Detection of plant reflectance anomalies in mining areas using imaging spectroscopy

Christian Fischer[a], Andreas Brunn[a], Christoph Dittmann[b], Peter Vosen[b], Wolfgang Busch[a]

[a] Institute of Geotechnical Engineering and Mine Surveying, Technical University of Clausthal, Erzstrasse 18, D-38678 Clausthal-Zellerfeld, christian.fischer@tu-clausthal.de

[b] Deutsche Steinkohle AG, Division for Engineering Surveying & Geoinformation Services

ABSTRACT

Underground mining activities lead to subsidence and ground movements at the topographic surface. The present and future modifications of the topographic situation have a permanent influence of the technical infrastructure as well as to changes of hydrological and ecological parameters. To detect possible influences of the vegetation it is necessary to define parameters, which can describe measured variables and resulting influences related to the considered geo-system. This is the prerequisite to detect relevant ecological effects. Because of the large extent of the affected area and the small-parcelled landscape structure, only high resolution imaging spectroscopy permits an appropriate way to map different biotopes and to detect changes.

Vegetation spectra usually appear similar because the main reflectance components are the same. This fact requires the adoption of a sophisticated strategy to classify different vegetation types and to describe them in terms of vitality. Therefore a set of different parameters derived from the reflectance signatures of different vegetation types were analysed. This approach includes well known parameters like the description of the red edge and the derivation of reflectance features using continuum removed spectra at the green reflectance peak near 0,57 µm. In addition derivative analyses, originally developed for chemical spectrometry applications, were adapted. These calculations led to different parameters which were analysed in particular to detect anomalies in different reflectance signatures. This approach allows the analysis of different locations influenced by mining activities and the related changes of the hydrological situation.

Keywords: HyMap, hyperspectral imagery, vegetation analysis, mining, monitoring

1 INTRODUCTION

DSK is obliged by federal mining law to develop a monitoring scheme for areas affected by underground mining activities. The shared-cost RTD project MINEO [1] supported by the EU (IST-1999-10337), offered an excellent platform to investigate and develop new techniques and methods using advanced Earth Observation technology. The aims can be outlined as:

1. development of a conceptual link between mining activities, hydrological changes and ecological parameters,
2. development of remote sensing methods to assess environmental impact caused by mining operations; this includes the detection of water logging areas and the assessment of vegetation status to describe it in terms of vitality,
3. development of parameters suitable for a long-term monitoring.

1.1 Subsidence

In case of underground mining, a dislocation zone transforms upward a flexure of the strata directly above the mined area. Subsidence occurs at the topographic surface. The shape of this subsidence will depend, among others, on the mining depth and the dip and thickness of the seams. Depending on the thickness of the strata and the extent of the mined area, the impacts on the surface start after around six months. Approximately after two years, around 80% of the anticipated maximum of subsidence has occurred. Final conditions are achieved after about five years. In the coalfields of the Ruhr, the amount of subsidence varies between a few meters in the older mining districts and goes up to 20 m in the modern mining region between the rivers Emscher und Lippe.

Presented at the 3rd EARSeL Workshop on Imaging Spectroscopy, Oberpfaffenhofen, May 13-16 2003

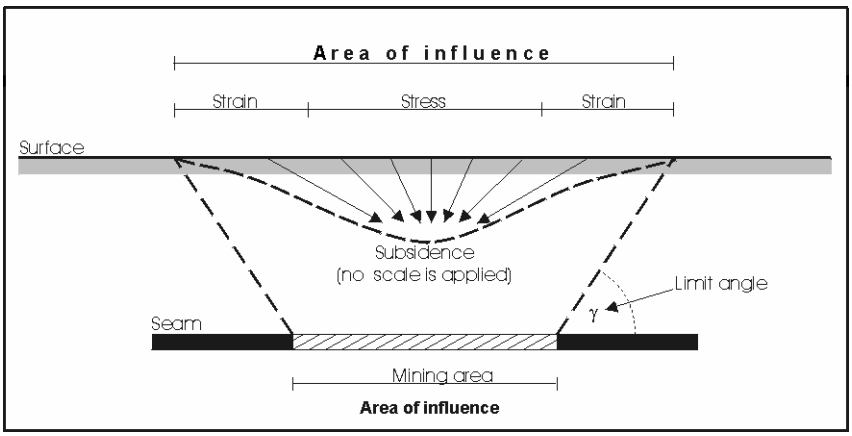

Figure 1: The occurrence of subsidence (without scale).

1.2 Hydrological Consequences

The consequences of the extensive depressions are changes of hydrological parameters. Such changes include alterations of surface and underground catchment areas and of individual watercourses. The resultant changes affect the runoff, sedimentation and erosion conditions. The impacts on the groundwater produce an extensive alteration in the spatial location and deformations of the groundwater-conducting strata ("aquifers"), and thus changes in the groundwater divides in directions and rates of waterflow. Locally, new isobars of the ground-water table will occur. Changes to watercourses can be adjusted locally by means of constructional provisions, whereas the registration and evaluation of extensive changes in the groundwater situation is only possible by GIS-related modeling techniques based on accurate digital terrain models and ground-water models in particular. The intensity of the influence of a regarded surface is steered by its position in the relief and by the local characteristics of soil and vegetation [2].

2 HYPERSPECTRAL SURVEY

On August 24th. 2000 the test site was flown by an aircraft equipped with the HyMap scanner and with a RMK camera. The size of the area recorded by the HyMap sensor covers the area that is mapped in the framework of the environmental impact assessment (EIA). The flight altitude of 2200 m resulted in a ground instantaneous field of view (GIFOV) of 5 m. The aerial photographs were taken with a scale of 1:13000. Quality control of the data and preprocessing steps are described in [3].

During the HyMap data acquisition field spectra from selected and representative targets were measured. Therefore an ASD FieldSpec Pro FR, operated by the GeoForschungsZentrum Potsdam (GFZ) and a GER Mark V, operated by the Federal Institute for Geosciences and Natural Resources (BGR), were used. With the Mark V different locations within open gravel pits were measured. The targets measured with the ASD were mainly agricultural land, such as pastures, fields of maize, potatoes and also bare soil. Additional measurements were taken in reforestation areas containing two recently-planted stocks of trees. In total 18 different sites have been measured.

3 VEGETATION ANALYSIS

Since the objective is to find out how changed hydrological parameters influence different types of vegetation stands, image analyses have been focused on the analysis of vegetation in terms of vitality and on the detection of anomalies. Therefore different approaches of analyzing the reflectance spectra were investigated. Spectra of vegetation appear generally similar, because vegetation consists of the same basic components. This fact requires the adoption of strategies other than the feature and band shape matching algorithms used for geological applications.

The following subsections describe the developed procedures, methods and tools applied for vegetation mapping and the detection of anomalies in corresponding reflectance spectra.

3.1 Red-edge Analysis

Foliar absorption is primarily caused by photosynthetic pigments in the visible (VIS) spectrum steered by chlorophyll a and b and β-carotene. The light in the near-infrared (NIR) range is not absorbed by the photosynthetic pigments which results in a sharp rise of the reflectance spectrum curve. The red edge position occurs typically between 0.68 and 0.74 µm, it is predominantly determined by the interaction between chlorophyll absorption of the red light and the internal scattering process on the leaf [4]. The shape of the reflectance spectrum in the mid-infrared range (MIR) is controlled by leaf-water-content, lignin, cellulose and other carbon-based compounds. According to [5] chlorophyll concentration is usually an indicator of photosynthetic capacity and consequently an indicator for different vegetation conditions.

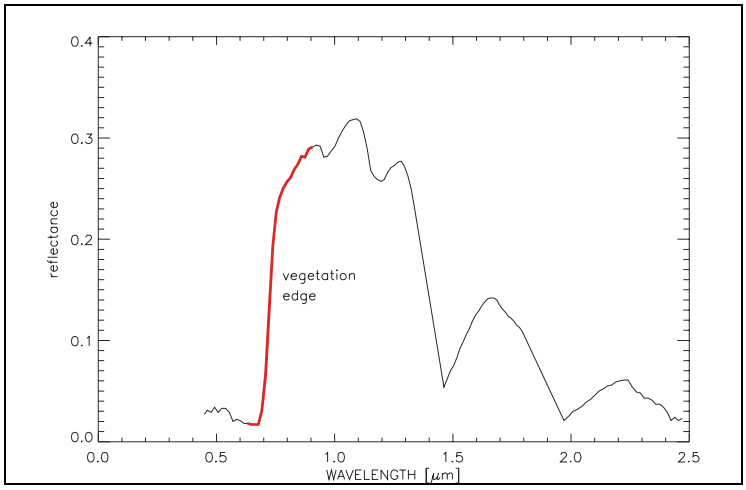

Figure 2: Typical vegetation reflectance spectrum highlighting the red edge between 0.68 and 0.80 µm.

Figure 2 shows a typical reflectance spectrum for vegetation between 0.42 and 2.48 µm. According to [6], it could be shown, that this red edge shifts to shorter wavelength for vegetation growing on locations with non optimal conditions. Nevertheless the shifts in the red edge may occur in both directions, towards the longer and shorter wavelengths [7]. The red edge wavelength is defined as the position of the reflectance curve, where the second derivative of the strong increase between red and infrared shows an inflection point. The wavelength regions between 0.57 and 0.75 µm are influenced as well by the concentration of chlorophyll as by the condition of the chloroplast membranes on which the chlorophyll is bound. The broadening of the chlorophyll absorption bands is related to disruption of these membranes. Suggestions stated that the direction of the red edge shift direction is dependent on whether the membrane disruption or the chlorophyll loss process dominates [7].

Using a field or laboratory spectroradiometer with a high spectral resolution it has been shown, that shifts can be retrieved effectively using polynomial functions. These instruments have up to 500 channels in this part of the wavelength, common airborne imaging spectrometers like HyMap have only 5 up to 12 channels here. This is the reason why methods for red edge parameterization had to be investigated, when this method should become suitable to detect changes with user required accuracy. For the determination of the red edge wavelength several different analytical methods can be used. A well known and documented method is the fitting of an inverted Gaussian Model to measure vegetation reflectance data [8]. The determined red edge features using the Inverse Gauss Model showed systematic variations in the shape and positions of the red edge [9]. The red edge differs between species, and that "blue shift" phenomena related to vegetation stress should be separated carefully from "blue shifts" resulting from species differences. A second approach is the parameterization by linearization which is described in detail by [10].

The model implemented here uses a combined method of interpolation and linearization. First an interpolation of the curve progression with cubic spline functions was performed. These functions can be derived twice. In a second step a linear interpolation was done to calculate the zero-point of the 2nd derivation, which represents the red edge wavelength. An important advantage using this spline interpolation is that splines directly touch every base of the spectrum that should be interpolated and influence the whole progression of the interpolated curve. This characteristic of spline interpolations makes it possible to consider even subtle differences in the reflectance curve. In the context of the red edge analysis five spectral features were calculated:

1. wavelength of the red edge position,
2. the reflectance minimum in the red wavelength,
3. the wavelength of the minimum in the red wavelength,
4. maximum reflectance near 0.80 µm,
5. distance in wavelength between the minimum in red and the red edge.

The features “red edge”, “wavelength of the minimum in red” and the “wavelength distance between the min. in red and red edge” are measured in wavelength units and are therefore independent from scaling differences and pixel brightness. This is most important when average pixel brightness changes due to canopy shape, illumination direction and distance from nadir.

3.2 Features from continuum removed spectra

Many studies have shown that vegetation will respond to changing conditions with changes in their spectral reflectance behavior. Next to the changes in the red edge region described above such changes have been observed at the green reflectance peak near 0.57 µm, at the chlorophyll absorption maximum near 0.68 µm and in the region of the infrared reflectance shoulder between 0.75 µm and 1.1 µm [7].

The geometric analysis of spectral features is primarily based on a geometric analysis of continuum removed spectra. Continuum removal is the ubiquitous first step of this feature extraction process. The continuum of a spectrum is described by a continuous convex hull, draped over the maxima of the source spectrum. Dividing the source spectrum by its continuum results in a continuum removed or normalized spectrum with values from 0.0 to 1.0 (ref. Figure 3a). Absorption features, which commonly occur superimposed on a background slope in the source spectrum, are transformed into features with a uniform, flat background of 1.0 in the continuum removed spectrum. This allows each absorption feature in a spectrum to be mathematically analyzed in respect of a consistent reference plane.

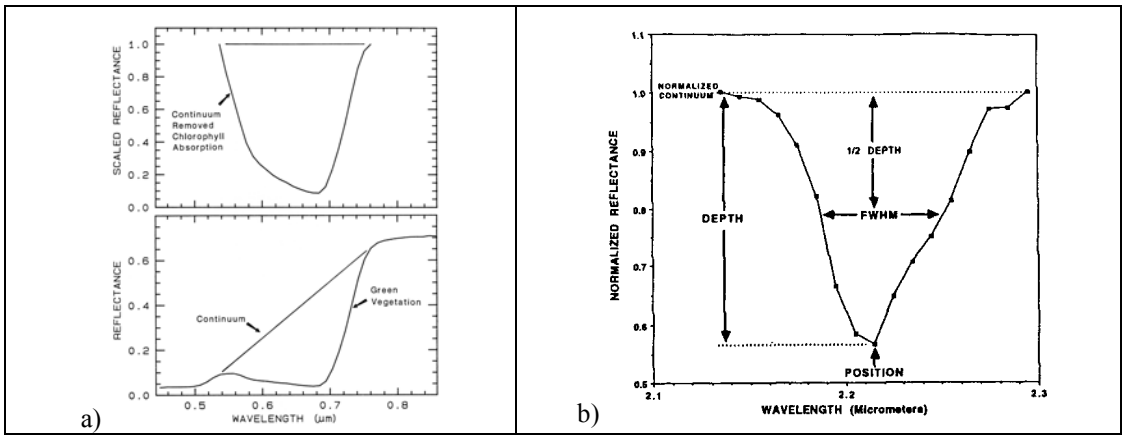

Figure 3: Continuum-removed example of a chlorophyll absorption in vegetation (a) and an example of the absorption band parameters: ‘band depth’, ‘band width’ and ’FWHM’ (b), [8]

The feature extraction algorithm contains several spectral attributes. The most common are the wavelength position of the maximum absorption depth, the band depth, the FWHM (full width at half maximum) and a factor of symmetry. This factor is defined as the sum of the reflectance values for feature channels to the right of the minimum divided by the sum of the reflectance value for feature channels on the left (ref. Figure . 3b). The logarithm of this value is taken to linearize the values. Symmetric bands have a symmetry value of zero. Bands asymmetrical towards longer wavelength have positive asymmetries. Using this definition, the 0.67 µm chlorophyll absorption band characteristically has negative values. Applied to HyMap data the maximum absorption depth (band depth) is correlated well to stressed vegetation. This band depth decreases dramatically, when the plants show any changes caused by different hydrological conditions.

3.3 Derivative Analysis

The derivative analysis was originally developed for spectrometry [11] and is in particular promising for hyperspectral remote sensing data. Derivatives not only emphasize subtle spectral details but also suppress the

mean level. They even minimize illumination and atmospheric effects [12], [13]. In spite of lots of advantages the derivative analysis needs to be applied with great attention because it is very sensitive to data noise.

Not all methods used in spectroscopy can be adopted directly to remote sensing analysis because there are significant differences between these two types of data. Data used in spectroscopy are usually collected in controlled laboratory conditions with full control over the intensity and spectral distribution of the illumination as well as viewing geometry. In contrast to that remote sensing has the lack of a defined preparation of the target substance, reflection and absorption standards etc. The most important deficiency of remote sensing data is that the spatial resolution of a single pixel is greater than several meters in diameter (often several tens of meters), and it is rare for a single object or target feature to fill one pixel completely. Thus, the characteristics of a pixel can rarely be considered truly homogenous.

To extract the features applying the derivative analysis to the HyMap imagery the curves were integrated and the associated areas under the curves were calculated. For the first group of features the integration was done over an interesting part of the spectrum. For the determination of plant features the well known wavelength around the red edge between 0.54 and 0.74 µm was considered and the areas of the first five derivatives of the spectrum were calculated. For the second group of features the integration over the whole spectral range was calculated. Fig. 4 shows the expanse of the areas concluded by the function curves of the first derivative of a spectrum as an example.

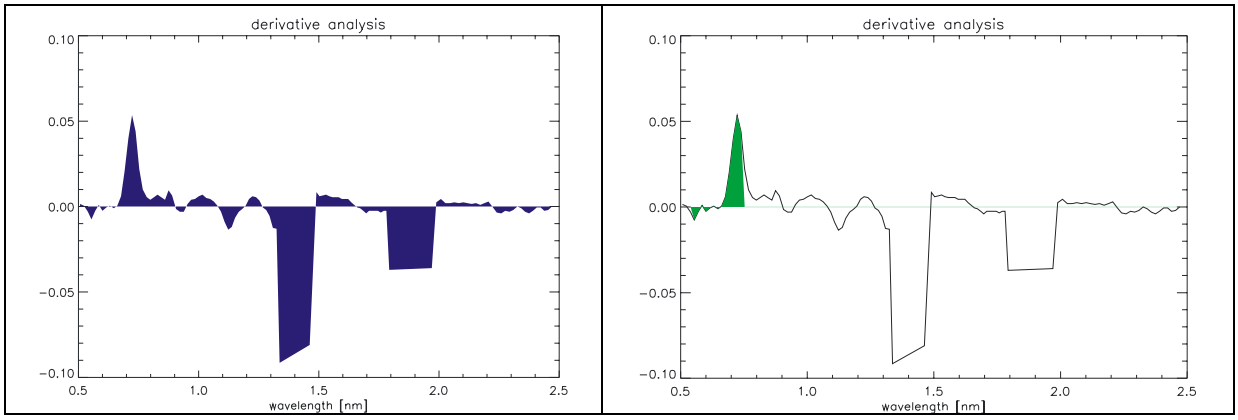

Figure 4: Area of the first derivative over the whole spectral range (left) and area of the first derivative in the wavelength range between 0.54 and 0.74 µm as an example of specific wavelength ranges are used for analysis (right).

4 MAPPING OF PLANT ANOMALIES

Because of the different sensitivities of different vegetation species (ref. table 1) further examinations have been applied on Pine and Beech trees, because they are most sensitive to soil moisture and different nutrient content of the soils. The following table shows a classification of requirements of different tree species. Higher values indicate, that the plant usually prefers locations with higher nutrient and water content. i indicates indifferent and means, that the plant usually is not linked to special locations [14].

Table 1: Plant indicators related to moisture and nutrient content of soils [14], increasing numbers indicate higher contents of moisture and nutrient in typical location of the specie, i indicates indifference of the specie.

Specie (used name / scientific name)	indicator for moisture status	indicator for nutrient status
Pine / Pinus Sylvestris	3	2
Birch / Betula Pendula	i	i
Alder / Alnus	7 – 9	i
Oak / Quercus Robur	i	i
Fir / Abies alba	i	i
Spruce /Picea Abies	i	i
Beech /Fagus Sylvatica	5	i
Maple /Acer	5 – 6	6 – 7

As described above plant status in terms of vitality is spectrally expressed in a change of shape and wavelength at the transition between red and infrared wavelengths. To describe the curve's progression eighteen features were calculated. These features are (together with common short cuts for each feature):

1. full width at half maximum (FWHM)
2. maximum absorption depth (MaxAb)
3. symmetry (sym)
4. red edge wavelength (red edge)
5. minimum in red (min in red)
6. wavelength of the minimum in the red wavelength (wl min in red)
7. reflection maximum near 0.8 µm (shoulder near 0.8, sh0.8)
8. wavelength region between the minimum in red and the red edge wavelength (wl red red edge)

9-13. areas of the 1st – 5th derivatives between 0.55 and 0.74 µm (derpart1-derpart5)

14-18. areas of the 1st – 5th derivatives between 0.42 and 2.5 µm (derges1-derges5).

Because changes of vegetation status can be expressed in the value of a difference from a standard value but not in the direction of this difference the following procedure has been applied on these forest stands. First a standard value for each feature and each forest class with no influence of the mining caused subsidence movements had to be defined. This has been done calculating the features for the predefined endmember spectra. These values are stored in a table and used as predefined standard values.

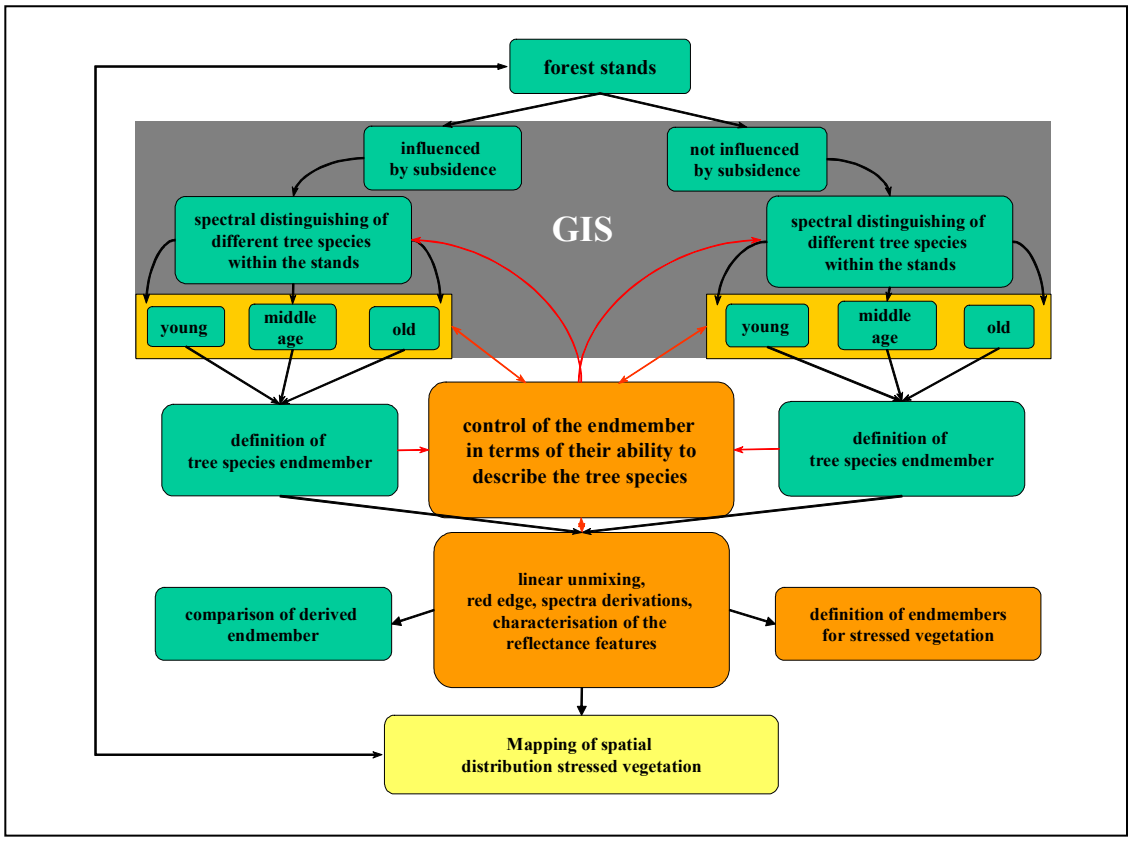

Figure 5: Approach to derive and to compare different endmember on different locations.

After that all the features for the hyperspectral image dataset were calculated. The evaluation took place by calculating the deviation from the standard feature values for each forest class separately, and the detected anomaly was defined as the absolute value of this deviation. For visualization the last step was a threshold classification (density slice). Fig. 6 shows the results of this stress detection algorithm for pine trees with one of the most promising features, which were the maximum absorption depth, the red edge wavelength and the area below the second derivative in the wavelength region between 0.55 and 0.74 µm.

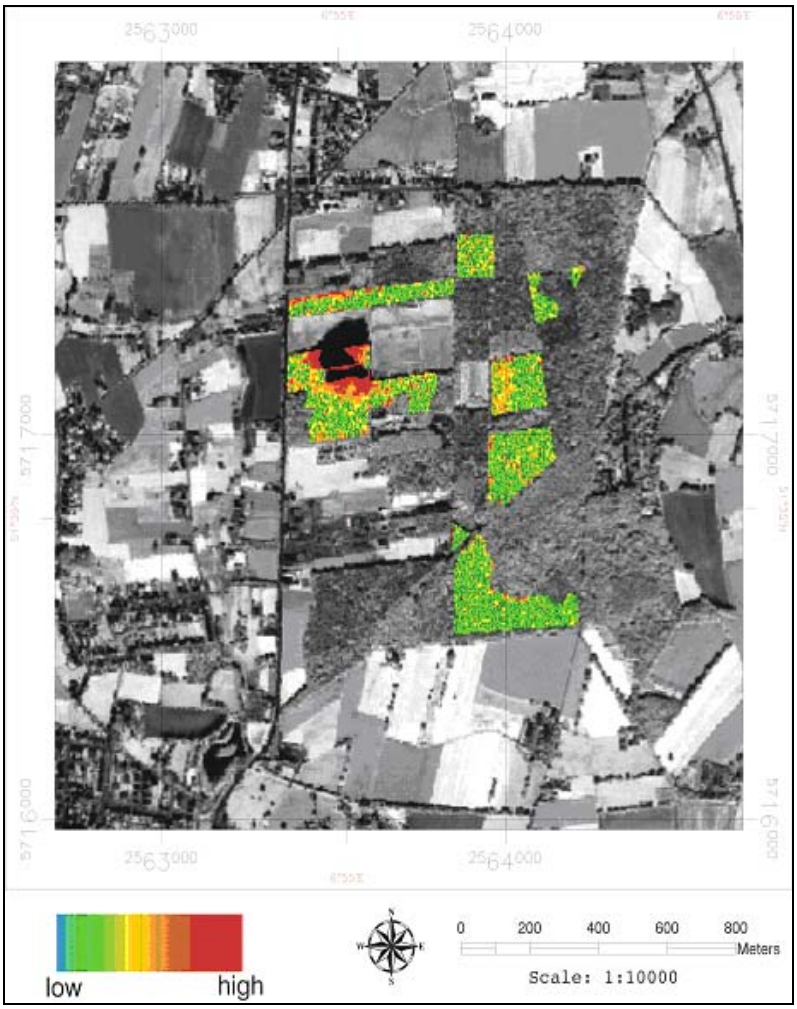

Figure 6: Mapping of plant status. Results calculated from 2nd derivative index between 0.5 and 0.74 µm.

It can be shown that as well the maximum absorption depth as the derivative feature has declined significantly in areas in the influence of mining induced ground-water alterations. The red edge wavelength value decreased as expected only slightly.

5 CONCLUSION

Mining projects require a long planning and exploration phase, and therefore a long term planning certainty related to the investments done and an ongoing monitoring of impacts are necessary. Mining operations are tied to the structure of the deposits and the changing knowledge of geological conditions during the mining. This results in a dynamic mode of mining operations in which the strategy of mining can only be finalized in detail during the ongoing mining activities.

Due to the high geometrical and spectral resolution of the data changes in the reflectance characteristics of different vegetation stands caused by changed hydrological parameters could be detected. Since the presented procedures are based on derived parameters of the reflection signatures, the development of change detection routines for time series analyses are plausibly feasible. This is a crucial step for the development of methods usable for an efficient long-term monitoring.

Therefore the achieved results and the developed methods are intended to become part of the monitoring concept of the DSK. One important step is that these methodical concepts are approved by the mining authorities. To fulfill the different requirements of the authorities, actually engaged in the development of a monitoring concept, further enhancements and improvements are required. Therefore a further flight campaign for this Test Site is planned.

ACKNOWLEDGEMENTS

The ASD FieldSpec FR is under courtesy of GeoForschungsZentrum Potsdam (GFZ), Section 1.4 "Remote Sensing". The authors are deeply grateful to Martin Schodlok for his assistance during the field measurement campaign. Special thanks go to all MINEO team members for the intensive discussions related to hyperspectral image processing techniques.

REFERENCES

[1] MINEO 2003: project web site: http://www.brgm.fr/MINEO

[2] DRECKER, P.; GENSKE, D., KLEMENS, H., NOLL, H.-P., 1995: Subsidence and wetland development in the Ruhr district of Germany. In. BARENDS, F.; E.A. (Ed.): Land Subsidence. Proceedings of the 5th International Symposium on Land Subsidence, The Hague, IAHS Publications No. 234, pp. 413-421.

[3] BRUNN, A., FISCHER, C., DITTMANNM, C., RICHTER, R., 2003: Quality Assessment, Atmospheric and Geometric correction of airborne hyperspectral HyMap Data. (This proceedings).

[4] CURRAN, P., 1990: The effect of a red leaf pigment on the relationship between red edge and chlorophyll concentration. Remote Sensing of Environment, Vol.35, pp. 69-76.

[5] FILELLA, I., PEÑUELAS, J, 1994: The red edge position and shape as indicators of plant chlorophyll content, biomass and hydric status. International Journal of Remote Sensing, Vol.15, No. 7, pp.1459-1470.

[6] HORLER. D. N. H., BARBER, J., BARRINGER, A. R., 1980: Effects of Heavy metals on the absorbance and reflectance spectra of plants: International Journal of Remote Sensing, Vol. 1, pp. 121-136.

[7] SINGHROY, V.H.; KRUSE, F., 1991: Detection of metal stress in boreal forest species using the 0.67µm chlorophyll absorption band. Proceedings of the 8th Thematic Conference on Geologic Remote Sensing, Exploration, Engineering and Environment, Denver, 29 April – 2 May, pp 361-372.

[8] BOHNAM-CARTER, G.F., 1998: Numerical procedures and computer program for fitting an inversed Gaussian model to vegetation reflectance data. Computers & Geosciences, Vol. 14, No. 3, pp. 339-356.

[9] RENCZ, A. (ED.), 1999: Remote Sensing for the Earth Sciences. In: Manual of Remote Sensing, 3rd ed., Vol. 3, Wiley & Sons, New York.

[10] GUYOT, G., BARET, F., 1988: Utilisation de la haute resolution spectrale pour suivre l'etat des couverts vegetaux. Proceeding of the 4th Colloquium on Spectral Signature of Objects in Remote Sensing, Aussois, France, ESA SP- 287, pp. 279-286.

[11] TALSKY, G., 1994: Derivative Spectrophotometry, Weinheim.

[12] SCHOWENGERDT, R., 1997: Remote Sensing: Models and Methods for Image Processing, 2nd ed., Academic Press, San Diego.

[13] PHILPOT, W.D., 1991: The derivative Ratio algorithm: Avoiding Atmospheric effects in Remote Sensing. IEEE Transactions in Geosciences and Remote Sensing, Vol. 29, No. 3, pp.350-357.

[14] ELLENBERG, H., 1992: Zeigerwerte für Pflanzen in Mitteleuropa, Göttingen.