Mapping of Spatial Variability within a Field by Using Remote Sensing

Verone Wojtaszek, M.
Institute of Geoinformatics, Alba Regia Faculty of Engineering, Óbuda University, Székesfehérvár, Hungary
E-mail: wojtaszek.malgorzata@amk.uni-obuda.hu

Abstract
Precision agriculture is a farming management concept based on observing and measuring variability in a field. Data collections and analysis play important role in decision making. The essential purpose of precision agriculture is to more efficiently apply a farm's limited resources to gain optimum yield. The article focuses on applying remote sensing techniques in order to evaluate homogenous zones within a field based on mapping the condition of crops and the soil fertility status. Very high-resolution UAV images and satellite images (Sentinel 2) in conjunction with object-oriented image analysis have been used for mapping within-field variability. Using the eCognition software with object-oriented methods, not only the spectral information but also the shape, compactness and other parameters can be used to extract meaningful objects. The data extraction includes the following steps: data pre-processing, rule set development, multi-scale image segmentation, the definition of features used to map heterogeneity within field, classification based on rule set and results analysis. The author's own research results confirm the potential of object-based classification for mapping heterogeneities within the field. The methodology is suggested for crop monitoring and supporting decision making.

1. Introduction

One of the major challenges to world agriculture in the 21st century is how to produce enough food of sufficient quantity and quality to feed the growing world population. An increase of production will be needed to sustain an estimated global population growth from the current level of about 7 billion to 9 billion by 2050 (Cohen, 2003). Agricultural practices like excessive fertilization applied to increase production has led to significant harmful environmental consequences in terms of water pollution, greenhouse gas emissions and damage to our natural surroundings (Geiger et al., 2010 and Kleijn et al., 2011). The agriculture sector has to face this main challenge and produce more in a sustainable way. The way to address this is to apply science and new technology for possible solutions (Tilman et al., 2011).

Modern agriculture must rely on expert knowledge and implement new technology to enable farmers for profitable production while fulfilling environmental and food safety conditions. Over the last few decades, many new technologies have been developed and used to support agriculture production. Examples of these include: remote sensing techniques, positioning systems, such as the Global Navigation Satellite System (GNSS), proximal biomass and leaf area index determination from sensors placed on-board agricultural machinery, sensors to measure soil properties, and reliable devices to store and process data (Pierce and Novak, 1999). These new technologies produce a large amount of very high resolution information and can be applied to optimize field-level management. Taking into consideration intra and inter-field variability provides a great help in making decision and has led to the development of site-specific agricultural management that is often named Precision Agriculture (PA).

Precision agriculture technology is a farm management system, which relies on various measurements, data collections and analysis, as well as decision making. Precision agriculture methods promise to increase the quantity and quality of agricultural output while using less input (water, energy, fertilizers, pesticides, etc.). The aim is to save costs, reduce environmental impact and produce more and better food. Concepts of precision agriculture (or precision farming) are opposed to traditional practices where the various crop treatments, such as irrigation, application of fertilizers, pesticides and herbicides were evenly applied to the entire field, ignoring any variability within the field. During the traditional cultivation a large variation in mineralization in a given field resulted local overdose on rich soil or poorly fertilized on poor soil. Spatial thinking has a long tradition, both in scientific research and practice. Research and application concerning site-specific

Online ISSN 2673-0014/

agriculture was started in the USA in the early 1980s and spread all over the world at the varying pace. In Europe (in Hungary too) it first appeared in 1990s. But it is important to mention that there have been many researches that attracted attention decades ago for heterogeneity, spatial diversity of Hungarian production sites (Györffy, 2000). Furthermore research was initiated toward the site-specific measurement of grain yield and quality. Technical, technological and economical aspects of precision farming have been published by many authors (Berzsenyi-Györrfy, 1995, Németh et al., 2007 and Smuk et al., 2010).

The introduction of precision technologies in agriculture has been motivated by the high degree of variability of agro-ecological conditions within fields. One of the criterions for introducing precision agricultural technologies is the development of an up-to-date arable crop information system that provides information on soils, crop land cultivation, plant status, etc. This information can be used as starting data for cultivation, for predicting yield estimate. In order to set up such an information system, it is essential to use modern data gathering and analysis technologies. Remote sensing is the most effective tool for surveying the Earth's surface and tracking its changes. To more efficiently apply a farm's limited resources we need precise and frequent data about the condition of crops. Remote sensing offers a very efficient way of gather data over a large scale operation. UAV offers farmers the chance to get easy access to relevant information out of a large amount of high quality imageries. In this study different kind of remote sensing data (Sentinel and the professional mapping drone (eBee) was used to get information about soil and vegetation. The papers give an overview of the potential of utilizing an UAV for the characterization and monitoring of cultivated land. During the work the vegetation indices have been used to extract information from imagery. High and very high-resolution data in conjunction with object-oriented image analysis (OBIA) have been used for detection of variations in conditions within a field.

2. Data and Methods

2.1 Data Gathering

Recently, a new data gathering technology so called UAV (Unmanned Aerial Vehicles) has been released. The use of these lightweight aircraft, operated by a remote pilot or autonomously through programming, provides a fast, save and cheap means of collecting valuable data. Data collection via UAV is a beneficial service for the agricultural sector. It offers farmers the chance to get easy access to individual relevant information out of a large amount of high quality imagery. These systems, commonly known as drones, can be equipped with RGB, NIR, multispectral or hyperspectral cameras. During my work the professional mapping drone (eBee) has been used to capture high-resolution aerial photos. The eBee developed by senseFly is a fixed-wing UAV that weighs less than 0.70 kg, including the camera, and has a wingspan of 96 cm. Its cruising speed ranges from 40 to 90 km/h, which makes it suitable for mapping up to 12 km^2 (1200 ha) with a maximum flight time of 50 minutes.

In this study the RGB and NIR cameras were applied to capture imaging bands in the visible and the near-infrared range. The images were transformed into orthomosaics & 3D models by using a Postflight Terra 3D software. This data was then run through a special processing algorithm to create the vegetation index imagery like NDVI (Normalized Difference Vegetation Index), RVI (Ratio-based Vegetation Index). The vegetation indexes were used for documenting and assessing crop and vegetation conditions and health. The main phases of data gathering and analysis are available in Figure 1. In the 'Flight Planning' stage preliminary parameters of UAV flight were evaluated based on area covered by the test area, wind velocity, atmospheric conditions, etc. During the 'Flight Session' and the 'Ground Measurements' stages the flights took place and ground control point (GCP) measurements were done. In the stage 'Generating Ortho-Images, DSM and Point Clouds,' a semi-automated process was conducted. The main objective of this study was to evaluate the effectiveness of UAV in mapping vegetation conditions. OBIA and vegetation indexes based classification approach was used to map the crop.

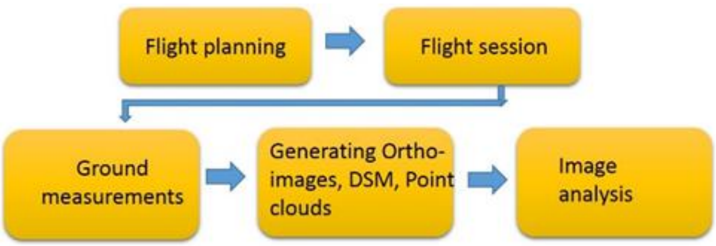

Figure 1: Study workflow

Satellite images were applied as additional data for soil condition determination within the field. According to the research results an optical and radiometric sensors have been able to measure soil physical and chemical properties including soil moisture content, organic and inorganic carbon content, electrical conductivity, pH, iron, etc. with promising results. The visible and near-infrared regions are most commonly used to infer soil properties (Ge et al., 2011). In this study Sentinel-2 data provided a tool for in-field soil property determination, identification of problems, mapping of productivity and homogenous zones. This information was used as input for selecting representative soil sampling points. The chemical and physical characteristics of the soil were analyzed in the laboratory based on site-specifically collected soil samples. Analysis of the samples is not the subject of this publication. The flight date was planned considering the growth stage of the crop. The first flight took place in December (pre-winter stage), the next two in February and April (before and after spring fertilization) (Table 1).

Table 1: The specification of remote sensing data

Datasets/Data Gathering	Spectral Resolution	Other Specification
Sentinal-2A/autumn, spring	visible/infrared (B2, B3, B4, B8)	Spatial resolution: 10 m
UAS Airborne photographs/autumn, spring	visible/infrared (RGB, NIR)	Spatial resolution: 3-6 cm

The research was carried out in two study areas with different crops, field geometries and background soils and topographical properties. The first test area covers 50 ha, it is situated in the middle of Hungary (Europe). The field is suitable for intensive agricultural production. The soils properties make this region attractive for various crops, including wheat, maize, oilseed rape and sunflowers. The second test area (10 ha) is situated in in the south-western part of Hungary close to Lake Balaton. It lies in hilly areas, despite the erosion problems, wheat and maize are grown in this region.

3. Image Processing

One of the main objectives of this study was to develop a methodology to map variations in conditions within a field from high spatial resolution images through object-based classification. Object base image analysis (OBIA) have been used for classification inside an agricultural field to detect lack of vegetation and map vegetation quality. The data extraction includes the following steps: data pre-processing, rule set development, multi-scale image segmentation, the definition of features used to map land use, classification based on rule set and accuracy evaluation. Using the eCognition software not only the spectral information but also the shape, compactness and other parameters can be employed to extract features required to create (map) homogenous zones. The object-oriented approach allows context consideration during the classification process.

Hierarchical framework (Figure 2) and the rule set (algorithms) were developed to get information about the status of the plants and identify problems with the crops. Additional data like satellite images and ground reference data were acquired during investigation. Sentinel data was used for mapping soil heterogeneity and identifying soil degradation problems within a field. The result of soil condition mapping was also directly linked to the lack of vegetation. Crop monitoring is the one of these applications since remote sensing provides us accurate, up-to-date and cost-effective information about the crop heterogeneity at the different temporal and spatial resolution. In this study classification was performed with different kind of vegetation indices. The rule set (algorithm) was developed to identify crop heterogeneity within field using the 3-6 cm spatial resolution UAV images. The process considered spectral value and spatial characteristics of objects and it included the following steps: segmentation, feature extraction and object classification. In this process, the images were segmented into homogeneous multi-pixel objects using the chessboard and multiresolution algorithm. The segmentation method is a process in which the image is subdivided into homogeneous objects on the basis of several parameters (band weights, scale, color, shape, smoothness and compactness) defined by the operator. Two levels of segmentation were used throughout the procedure: identification of study area (chessboard segmentation) and the second level to generate smaller objects for mapping crop conditions (Figure 2)

3.1 Feature Extraction

One of the critical steps in image analysis is to determine the most relevant features and algorithms to be used in classification (Blaschke, 2010). The eCognition works with objects, the image pixels are grouped together and, as a result, information of whole objects is available for example the spectral signature of all bands, the shape and size or context. All these attributes can be applied and combined for classification. Features usually define the upper and lower limits of a range measure of characteristics of image objects.

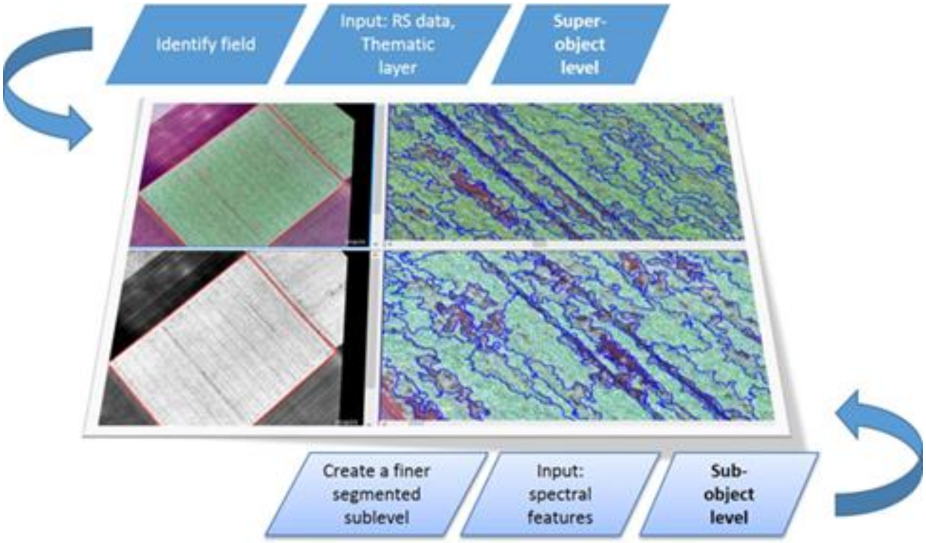

Figure 2: Hierarchical segmentation workflow

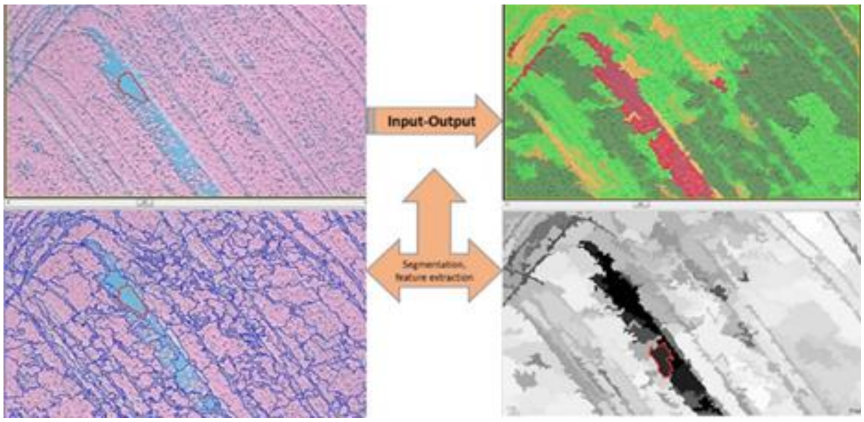

Figure 3: Image analysis: original image (subset), segmentation results, NDVI image and results of classification: yellow and red colour indicate lack of vegetation

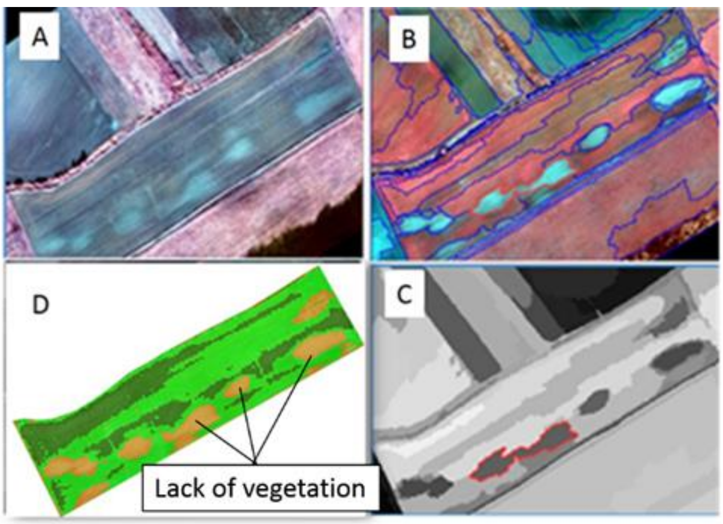

Figure 4: Effect of erosion on plant growing: winter wheat field in autumn (A) and spring (B). C:NDVI image, D: classification results (yellow color: lack of vegetation) (Verőné Wojtaszek, 2015)

Table 2: The results of classification

Classes	NDVI	Area %
Closed canopies_ 1 (higher VI)	> 0,3	39
Closed canopies_ 2 (lower VI)	0,1 – 0, 3	47
Mixed area /open canopies	-0,1 – 0,1	8
Lock of vegetation	< -0,1	6

Image objects within the defined limits are assigned to a specific class, while those outside of the feature range are assigned to a different class (or left unclassified). The following list of features was used during the classification process:

- Color: mean and standard deviation of each band, band ratios (NDVI, RVI,..)
- Size: area, length to width ratio, relative border length
- Relation to neighbour (class level).

3.2 Rule set Based Classification

The classification of study areas was done in two levels. In the first one the study field was identified by usage of thematic layer. In the second level thematic categories were determined by taking advantage of spectral properties of image. In this process indexes and other features were created and used to select vegetation and no-vegetation (lack of vegetation) and to investigate quality fluctuation of vegetation (Figure 3, Table 2). The classification results can be used to determined management zones to get an optimal amount for each input in crop production, founded on variability of soil characteristics and the other factors conditioning a crop yield. In this case, we define locations within field with the same or very similar conditions for crop planting. The figure below (Figure 4) shows the effect of erosion on plant growing (winter wheat field in autumn and spring). As wheat evolves, it is increasingly marked difference between the eroded area and the area not affected by erosion.

The information about the vegetation will influence the use of economic resources. Drone images can provide needed information for differentiated fertilization, chemical treatments, which are very important in terms of environment and cost. Computing the right amount of resources reduce the expenditures. The differential use of supplies balances the yield. Due to the information getting from drone pictures the agricultural waste decreases, the revenues thru the additional product increase and the level of inventory can be minimized. The operation and maintenance cost of the machines can be reduced because they are used only on the necessary areas what are indicated by the images.

4. Conclusion

Drones can help farmers catch problems faster and react more quickly, which can save money in crop losses per field. The data generated by drones can give more accurate and detailed picture of how the crops are reacting to the management strategies, which can lead to more effective use of resources. By using the precise drone data the farmers can calculate the company efficiency based on the accounting information. This contributes to the efficient land management and farming. The reduced resources and increased productivity can optimize the use of the agricultural land. Spectral indices derived from satellite data are widely used for land cover change research. They can reduce the data volume for analysis and provide combined information that is more strongly related to changes than any single band. Vegetation indices use various combinations of multi-spectral satellite data to produce single images representing the amount of vegetation present, or vegetation vigor. Low index values (Table 2) usually indicate little healthy vegetation while high values indicate much healthy vegetation. Different indices have been developed to better model the actual amount of vegetation on the ground. In summary remote sensing data can be used effectively in the following cases (Verőné Wojtaszek and Körmendy , 2015 and Milics et al, 2018):

- Plant growing monitoring
- Monitoring Crop Status
- Identification of problems (lack of sowing, cultivation problems, pests, ..)
- Identifying stressed plants
- Variable requirements for irrigation within one field
- Estimating plant population and future yield
- Identifying fertilization and pesticide requirements
- Mapping potential management zones within fields

References

Berzsenyi, Z. and Györrfy, B., 1995, Különböző Növénytermesztési Tényezők Hatása a Kukorica Termésére és Termésstabilitására. *Növénytermelés*, Vol. 44. 507-517.

Blaschke, T., 2010, Object Based Image Analysis for Remote Sensing. *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 65(1), 2-16, https://doi.org/10.1016/j.isprsjprs.-2009.06.004.

Cohen, J. E., 2003, Human Population: The next half century. *Science*, Vol. 302, 1172–1175. DOI: 10.1126/science.1088665

Ge, Y., Thomasson, J. A. and Sui, R., 2011, Remote Sensing of Soil Properties in Precision Agriculture. *Frontiers of Earth Science*. Vol. 5(3), 229-238. DOI 10.1007/s11707-011-0175-0

Geigera, F., Bengtsson, J., Berendse, F., Weisserc, W. W., Emmerson, M., Morales, M. B., Ceryngier. P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T., Bretagnolle, V., Plantegenest, M., Clement, L. W., Dennis, C., Palmer, C., Oñate, J. J., Guerrero, I., Hawrog, V., Aavik, T., Thiesi, C., Flohre, A, Hänke, S., Fischeri, C., Goedhart, P. W. and Inchausti, P., 2010, Persistent Negative Effects of Pesticides on Biodiversity and Biological Control Potential on European Farmland, *Basic and Applied Ecology*, Vol. 11(2), 97-105. https://doi.org/10.1016/j.baae.-2009.12.001.

Kleijn, D., Rundlöf, M., Scheper, J., Smith, G. H. and Tscharntke, T., 2011, Does Conservation On Farmland Contribute To Halting The Biodiversity Decline?. *Trends in Ecology & Evolution*, Vol. 26(9), 474-481. https://doi.org/10.1016/j.tree.2011.05.009

Milics, G., Smuk, N., Virág, I. and Néményi, M., 2018, *Precision Agriculture Technical Development for Sustainable Agriculture*. *Nemzti Tankönyvkiadó Budapest*. 231-240. ISBN 978-963-19-7352-5

Németh T., Neményi M., Háros Zs., 2007, *A precíziós mezőgazdaság módszertana*, edited by JATEPress-MTA TAKI, Szeged

Pierce, F. J. and Novak, P., 1999, Aspects of Precision Agriculture. *Advances in Agronomy*. Vol. 67, 1-85. https://doi.org/10.1016/S0065-2113(08)60513-1

Smuk N., Milics G., Neményi M., 2010, Jövedelemtérképek a precíziós növénytermelésben. *Gazdálkodás* 54. évfolyam, 2. szám. 176-181.

Tilman, D., Balzer, C., Hill, J., et al., 2011, Global Food Demand and the Sustainable Intensification of Agriculture. *Proceedings of the National Academy of Sciences*, Vol. 108(50), 20260-20264.

Verőné Wojtaszek M. and Körmendy, E., 2015 Távérzékelés Szerepe a Precíziós Mezőgazdaságban, Különös Tekintettel az UAV Felvételekre. *Remote Sensing*, Vol. 5(2), 426-430.

United Nations, Department of Economic and Social Affairs, Population Division, 2013, World Population Prospects: The 2012 Revision, Highlights and Advance Tables. *Working Paper* No. ESA/P/WP.228.https://population.un.org/-wpp/Publications/Files/WPP2012_HIGHLIGHTS.pdf