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Aerial photo interpretation and satellite image analysis in agricultural sciences

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Aerial photo interpretation and satellite image analysis in agricultural sciences

Werner Schneider, Renate Bartl, Hannes Burger, Joachim Steinwendner, Franz Suppan, Vienna

1. Introduction

The Universität für Bodenkultur (BOKU, University for Agricultural Sciences, Vienna) offers education and training and conducts research in the fields of agriculture, forestry, civil engineering and water management, landscape architecture and planning as well as food science and biotechnology. In most of these disciplines, data on large areas (ranging from the size of a parcel of land up to regional, national, continental or even global dimensions) are required both for scientific research and for practical operational applications. The type of information needed may concern the geometrical size, shape and location of objects, regions and phenomena on the surface of the earth (e.g. of agricultural fields or vegetation areas or areas of deforestation), it may be related to soil and vegetation properties (e.g. soil type, crop type and condition, forest damage), or it may refer to general land use patterns and landscape structures. The major advantages of using image data remotely sensed from aircraft and satellites as compared to traditional methods such as field work, statistical surveys etc. can be seen in the following points:

- quality of information: Certain information on the terrain, on the vegetation cover and on the type and distribution of objects on the terrain can be obtained much better and with higher quality from above. A bird's-eye view of forest stands yields information on the condition of tree crowns which cannot be obtained from below. The synoptic view of a landscape as represented by a satellite image allows insights into the geological, ecological and socio-economic conditions inattainable by other methods. The homogeneity of the information over large areas as offered by remotely sensed image data is of special advantage in many applications.

- reliability of information: Aerial photos and satellite images represent incontestable documents of the state of the terrain at the time of image acquisition. Image interpretation and analysis may be performed and, if necessary, repeated and checked at any later time.
- economy of data acquisition: Depending on the area to be covered, remote sensing often is the most economical technique for data acquisition. For monitoring purposes with periodically repeated surveys, remote sensing may provide the only economically feasible method.

The Institute for Surveying, Remote Sensing and Land Information (IVFL) at BOKU offers expertise in this field of remote sensing. Expert knowledge and methods from a variety of interrelated disciplines are involved, including photogrammetry, aerial photo interpretation, satellite remote sensing, image processing and pattern recognition, computer vision, cartography and geoinformatics.

This article discusses some general principles of photo interpretation and satellite image analysis in the agricultural sciences as represented at BOKU and gives examples of applications in the different fields.

2. Remote sensing in agricultural sciences

Given the wide scope of varying demands from the application fields on the one hand and the broad range of image data from different (airborne and spaceborne) sensors and of different evaluation methods on the other hand, choosing the proper data type and the adequate analysis procedure is essential for every project involving remote sensing.

The demands from the application fields can be specified as geometric requirements and as thematic requirements:

The geometric requirements concern the needs for spatial resolution and geocoding of the image data. In Austria and in many parts of Europe, a high spatial resolution is required because of the fine spatial structures of land use, the narrow agricultural parcels and the heterogeneous forests.

Thematic information requirements strongly depend on the application. Thematic information may be derived from

- the shape of individual objects, as e.g. in forestry, where the shape of individual tree crowns is indicative of tree species, but also of forest condition: In this case, high spatial resolution is required to obtain the thematic information needed. Stereo capability may be useful or necessary in cases where 3-dimensional shape information is required.
- texture: This concept denotes the quasi-periodic fine structure of regions. It is a signature type important in high spatial resolution images and is often caused by shadow effects, e.g. in the case of vegetation stands with a vertically structured surface.
- multispectral reflectance: This is most useful for mineral, soil and vegetation identification and for vegetation damage assessment. Multispectral information is the strong point of low spatial resolution electrooptical, especially satellite imagery, where it may, to a certain extent, substitute other types of information based on high spatial resolution, such as shape and texture.
- RADAR backscattering: The strength of RADAR backscattering conveys information on electrical (water content) and structural (3-dimensional arrangement of vegetation components) properties of the terrain.
- pattern and context: This type of information is most important in visual interpretation. It is, however, difficult to formalize and to be exploited in automated analysis systems.

In selecting proper image material, one has the choice between

- aerial photos: Their strong points are highest spatial resolution, ready realization of geocoding employing the well-established methods of photogrammetry, as well as stereo capabilities.
- digital images from frame cameras and video systems: They are gradually replacing photographic systems for thematic applications. The advantages of the new electrooptic methods (as compared to metric aerial photography) lie in the extended spectral range of sensitivity, in the radiometric fidelity, in the suitability for subsequent digital analysis and in the (potentially) low costs of data acquisition and analysis. The major disadvantage of digital frame cameras is the still limited frame size in terms of the number of pixels. This results in a larger number of frames necessary to cover a given project area with a predefined spatial resolution, thereby increasing the expenditure of photogrammetric orientation and georeferencing. Modern techniques of image matching and information fusion

can help to alleviate and overcome this problem.

- satellite image data: In the past, the fine spatial structures of land use, the narrow agricultural parcels and the heterogeneous forests in Austria precluded or at least limited the use of satellite images with pixel sizes of tens of metres. Land use mapping and forest stand mapping with reference to the cadastre and the forest management map called for the use of aerial photos in most cases. The situation is changing now: Subpixel methods allow the analysis of land use structures not much larger than the average pixel size, and a new generation of satellite sensors with pixel sizes down to 1 metre open up new application areas reserved to aerial photos up to now.
- RADAR data: Their all-weather capability and high expectations in thematic information content contrast with the tremendous problems of extracting this information. Practical applications in the agricultural sciences therefore are still limited.

In selecting a proper analysis method, the main alternative is visual interpretation versus automated digital analysis. Visual interpretation makes use of the great capacity and efficiency of the human visual system in analyzing spatial patterns (monoscopically or even in stereo). Experts from the specific application fields may extract information by employing intricate reasoning and profound expert knowledge. Visual interpretation is, however, highly subjective and time consuming. Automated digital analysis may overcome these difficulties, albeit at the expense of subtle aspects of information contained in the images. At IVFL, within the framework of the joint research programme „Theory and Applications of Image Processing and Pattern Recognition" of the Austrian Science Foundation, a 5-year project on „Physical models in remote sensing image understanding" is in progress. The aim is to develop an automated knowledge-based image analysis method which tries to imitate the work of a human image interpreter.

Another important aspect of the analysis of remotely sensed images is the structuring of information. In the past, the results of image interpretation used to be laid down as a thematic map which formed the basis for further expert work. The experts using the map were capable to cope with small inconsistencies in these maps. Today, the results of image interpretation most often are stored in geographic information systems, where they are further analyzed together with information from other sources, sometimes also for purposes they were not intended for originally. Hence follows that the results of image analysis must be strictly structured (i.e. defined and represented according to rigid rules) in order to facilitate subsequent use in the geographic information systems [12].

3. Forestry

Forestry is traditionally one of the most important areas of application of aerial photography and remote sensing. Driven by the demand for reliable information on the large areas they have to manage, foresters were among the pioneers of aerial photo interpretation and remote sensing. Image data used in forestry encompass all types from aerial photos to satellite images. In the following, two forestry projects conducted at IVFL are presented.

3.1. Mapping of protection forest formation phases

The condition of protection forests can be characterized advantageously using the concept of forest formation phases [6]. These phases describe the stage of development of forest stands during their life cycle and are indicative of their protection potential. A frequently used classification distinguishes between blank, regeneration phase, juvenile phase, initial phase, optimum phase, terminal phase, and disintegration phase, with further subdivisions of some of these phases.

High spatial resolution and stereo information are essential for identifying formation phases on

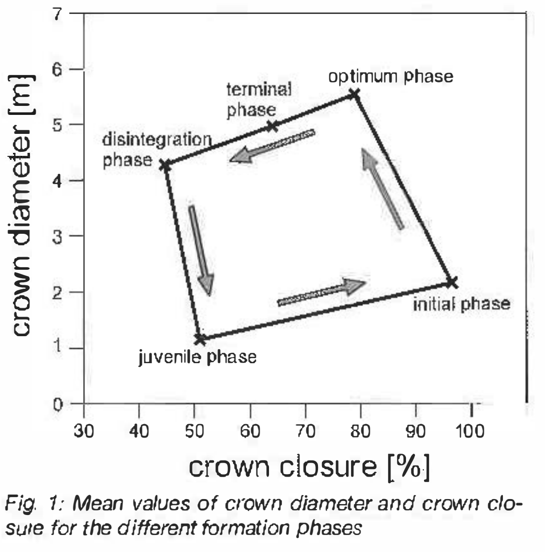


Fig. 1: Mean values of crown diameter and crown closure for the different formation phases

remotely sensed images. Colour infrared photos are superior to any other imagery for this purpose. In a project at IVFL, three different approaches to the mapping of protection forest formation phases were studied:

- In visual integral interpretation, the interpreter identifies the phase of every forest stand on the basis of its integral stereocopic appearance, without explicitely interpreting or measuring individual features. This method can bring out fine forest stand subtleties if conducted by an expert interpreter; it is, however, subjective.
- Visual interpretation supported by metric measurements is more objective. The following individual features are being interpreted or measured: tree species and mixture distribution, tree height and stand height (minimum, mean, maximum), crown diameter, crown closure, stand structure (horizontal and vertical), crown thinning state. The phase of a stand is deduced from these features following fixed rules. Fig. 1 illustrates the mean values of crown diameter and crown closure as measured from colour infrared photos for the different formation phases.
- An even higher degree of objectivity can be attained by photogrammetric stereo measurement of canopy profiles. This method is described in more detail in [9].

3.2. *MISSION-FORST*

The project „Study of forestry applications of high-resolution satellite image data" (MISSION-FORST) is part of the joint Austrian science project MISSION (Multi Image Synergistic Satellite Information for the Observation of Nature) [7] (under the contract of the Austrian Ministry for Science, Research and Art). Its general objective is to promote remote sensing technology in various application fields in Austria. The concrete inducement is the German sensor MOMS-02 which has been brought to the PRIRODA Module of the Russian space station MIR in May 1996 to collect images of the earth's surface for the next 18 month. MOMS-02 with 4 multispectral bands, on-track stereo bands and one high-resolution band of 6m × 6m ground pixel size is seen as a precursor of a new generation of high resolution satellite sensors.

One special target of the program is to involve potential future users in the process of developing and adapting image analysis methods for the specific applications, thereby improving the practical usefulness of the developed methods

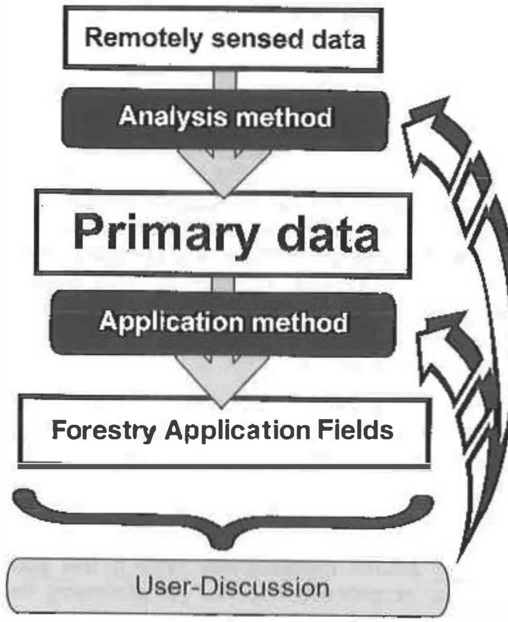


Fig. 2: Structure of project MISSION-FORST

and ensuring their future operational employment.

The information requirements for the different forestry application fields like forest management planning, protective forest management, forest inventory, wildlife management etc. can be traced back to a small number of so-called „primary data". These primary data, e.g. tree species, species proportion by area, tree height, crown diameter, crown closure and crown thinning state, are then used in the different forestry application fields for specific requirements. The basic idea of this project is to improve and to standardize the methods for deriving the primary data from satellite images on one hand and to develop procedures to use these data in the different forestry applications. This leads to the project structure as shown in figure 2. The analysis methods for extracting the primary data from the remotely sensed images are worked on at IVFL. Satellite data from different sensors (MOMS-02, LANDSAT TM, KFA-1000) are being analysed. Application procedures are developed and refined in cooperation with a small group of potential future users (Federal Ministry of Agriculture and Forestry, Umweltdata Ges.m.b.H.). In an advanced stage of the project the preliminary results will be discussed and evaluated with a larger group of potential users. Feedback from these evaluations will be used to improve iteratively both the image analysis methods and the application procedures.

4. Landscape ecology

Remote sensing techniques usually are employed to satisfy pre-defined data requirements in the various application fields. In contrast to this, the analysis of satellite imagery for landscape structure assessment as described here is an example of the use of satellite imagery und computervision methods to obtain new theoretical insights and to promote and stimulate basic research in landscape ecology [5]. This work is being performed within the scientific programme „Sustainable Development of the Austrian Cultural Landscapes" [4].

The concrete aim of the research module refered to here is the development of reliable indicators for assessing and monitoring the sustainable use of cultural (man-dominated) landscape. These indicators can be space-oriented (based on the spatial structure of landscape and the spatial relationships among the ecosystems) or process-oriented (emphazising the interactions and flows of energy, materials and species within and among the component ecosystems).

Concentrating on the space-oriented approach, and using the model conception that the landscape is composed of „landscape elements" (ecosystems) which are internally homogeneous, but differ from each other [5], we try to discern the landscape elements in satellite images and to extract structural features and ecologically relevant attributes (e.g. based on the vegetation index) from the images. An automatic analysis procedure based on image segmentation is being developed. Figure 3 shows as a preliminary result a section of a thematic map obtained from LANDSAT TM by region growing segmentation. The regions have been assigned according to information from the vegetation index.

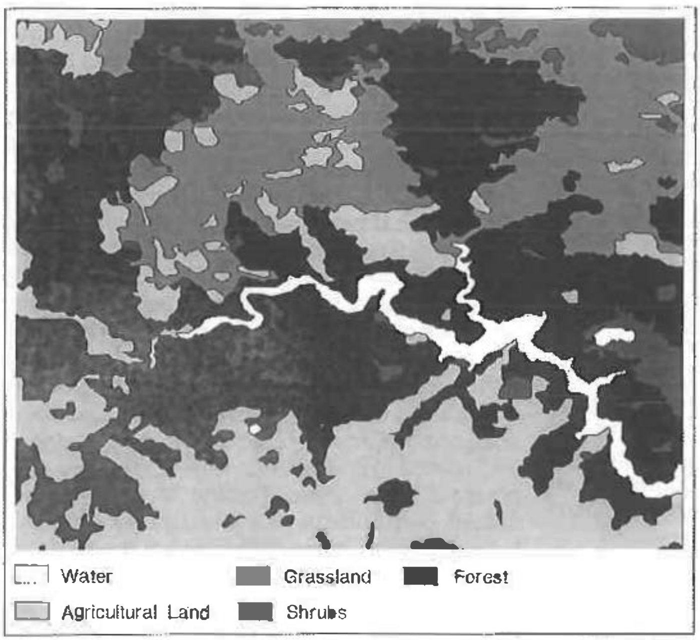


Fig. 3: Thematic map obtained from LANDSAT TM by region growing segmentation

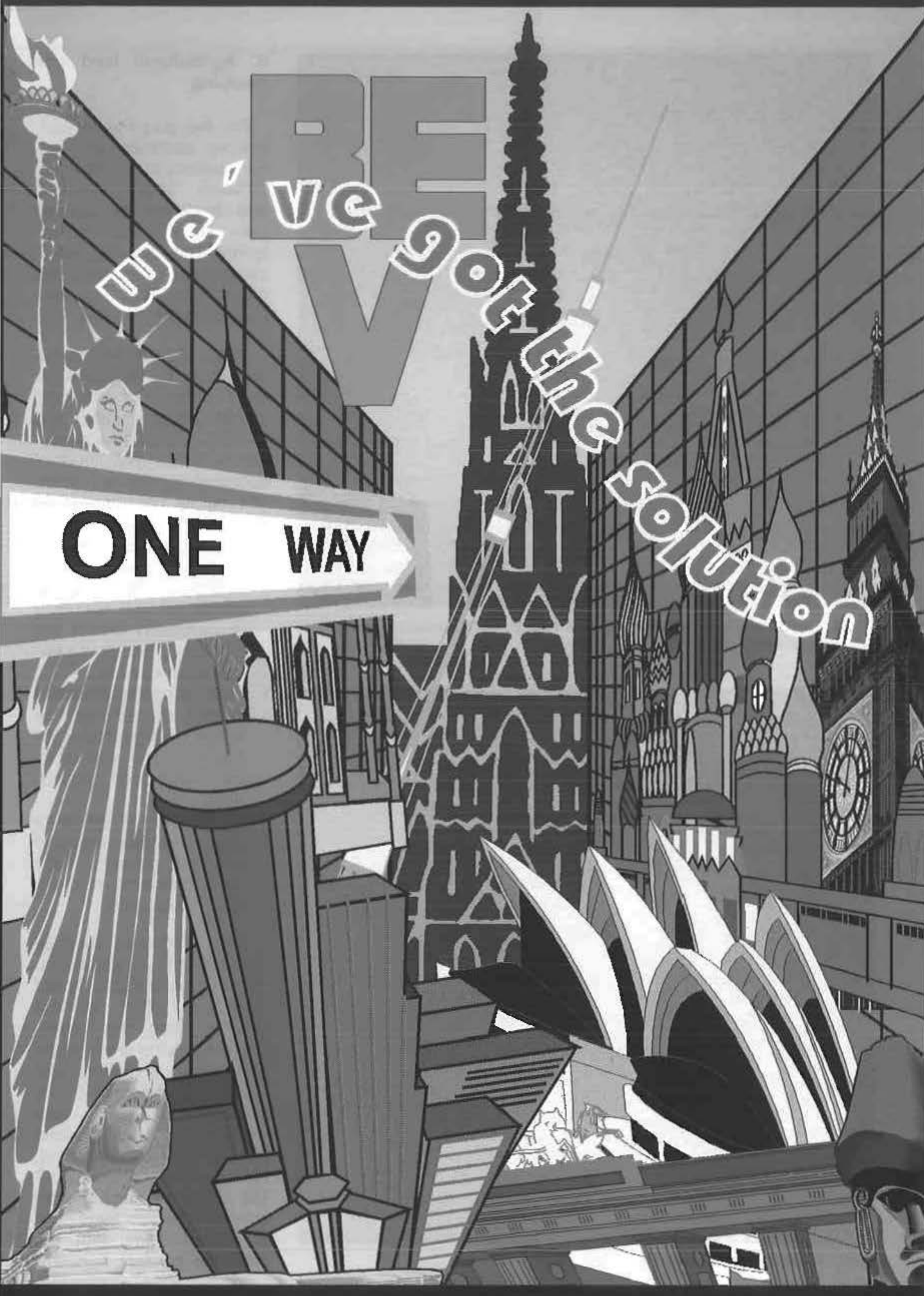
5. Water management

Data on the maximum runoff in catchment areas are required in sewerage system design. Runoff can be estimated using a hydrological model. Land use data are needed as input information for the hydrological model. The combined effect of land use and soil type may be described by a „runoff curve index" [8].

In [1], colour infrared aerial images have been used for stereoscopic land use classification. A stastistical raster sampling method has been employed. Visual interpretation of aerial images is, however, time consuming and expensive. We therefore tried to derive the hydrologically relevant land use information from satellite images by digital image analysis, exploiting the dependence of the runoff curve index on the vegetation cover as characterized by the NDVI (Normalized Difference Vegetation Index [10]). The NDVI is computed as a combination of the red and the near-infrared band of the satellite image (e.g., band 3 and band 4 of LANDSAT TM).

Figure 4 shows a map of catchment areas in Upper Austria registered onto the near-infrared band of LANDSAT TM imagery. For the same region, figure 5 displays the mean NDVI within catchment areas coded as gray value, i.e.the brighter the areas, the higher is the mean NDVI, the more vegetation is present.

Figure 6 illustrates the relationship between NDVI and the runoff curve index [8] for all catchment areas and 4 different soil types.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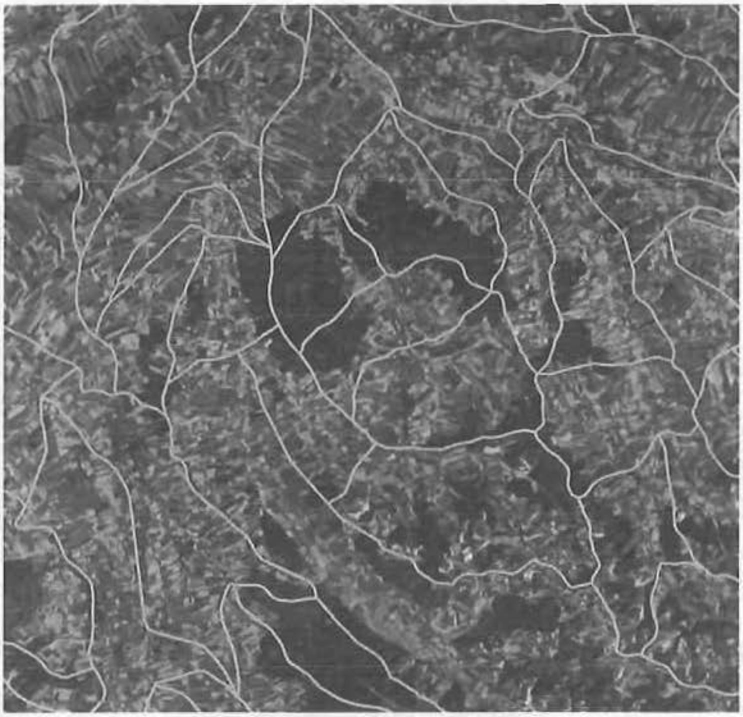

Fig. 4: LANDSAT TM image (band 4, near infrared) with borders of catchment areas superimposed

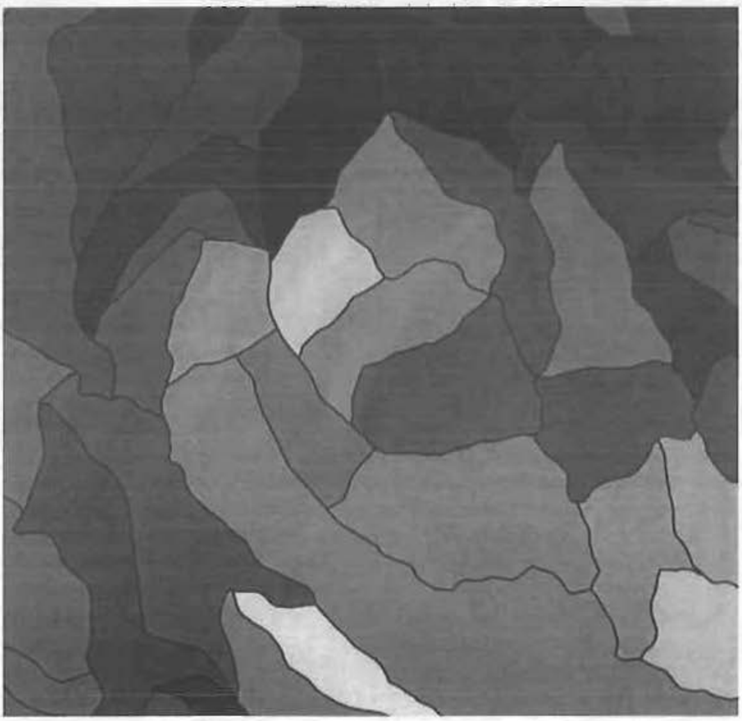

Fig. 5: Mean NDVI within the catchment areas

6. Agricultural land use mapping

For the purpose of agricultural statistics and administration, the relationship between land ownership and land use as derived from satellite data is required. The following analysis modules which are being developed at IVFL can serve to accomplish this task.

Image data and cadastral data must be registered to each other. For standard satellite image data (e.g LANDSAT TM with a resolution of 30m x 30m) subpixel accuracy is required which can hardly be attained by conventional methods of image registration due to the following problems:

- A large number of control points of high accuracy is necessary which are difficult to find in the image automatically.
- High subpixel accuracy cannot be attained for image data geometrically preprocessed with nearest neighbour resampling.
- If the terrain is not flat, a digital elevation model is required causing additional problems of availability and costs.

Thus, spatial subpixel analysis [11] is applied to the image to obtain subpixel resolution. This method benefits from the knowledge that fields are typically homogeneous regions with straight line borders. In the preprocessed image lines representing the (visible) field borders are extracted. Fig. 7 shows a LANDSAT TM image resampled after subpixel analysis (new pixel size 10m x 10m) with the cadastral borders superim-

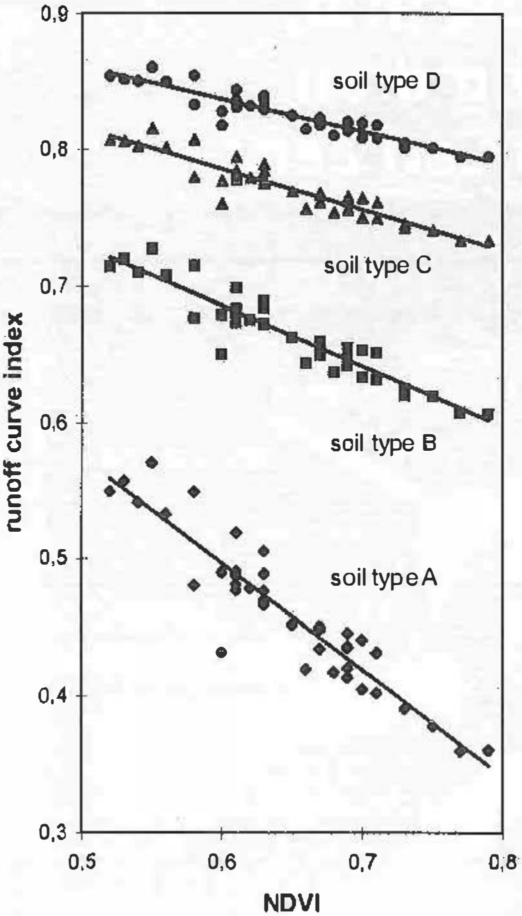

Fig. 6: Relationship between NDVI and runoff curve index for 4 different soil types

posed in black and the extracted image lines in white.

In the next step, the field borders and the cadastral borders have to be matched. In this process, one has to take into account some differences between these data sets:

- Several crop types on one farmer's land result in the appearance of additional image lines which do not have corresponding cadastral lines.
- The same crop type on neighbouring fields might cause that some field borders are not detectable on the image.

Consequently, the applied matching algorithm must be robust against additional and missing lines in both data sets. Additionally, it must be able to match the long and perfect cadaster lines to the imperfect image lines. The latter can have small relative shifts due to noise, can be broken into short segments or partially missing, e.g. near corners. The identification of perceptual lines [3] can help to eleviate the problem furthermore.

One matching method performed [3] uses the relaxation labeling method, the other [2] a special kind of representing and ordering lines. Good results are provided by both approaches at the cost of low efficiency as the matching includes a comparison of each image line with eaoh cadastral line. Using coarse knowledge about the relative orientation of Image and cadastre can be utilized for optimization by limiting the spatial search space.

Based on the achieved matching result the parameters for the registration can be determined.

7. Conclusions

Remote sensing has proven to be an important tool for applications in agriculture, forestry and water management. Due to the requirements for higher spatial resolution, aerial photos were the most widely used type of imagery for this purpose in the past. The situation Is changing now. Satellite images are being used to an increasing extent as a consequence of advances in sensor technology (improved spatial resoluti-

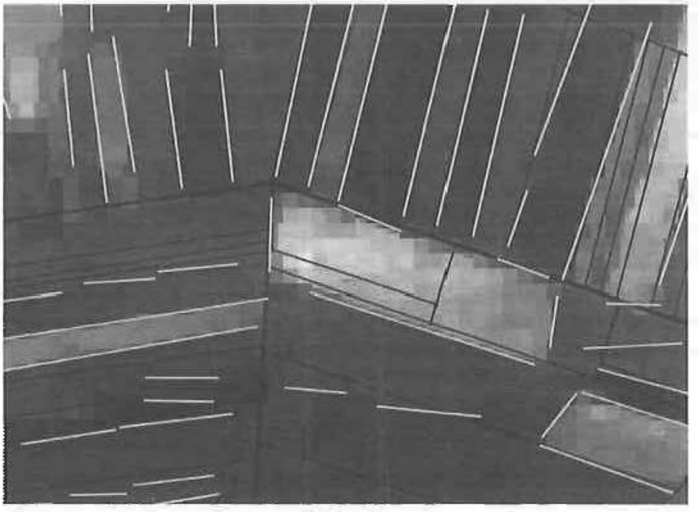

Fig. 7: LANDSAT TM image after subpixel resampling with pixel size 10m × 10m, cadstral borders in black, extracted image lines (visible field borders) in white

on) as well as new developments in the fields of image processing and computer vision.

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Von Kühen, Muren und Bäumen – Photogrammetrie einmal anders

Reinfried Mansberger, Wolfgang Kusché, Wolfgang Rieger, Wien

Zusammenfassung

Ein Forschungsschwerpunkt des Instituts für Vermessung, Fernerkundung und Landinformation an der Universität für Bodenkultur liegt in der Erfassung, Bearbeitung und Visualisierung thematischer Daten. Ausgewählte Beispiele, wie die „Pseudo-Echtfarb"-Visualisierung von Farb-Infrarot-Aufnahmen, die photogrammetrische Bestimmung von Individualdistanzen zwischen Rindern, die Bestimmung von Modellmuren-Oberflächen und die Erfassung und Analyse eines hochauflösenden Waldoberflächen-Modelles werden beschrieben.

Abstract

One focus of research activities of the Institute for Surveying, Remote Sensing and Land Information at the Universität für Bodenkultur (University for Agricultural Sciences, Vienna) lies in the acquisition, processing and visualization of thematic data. Selected examples, such as the pseudo-true-color visualization from colour infrared photographs, the photogrammetric measurement of individual distances between cattle, the acquisition of surfaces from debris flow models, and the capture and analysis of a high resolution digital forest-surface model will be described.

1. Einleitung

Die Aufgabenstellung eines Photogrammeters an einer naturwissenschaftlich – technischen Universität liegt – bedingt durch die Nähe zu ökologisch orientierten Instituten – vorrangig in der Entwicklung und Verbesserung von operationell einsetzbaren, effizienten Methoden zur Erfassung, Verarbeitung und Visualisierung raum-/zeitbezogener Umweltdaten. Die Effizienz des Verfahrens richtet sich sowohl auf die Wirtschaftlichkeit (Personal- und Geräteeinsatz) als auch auf die Datenerfassung mit ausreichender geometrischer und insbesonderer hoher thematischer Qualität.

Am Institut für Vermessung, Fernerkundung und Landinformation (neuer Name seit April