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Multivalent Use of Remote Sensing Sensors for Geology and Mining

Dipl.-Ing. Andreas Forgber, Dr. rer. nat. Monika Pilarski, Dipl.-Ing. Beatrix Wagner, Dipl.-Ing. Martin Wagner, ILV-Fernerkundung GmbH, Berlin

Introduction

ILV-Fernerkundung GmbH has long-standing experiences as service provider as well as developer in the field of airborne and bathymetric survey and in satellite application for lignite mining in the Eastern districts of Germany. As one of the first companies in Europe in spring 2004, ILV started with digital airborne imagery. There were published first results about comparisons between film-based airborne cameras and new opportunities by the digital camera systems DMC (Digital Mapping Camera) in Hannover 2005 [1].

In the year 2005, ILV introduced the digital airborne survey into the regular flights for lignite mining survey services in Middle Germany and Lusatia. These new technologies were used also for photo flights in case of mining accidents like landslides and other ground movements.

Since December 2004, ILV has collected extensive experiences in many digital airborne survey projects in different African countries. Special challenges arose from specific climatic conditions in the tropical zone of the coast of Nigeria and in the arid zone in Libya.

The post mining landscapes in the lignite mining areas have a lot of remaining holes which develop into lakes during a long-lasting process of rising groundwater. It is an important task to observe such lakes with bathymetric surveying methods to register ground movements until reaching a stabile system. In the year 2004, ILV created the conditions and since that time it carries out such investigations.

Technical conditions for airborne and bathymetric surveys

ILV operates special equipped aircrafts for aerial photogrammetry, airborne lidar systems and aerogeophysics. Figure 1 shows a view to the turboprop twin-engine Cessna 441 Conquest. Its endurance is 2,566 km.

Figure 1: ILV's special equipped Cessna 441.

The airplane is equipped for the specific needs of aerial image acquisition, e.g. with a glass covered camera hole fitted for DMC, several GPS antennas, TCAS, weather radar. As photo flight navigation system ILV uses the CCNS-4, DGPS registration with Trimble 5700 at 10 Hz and AeroControl (IGI) photo flight navigation/real-time positioning system with DGPS and Inertial Measurement Unit (IMU).

ILV has used the large format metric Digital Mapping Camera (DMC) of the company Zeiss/Intergraph since spring 2004. Since spring 2008 ILV owns the second DMC (№ 01-122). That has opened more flexibility in executing its projects at home and abroad.

The 48-bit radiometric pixel format of the DMC provides excellent feature identification conditions in deep shadows and bright environments, as well as superb color adjustment and image balancing options for seamless orthoimage mosaics. In comparison to standard 24-bit color scanned film images the DMC has an information content per pixel, that is on average 10-times higher, i.e. instead of a maximum of 200 to 230 grey values at 8-bit usually 2,300 to 2,500 usable grey values at 12-bit.

Keywords
Schlagworte

Airborne and bathymetric survey
Luftbild- und bathymetrische Vermessung

3d terrain models
3D-Geländemodelle

Satellite remote sensing
Satelliten-fernerkundung

In this paper there are presented digital airborne as well as bathymetric survey systems for generating high accurate 3d terrain models. The technical conditions and various examples in remote surveying from more than ten years of experiences in Germany and Africa show a wide range of applications for the mining industry. Furthermore a satellite remote sensing approach for monitoring of post lignite mining landscapes in East Germany is presented.

Multivalente Nutzung von Fernerkundungssensoren für Geologie und Bergbau

In diesem Beitrag werden sowohl digitale luftgestützte als auch bathymetrische Systeme zur Generierung hochgenauer 3D-Modelle vorgestellt, welche in der Regel effektiver und kostengünstiger als das Laserscanning sind. Die verschiedenen Beispiele der Geofernerkundung aus mehr als zehn Jahren Erfahrung in Deutschland, Europa und insbesondere Afrika zeigen eine breite Anwendung für Geologie und Bergbau. Abschließend wird ein Satellitenfernerkundungsansatz für ein Langzeit-Monitoring von Bergbaufolgelandschaften in der Lausitz dargestellt.

Data capturing using DMC that is geometrically and radiometrically calibrated can reach higher accuracies than using a lidar system in combination with a medium sized camera. Thus, the new DMCII 250 with one chip only for panchromatic recording is more than an alternative to laser scanning especially regarding accuracies and point density. This was checked by ILV during a photoflight in 2012.

Besides the equipment for airborne surveying, ILV owns modern technical equipment for acquisition of high resolution bathymetric data to generate very accurate 3d information. This includes special equipped survey boats for using on inland waters which the company has applied since 2003.

Figure 2 shows a schematic diagram with a Multi-Beam Sonar at the bow, a DGPS/INS system to record the position including a GPS antenna, a probe for measurement of sound velocity and a multi-port data receiver with display and storage unit.

Main objective of the measurements are 3d bathymetric information which are acquired by a modern Multi-Beam Sonar RESON-8125H (455 kHz) (Figure 5). Since the year 2011, ILV has used this new system.

Essential parameters of the system are the high frequency of 455 kHz and the very high depth resolution of 6 mm. Some interesting parameters are given in Table 1.

The software system QINSy is used for data acquisition and processing. Besides others it merges the data streams of the different sensors.

The feature controllable fan allows to vary and to control the width of the fan. In the application head swerve, the head is physically up to 30° tilted to one side to the desired area (e.g. a dam) to light with centimeter accuracy (Figure 3).

In the following sections examples of different projects at ILV regarding mining application are presented.

High-resolution aerial survey in Libya

The background of the project was the oil and gas exploration in the concession area 201 of Wintershall in Kufra Basin Southwestern Libya in the arid desert zone of Northern Africa. The Wintershall team intended to develop a time and cost effective way to acquire information for

- Geophysical & geological application
- Logistics
- HSE

The integration of digital high-resolution aerial photo imagery, derived high-resolution digital terrain models and satellite imagery were suitable tools to find answers [2].

The airborne services of the interested area of ≈11,500 sq km were carried out by ILV using the digital mapping camera DMC. It was estimated that in comparison lidar technologies would have taken several month with approx. 10 times more of the costs than using DMC.

Essential objectives of the ILV project were:

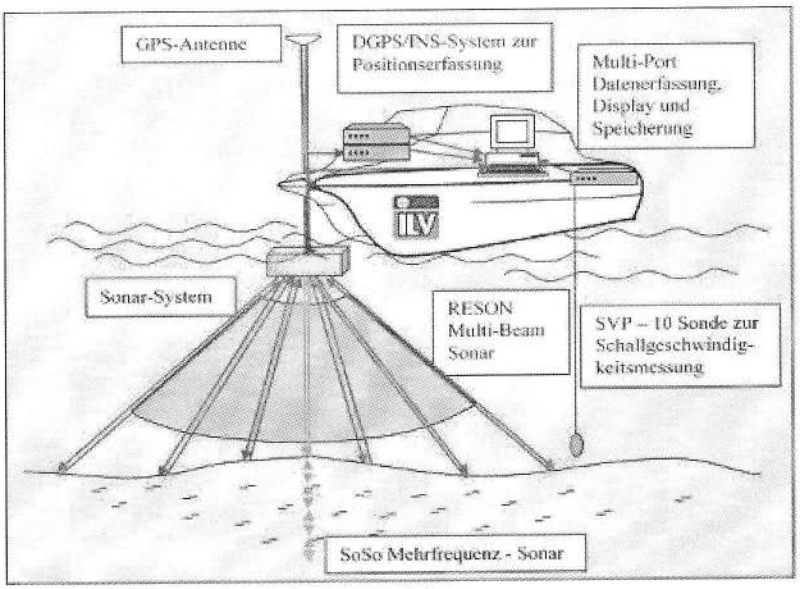

Figure 2: Schematic diagram of the sensors and measuring system.

- Acquisition of digital aerial photographs (GSD = 40 cm)
- Generation of digital orthophotographs (DOP)
- Generation of Digital Terrain Models (DTM) with grid size 10 m

Figure 4 gives an impression of the investigation side in October 2007 and an idea of the difficult conditions in the desert with vast areas without infrastructure.

To achieve accuracies of the geo-referenced images into the size of one pixel, the measurement of ground control points (GCP) were necessary. This was prepared by ILV as well as by the Wintershall team. Such an extra ground control point installed by Wintershall shows Figure 5. On the right side of the figure, ILV's own DGPS base station at Kufra airfield is presented.

In the photoflight campaign in the end of October, 2007 ILV captured nearly 3,000 images which corresponds approximately 230 GB of data.

The DTM and orthophoto generation for the area NC 201 have been carried out since December 2007 in several phases:

- preliminary generation in more coarse resolution (DTM—20 m raster; DOP—2 m pixel resolution)
- generation in higher resolution (DTM→10 m raster; DOP 40 cm pixel resolution)
- calculation of the DTM—5 m raster including of 3D recorded breaklines and formlines for the more structured areas.

Operating frequency	455 kHz
Depth resolution	6 mm
Max. range	120 m
Number of beams	256/512 (equi distance/equi angle)
Beam width	1° / 0.5° (along / across track)
Horizontal swath width	120°
Max. update rate	40 measurements/sec/beam

Table 1: Parameters of the Multi-Beam Sonar RESON 8125-H.

Figure 3: Variations of fan swerve.

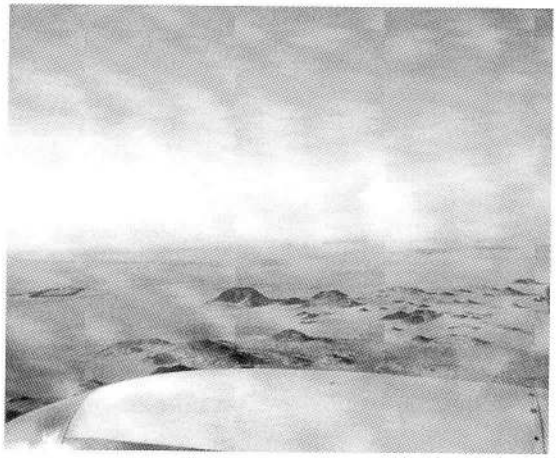

Figure 4: Impression of the investigation site – Kufra Basin, ILV 2007.

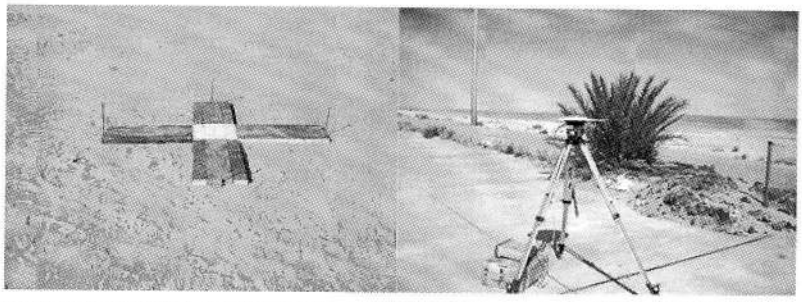

Figure 5: Installed ground control point by Wintershall and ILV's DGPS base station.

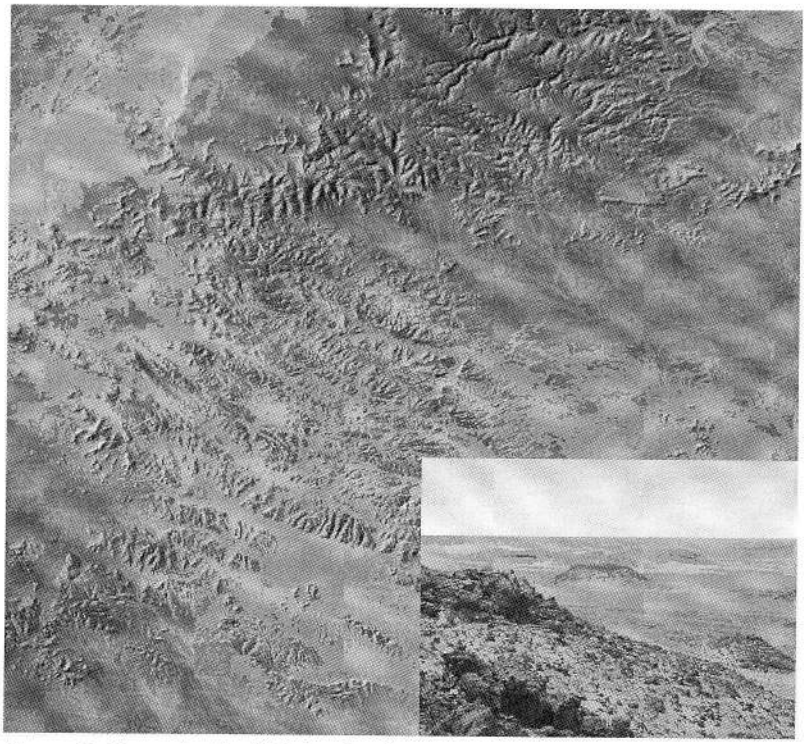

Figure 6: Example of a digital orthophoto, ILV with insert photograph, Wintershall.

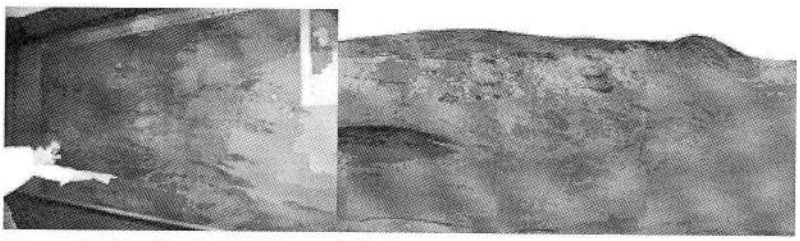

Figure 7: Working in the Wintershall show room with 3d information.

The software program package Orthobox of the company INPHO was used for the orthophoto generation. This involves the programs Orthomaster and Orthovista.

The generation of position-accurate image data—the orthophotos—was made by rectifying the image data using DTM data in a fully automatic process.

However, the following control process was relatively extensive. The automatically generated lines during image fusion were checked and if necessary changed. This working step guarantees that also visually good image data are created.

Area NC 201 can be characterized by a very high surface homogeneity, a peculiarity not normally encountered in our work. As a result, relative low radiometric differences in the images (for example by light differences at the lines) are clearer than usual. They can be reduced only partially by radiometric adjustment operations.

Figure 6 shows one of the generated orthoimages.

In a special equipped show room at Wintershall, specialists worked with the 3d information to learn about the topographic situation of the area and to create effective lines for transport and seismic investigation (Figure 7).

In the resume of this project the company Wintershall evaluates that high-resolution imaging in combination with a detailed DTM is a very powerful tool for exploration:

- Regarding seismic survey preparation (e.g. design and line planning, seismic processing, journey management)
- Regarding geological interpretation (surface and structural geology)
- Terrain hazard analysis
- Environmental snapshots

Bathymetric survey in post mining lignite landscapes

Since the year 2004, ILV executed different bathymetric survey projects in lakes which were formed in post mining processes of the lignite mining regions of Middle Germany and Lusatia. The 3d data are used to investigate changes on the lake ground especially at the slopes during the process of rising groundwater. They are a basis to decide and plan geo-technological measures that the lake body becomes stabile.

In comparison with the multibeam techniques used by ILV in 2003–2010, the absolute accuracies of the systems have basically improved so that today smallest changes of lake grounds or of hydraulic structures can be detected three-dimensionally. In 2005, the absolute accuracies were at ≈0.5 m. In 2010, there were already ≈0.3 m reached, and with the new equipment systems the centimeter dimension is possible.

Following innovative measurement methods which are due to a new structure of the processor and the connected near-hardware regulation of the beams proved to be particularly valuable at practice:

- Equi-Distant Modus (512 ED beams) instead of Equi-Angle Modus (240 EA beams)

- Use of Flex Modus; the ED beams are be formed in such way that the sounding distance keeps cross to the fan and all other beams lay in a small EA sector.
- Controllable fan (Figure 3); this feature allows to vary and control the width of the fan.
- Stability of roll; this means the insert of data from the moving sensor (laser gyroscope—INS/DGPS) control every vertical beam dynamically corresponding to the vessel movement. If zero degree the roll movement lays in the center of the fan directly under the vessel. If the vessel rolls, the center does not lay under the vessel.

One example of bathymetric surveying by ILV is the remaining hole Frose near Nachterstädt in Saxony-Anhalt. The soundings were done in 2009. At Figure 8 in the unfiltered tracks trees and a building (like in this case a former water station) are recognizable very well.

A further example is the bathymetric survey project at the remaining hole Schlabendorf in Lusatia. It was sounded by ILV in the years 2011 and 2012. The fan-like data collection and overlap gives a complete coverage of the lake bottom. To observe small mass movements at a steep slope in the North (Figure 9), line spaces between 10 and 20 cm were applied. Because of the very high point resolution of 512 points synchronously the contours of the bottom are seen very clearly.

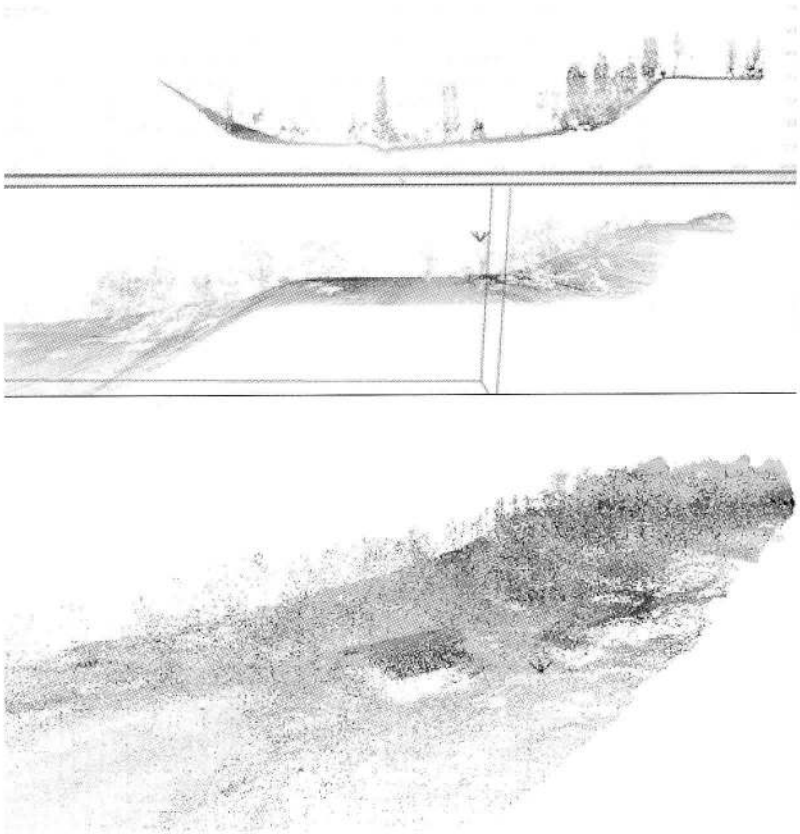

Figure 8: Example – remaining hole Frose near Nachterstädt (Saxony-Anhalt). Top: profiles unfiltered and filtered. Bottom: unfiltered track with depth at centimeter.

Satellite remote sensing methods for monitoring of post mining landscapes

Designing of post lignite mining landscapes (PML) is a great challenge for rehabilitation and reclamation. With their special features as large-scale modification of all landscape components, small-scale heterogeneity (in terrain, soil, vegetation) and high dynamics during long-lasting reclamation processes, these landscapes are also of important interest for environmental research. In the years 2000 to 2010, the multi-disciplinary research project SUBICON (Successional Change and Biodiversity Conservation) was executed at Brandenburg University of Technology Cottbus, professorship General Ecology promoted by the Federal Ministry of Education and Research (01LC0618A2). Results of these complex investigations in biodiversity and nature protection are published in [3].

ILV-Fernerkundung was associated in this project with multi-temporal investigations of the test side *Schlabendorfer Felder* using different satellite remote sensing data sets. In this section results of an object-oriented classification approach using very high-resolution (VHR) satellite data are presented.

Figure 10 shows the test area Schlabendorfer Felder with the PML of the former open-cast mining Schlabendorf-North (≈2,000 hec) and Schlabendorf-South (≈4,000 hec).

Main objectives of these partial investigations were the creation of rules for classification of land cover types like biotopes and biotope information using VHR satellite images of different years as an application of the segmentation-based software *eCognition*. This includes determining appropriate parameters of the segmentation processes and creating a transferable classification description for satellite data acquired in different years.

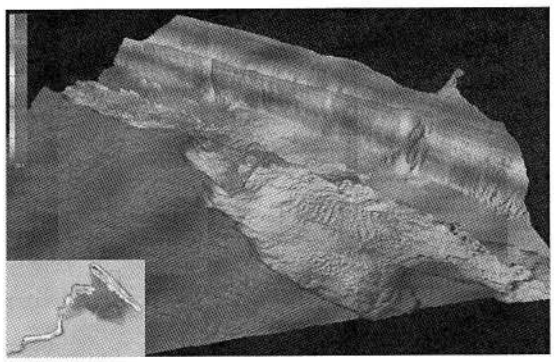

Figure 9: 3d visualization of sounding results at remaining hole Schlabendorf (Lusatia), frame of the Northern slope with small mass movements.

	Satellite system	Geom. resolution of multispectral bands	Acquisition date	Data quality
1	IKONOS 2	4 m	15-07-2005	dusty areas
2	IKONOS 2	4 m	15-08-2007	clouds in the North
3	GeoEye 1	2 m	21-08-2009	free of dust & clouds

Table 2: Overview about the used satellite data sets.

Three data sets were available for the investigation (Table 2).

Because of the different acquisition dates and variations in the quality of the data, atmospheric correction procedures of each 4-band data set were

Figure 10: Area "Schlabendorfer Felder" by satellite data GeoEye 1, 21-08-2009.

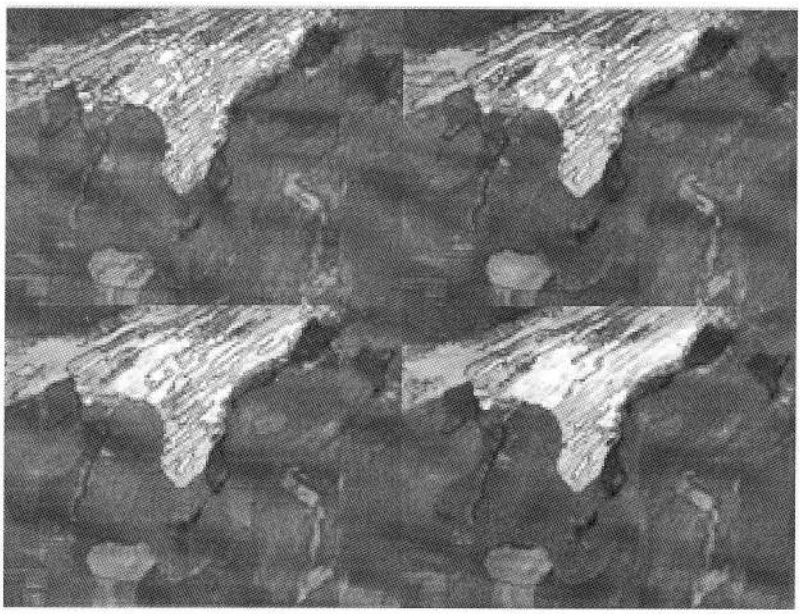

Figure 11: Several levels with different scaling factors for feature generation with IKONOS data (bottom left: L 1, sc.f. 20; bottom right: L 2, sc.f. 36; top left: L 3, sc.f. 53; top right: L 4, sc.f. 80)

applied using the software module ATCOR which is included into the image processing software package ERDAS IMAGINE. Three data sets are produced in this processing which are radiometrically comparable.

The executed semi-automatic classifications of land cover and land use types are based on an object-oriented approach. That means segmentation processes are preceded to the real typing. In the result relative homogeneous units named segments arise which should correspond to real objects of the landscape.

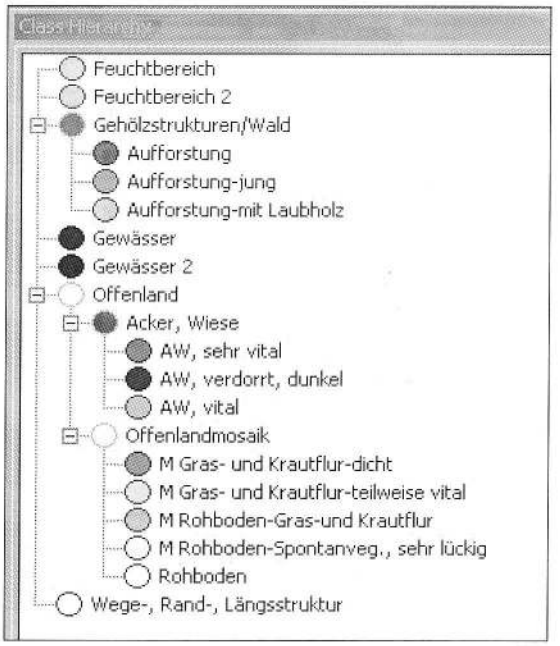

Figure 12: Class hierarchy for the IKONOS data set, 2007.

The various sizes of the objects are taken into account by several scales inside the segmentation process. The applied software *eCognition* involves a region growing method for the segmentation processes [4]. The determination of the scaling parameters for the extraction of segments was performed in an iterative process. The scaling factor (sc.f.) accordingly biotopes and land use types in 4 levels (L) are presented on image frames in Figure 11. Other tunable parameters were selected as standard like shape factor and compactness. For the GeoEye data set with a higher geometric resolution the parameter scaling factor was adapted as for level 4 with the value 140.

In the classification processes there were used spectral and derived information as well as structural ones. It was begun with the data of 2007 which has a good radiometric quality in the area Schlabendorf-South. To separate different land cover types, rules were developed in a so called class hierarchy (Figure 12).

After adaption of spectral thresholds for individual class und inserts of new classes the developed class hierarchy could be applied to the other two data sets. This was possible because all the data sets were atmospherically corrected. In Figure 13, results of classification in the levels of detail two and four are presented.

It could be shown that a segment-based approach for land cover classification is a suitable tool for monitoring of post mining landscapes. A unique build-up class hierarchy can be used after marginal adaption for classification of further satellite data sets which makes the whole technological process efficient.

Conclusion

It was shown that airborne and bathymetric survey and applied satellite remote sensing methods are efficient methods for different tasks for the mining industry: in the exploration phase in unknown areas, for

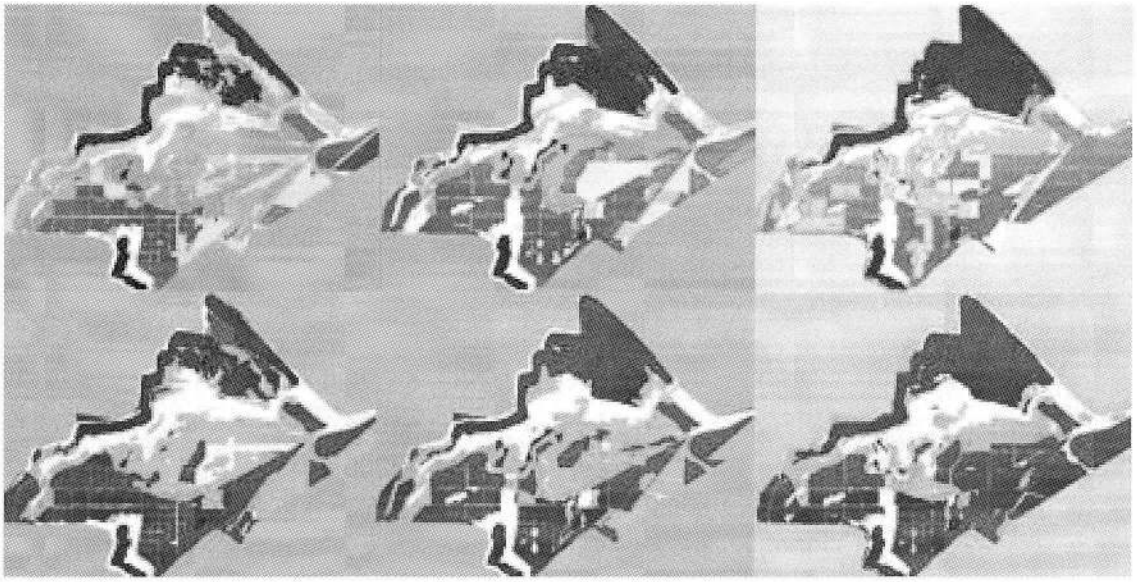

Figure 13: Results of classification of land cover types in two levels of detail.

Dark: water types
Dark grey: afforestation types
Middle grey: open fields with sparsely vegetation cover
Light grey: open fields with grass and herbs
White: ways & long structures).

surveying of opencast lignite mines, mass calculation of coal and overburden, surveying of disaster events or for observation of reclamation and rehabilitation measures. The applied equipment has been developed continuously and the results become more accurate.

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Anschriften der Autoren:

- Dipl.-Ing. Andreas Forgber
- Dr. rer. nat. Monika Pilarski
- Dipl.-Ing. Beatrix Wagner
- Dipl.-Ing. Martin Wagner

ILV-Fernerkundung GmbH
Wallstraße 15/15A
10179 Berlin

E-Mail ilv-fernerkundung@t-online.de