Forest damage classification of thermal effluent blak. : shadows and lanes, white : grass, spectral blue : Fagus Ⅰ(sickly beech), brown : Fagus Ⅱ(damaged beech), magenta : Abies 0(healthy fir), orange : Abies Ⅰ(sickly fir), blue : Abies Ⅱ(damaged fir), turquoise : Picea Ⅰ(sickly spruce), blue-green : Picea Ⅱ(damaged spruce), yellow : Picea Ⅲ(severely spruce)

These mixed picture elements in thermal imagery (Figure 8) were not quite different from those in supervised classification of infrared band (9) and band (4).

Ⅳ. 2. Classification with Near-IR Band (9) and Blue Band (4)

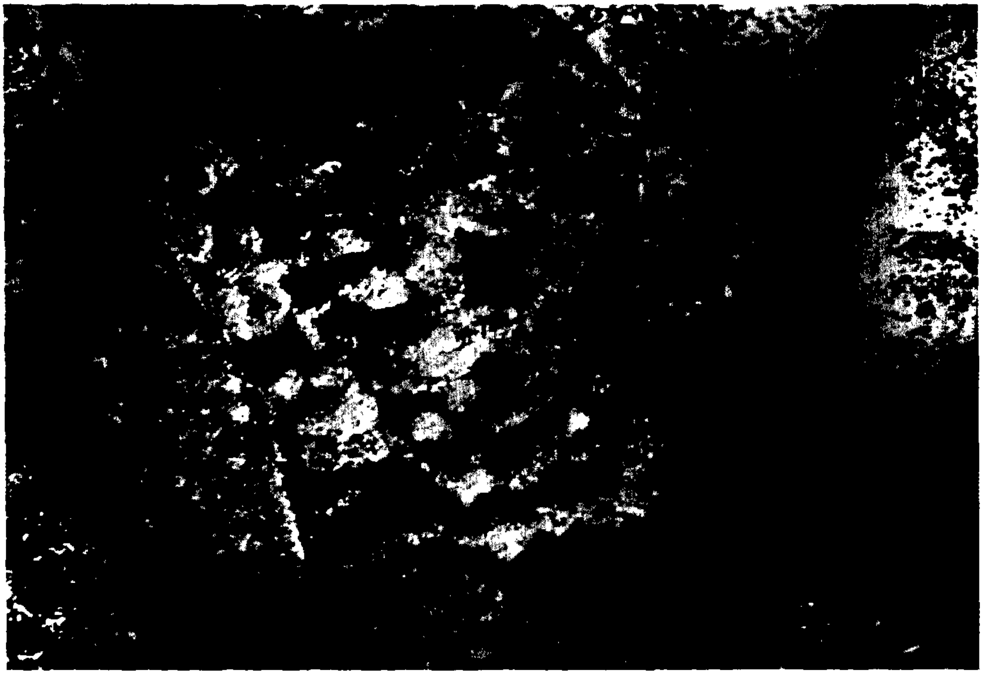

Fig. 9. Forest damage classification with the near-infrared band (9) and green band (4). black : shadows and lanes, white : grass, spectral red : Fagus Ⅰ (sickly beech), yellow : Fagus Ⅱ (damaged beech), spectral blue : Abies 0(healthy fir), turquoise : Abies Ⅰ and Abies Ⅱ (sickly and damaged fir), green : Picea Ⅰ (sickly spruce), magenta : Picea Ⅱ (damaged spruce), violett : Picea Ⅲ (severely damaged spruce)

Figure 9 displayed the forest damage classification based on the near-infrared band (9) in wavelength 0.76～0.86μm and green band (4) in wavelength 0.54～0.58μm.

The same training areas were used both for the forest damage classification and for the pixelwise considerations so that the results could be compared. A comparison of composited bands (4) and (9) with band (11) is given in Table 2. Shadows and grass are included in the misclassified signatures because they are important factors for assessing this type of data. It is shown in Figure 5, 6 and 7 that the shadows often misclassified as damage were caused by low spectral reflectance and low radiation temperature in all optical wavelengths. In the other extreme, grass has a high value.

Ⅳ. 3. Classification with Near-IR Band(9), Green Band(4) and Red Band(6)

Because the forest crown has such a heterogeneous structure, there are many possible factors which could cause misleading or complex classifications. A main point of multispectral classification reduces existing classification errors. The multispectral classification with bands (9), (4) and (6) corresponded fairly well with the composite bands (4) and (9) classification as shown in Table 2.

Table 2. Varying of classification results for the test site, CSML : Constant multiplier used for maximum-likehood class, PCI : a percentage of included pixels, PCC : a percentage of classified pixels

	Band 11		Band 9 & 4		Band 9, 4 & 6	
	CSML=4		CSML=2		CSML=2	
% of classified	100		97.26		96.89	
	%		%		%	
Class	PCI	PCC	PCI	PCC	PCI	PCC
shadow	26.85	26.85	16.57	17.04	14.55	15.02
grass	17.46	17.46	12.81	13.17	11.57	11.94
Spruce 0	0	0	0.28	0.29	0.60	0.62
Fir Ⅲ	0	0	3.79	3.89	1.27	1.31
Beech Ⅰ	3.71	3.71	8.11	8.34	9.18	9.48
Fir Ⅰ	2.94	2.94	0.13	0.14	0.13	0.13

In addition, the number of misclassified pixel were reduced in n-dimensional feature space, because the mixed signatures decrease through value extraction process. The multispectral classification should ultimately be checked by a digital crown map which was developed through color infrared aerial photographs and ground control data.

V. Conclusion

The airborne MSS data from 300m altitude can be use to classify even different trees with varying damage for forest damage classification. The airborne thermal infrared data can be evaluated for forest damage classification almost independently of the observation angle. The mixed pixels caused by confusing objects, can be reduced through the multispectral classification. In the future, an assessment of airborne MSS data from 300m altitude will be useful in quantification and monitoring of forest damage and decline.

References

Gate, D. M., 1963, Leaf temperature and energy exchange, *Arch. Met. Goeph. Biokl.*, B12, pp. 321~336.

Hildebrandt, G. and A. Kadro, 1984, Aspects of Countrywide Inventory and Monitoring of Actual Forest Damage in West Germany, *BuL* 52 (1984), Heft 3a.

Kadro, A., Kuntz, S. and C. Kim, 1985, Entwicklung eines Verfahrens zur Waldschdensinventur durch multispektrale Fernerkundung. 1. Statuskolloquium of *PEP* vom 5-7. Maerz 1985, Karsruhe.

Kim, C., 1987, Method development and experiences in application of airborne MSS data for forest damage detection, *IGARSS'87*, Vol. II, pp. 1213~1216.

Lorenz, D., 1973, Die radiometrische Messung der Boden-und Wasseroberflächen-temperature und ihre Anwendung insbesondere auf dem Gebiet der Meteorologie, *Z. f. Geophysik* 39, pp. 627~701.