Weed Mapping Based on Integrated Remote Sensing Methods

Éva Lehoczky[1], János Tamás[2], Péter Riczu[2] and Miklós Herdon[3]

[1]Institute for Soil Sciences and Agricultural Chemistry, Centre for Agricultural Research, Hungarian Academy of Sciences, Herman Ottó str. 15. Budapest, Hungary, lehoczky@rissac.hu
[2]University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management, Institute of Water- and Environmental Management, Böszörményi str. 138. Debrecen, Hungary, tamas@agr.unideb.hu, riczu@agr.unideb.hu
[3]University of Debrecen, Faculty of Applied Economics and Rural Development, Institute of Economic Analytical Methodology and Applied Informatics, Böszörményi str. 138. Debrecen, Hungary, herdon@agr.unideb.hu

ABSTRACT

It is well known that weeds compete with the cultivated plant for the nutrient and water, thus weed coverage could a great influence on the profitability of production. Accordingly, to define the distribution of weed patches is a very important task in precision agriculture. Some traditional and modern methods are available to scout weeds. To survey weed coverage on larger fields by traditional methods is often time consuming. Remote sensing instruments are effective tools to detect weeds in larger area and it is relatively cheaper than traditional way. Two new different techniques of the remote sensing technologies become known: the airborne laser scanning (ALS) and the hyperspectral imaging. From the hyperspectral data, vegetation indices can be calculated, which can help to segment weeds form the soil. In this paper, the writers present a method, where the airborne LIDAR and hyperspectral technique were integrated into a common geoinformatics environment. The test site was a one hectare arable field. Different surface coverage categories were defined by the hyperspectral image. Based on these classes, an n-dimensional classification algorithms were used to define the combination of weed coverage and the extent of biomass. Based on the laser scanning data set a 3D surface was created with runoff conditions. Determination of weed coverage is very important, while it could provide basic information for managing to pass the herbicides out in precision agriculture.

Keywords: Weed detection, remote sensing, hyperspectral imaging, LiDAR survey, NDVI, Hungary

1. INTRODUCTION

Growing weeds have some harmful effects in an arable land, which influence the suitable development of cultivated plants. One of the most common competitions is for available growth factors, such as water, nutrient, light, etc. (Lipecki, 2006). Weeds could cause various diseases (Meziere et al., 2013) in an agricultural field or a horticultural plantation and could cause significant yield mass and quality losses (van Heemst, 1985).
Distribution of weeds could be excessively heterogeneous (Nagy, 2004). The spatial distribution of weeds is important to apply appropriate site-specific weed management. Traditional

techniques for weed detection are time-consuming, difficult and not so effective (Wiles et al., 1993). Farmers used practically homogenous pesticide application to decrease the amount of weeds on a field by conventional weed control techniques (Clay and Johnson 1999; Nagy, 2004), but there are some weed detection techniques to develop variable rate application (Wells and Dollarhide 1998; Dammer and Wartenberg 2007; Mohammadzamani and Rashidi 2009).
Nowadays, some effective and quick methods are available to identify weed coverage on an agricultural field in real time. Active and passive remote sensing methods can acquire information about larger areas at the Earth’s surface without being in direct physical contact with the object or area. The basis of remote sensing is incoming electromagnetic radiation (EI) to the object. When the radiation incident upon the object’s surface, it is reflected (ER) by that surface, transmitted (ET) into the surface or absorbed (EA) by the surface. Thus, it could be established that the reflection, absorption and transmission are equal to the total incoming radiation on a given wavelength (Aggarwal, 2004). Most remote sensing systems are designed to collect reflected radiation (Short, 2011). Remote sensing is an effective tool for monitoring biomass production (Curran, 1981; Kale et al., 2002) and detect weeds (Medlin et al., 2000). Certain reflectance values in the electromagnetic radiation are useful to create vegetation indices, which correlate well with the changes in biomass (Silleos et al., 2006). Plants reflect the visible (VIS) band in a small compass, but in the near infrared (NIR) band, the reflectance increases depend on the chlorophyll content of leaves and changes proportionally to produced biomass (Tucker, 1979). Using the reflection of the RED (630-690 nm) and the NIR bands (760-900 nm), a plant’s green mass may be determined by the following equation:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Based on the number of spectral bands, multi and hyperspectral technologies were spread, which provides analyzing of the surface. Hyperspectral remote sensors collect image data simultaneously in dozens or hundreds of narrow, adjacent spectral bands (Smith, 2006). Thus, hyperspectral surveys could provide relatively more information that multispectral imaging (Tupin et al., 2014). Hyperspectral imagery is an effective tool to detect weed patches and species, which is shown by some researches. Yang and Everitt (2010) executed three case studies on the use of hyperspectral remote sensing for mapping invasive plant species.
Laser scanning is a new active remote sensing technology, which is useful to get spatial 3D information about the surface. In the case of LiDAR systems (Light Detection and Ranging), a laser light sweeps the object or the earth’s surface (Vosselman and Hans-Gerd 2010). Based on the reflected part of laser beam, laser scanners analyze the real-world or object environment to collect data on its shape and spatial expansion. The advantage of laser scanning is the fact that it can record huge numbers of points with high accuracy in a relatively short period of time (Lerma García et al. 2008). Results of surveying a high resolution so-called point cloud. Static and dynamic laser scanners are available to acquire information about the surface. Mobile laser scanners could collect information quicker and from relatively larger area, than terrestrial laser scanners. High laser point density provides to create high resolution DEM/DSM, so it could be mapping the surface roughness with the objects (trees, power lines, buildings, etc.) up to cm accuracy by appropriate post processing software (Means et al., 1999; Clode and Rottensteiner 2005; Forlani et al., 2006). Most laser scanners can record multiple reflection (echo) of the laser pulse (Wehr and Lohr 1999). These scanners have full waveform analysis and echo digitization

processing systems (Wagner et al., 2006). Based on the travel time of the reflected laser beam the echo digitization system analyze the form of the echo, thus ground and canopy levels could be separated from each other (Ullrich and Pfennigbauer 2011). Waveform analysis systems provide to record multiple echoes (Wagner et al., 2008) (Figure 1).

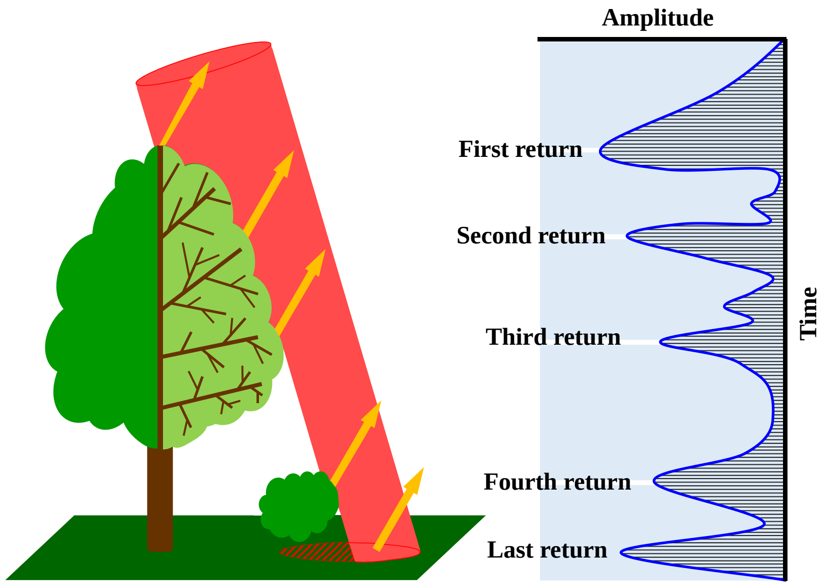

Figure 1. Multiple echoes and digitized waveform

Divergence of the emitted laser beam from the aerial vehicle is depend on the flight altitude and the wavelength of laser. Typical laser beam divergences vary between 0.3 and 2.7 mrad (Wehr, 2008). This means that spot diameters on ground between 21 cm and 189 cm are realized for a flying altitude of 700 m. Mapping weeds by ALS is less studied, but there are researches, which combines laser scanning with hyperspectral images (Asner et al., 2008; Jones et al., 2010).
In our study we elaborate the hyperspectral image classification, thus weed patches could be detected. Beside weed detection, high resolution ALS data provide to create DTM and establish surface runoff conditions on an arable land.

2. MATERIAL AND METHODS

In order to acquire spectral and LiDAR data, hyperspectral and laser scanning surveys were carried out within the frame of the ChangeHabitats 2 project. The flight areas were hilly areas around the city of Sopron (western part of Hungary). Our study area was a one hectare agricultural field, where weed coverage and terrain analysis were carried out.

2.1 Hyperspectral imaging

The hyperspectral data was acquired by AISA DUAL hyperspectral imaging system (Table 1). One of the most important parts of the hyperspectral sensors are the spectrographs, which dissolve the electric waves arrived through the optical rift with the help of prisms and optical screen. The hyperspectral sensor consists of one optic, one spectrograph and one digital cam. The two sensors are assemble in a house, therefore it is known ASIA DUAL system. The two cams can perceive in the visible wavelength, near infrared range and short wave infrared range.

AISA DUAL camera system has a so-called push-broom hyperspectral imagery sensor with fibre optic radiation meters (FODIS), which collect information about the incoming light. Thus, certain aerial corrections could be elaborated. The integrated GPS/INS sensor serves the positions (X, Y, Z) and momentary situation (pith, roll, yaw) of the airplane. In order to elaborate the radiometric and geometric correction, the collected hyperspectral data were processed in CaliGeo software package, under ENVI software environment.

Table 1. Technical information of ASIA DUAL hyperspectral system

	VNIR sensor (Eagle)	**SWIR sensor (Hawk)**	**AISA DUAL**
Spectral range	400-970 nm	970-2450 nm	400-2450 nm
Spectral resolution	244	254	498
Spectral sampling/px	2.3 nm	5.8 nm	
Spectral binning options	12	14	14
Spatial pixels	1024	320	320
Fore optics	18.04 mm	18.04 mm	
FOV	37.7 degrees	24 degrees	24 degrees
IFOV	0.037 degrees	0.075 degrees	0.075 degrees
Image rate	Up to 100 img/s	Up to 100 img/s	Up to 100 img/s

Image processing was carried out in ENVI 5.0 and GlobalMapper 15.0 software environments.

2.2 Airborne LiDAR data acquisition

In order to collect spatial information about surface and objects (trees, buildings, etc.) 3D LiDAR survey was carried out. The laser scanner was a RIEGL LMS-Q680i full waveform laser scanner, which have echo digitization. Laser pulse repetition rate of the scanner is 400 kHz. The surveyed area was approximately 90 km^2, which created by 22 flight stripes. The produced point cloud contained more than 530 million of points. The average point density of the surveyed is 9.83 pts/m^2. Due to the echo digitization, 7 return pulses (first, second, last, single, first-of-many, second-of-many, third-of-many, last-of-many returns) and 4 LiDAR point classes (unclassified, ground, medium vegetation, high vegetation) were identified. Raw point cloud of the LiDAR survey was processed in GlobalMapper 15.0, ENVI LiDAR 3.2 and Surfer 11 software.

3. RESULTS AND DISCUSSIONS

In order to process the hyperspectral image, Vegetation Delineation tool was used in ENVI 5.0. The test site was robust classification by this operation, while this tool identified the presence of vegetation and visualized the vigor levels of it. The tool categorized the area into 4 classes (no vegetation, sparse, moderate and dense vegetation) (Figure 2).

Figure 2. Result of Vegetation Delineation operation

Vegetation Delineation could not consider the effect of mixing pixels, but other sophisticated methods are useful to segregate noise in the data. We used a special processing workflow to elaborate hyperspectral pixel unmixing. Minimum Noise Fraction (MNF) Transformation is used to determine the inherent dimensionality of image data (Boardman and Kruse, 1994). MNF is a linear transformation, which chooses the unsuitable signal-to-noise ratio (SNR) and examine the eigenvalues. Higher data variance were indicated in the transformed band by larger eigenvalues and it may help indicate data dimensionality. The dimension of the data can indicate the number of intrinsic endmembers, which contained in the data set. From limited bands, Pixel Purity Index (PPI) reduced the number of pixels to analyze for determining endmembers. Based on the given endmembers, the investigated area was classified by the Spectral Angle Mapper (SAM) (Figure 3).

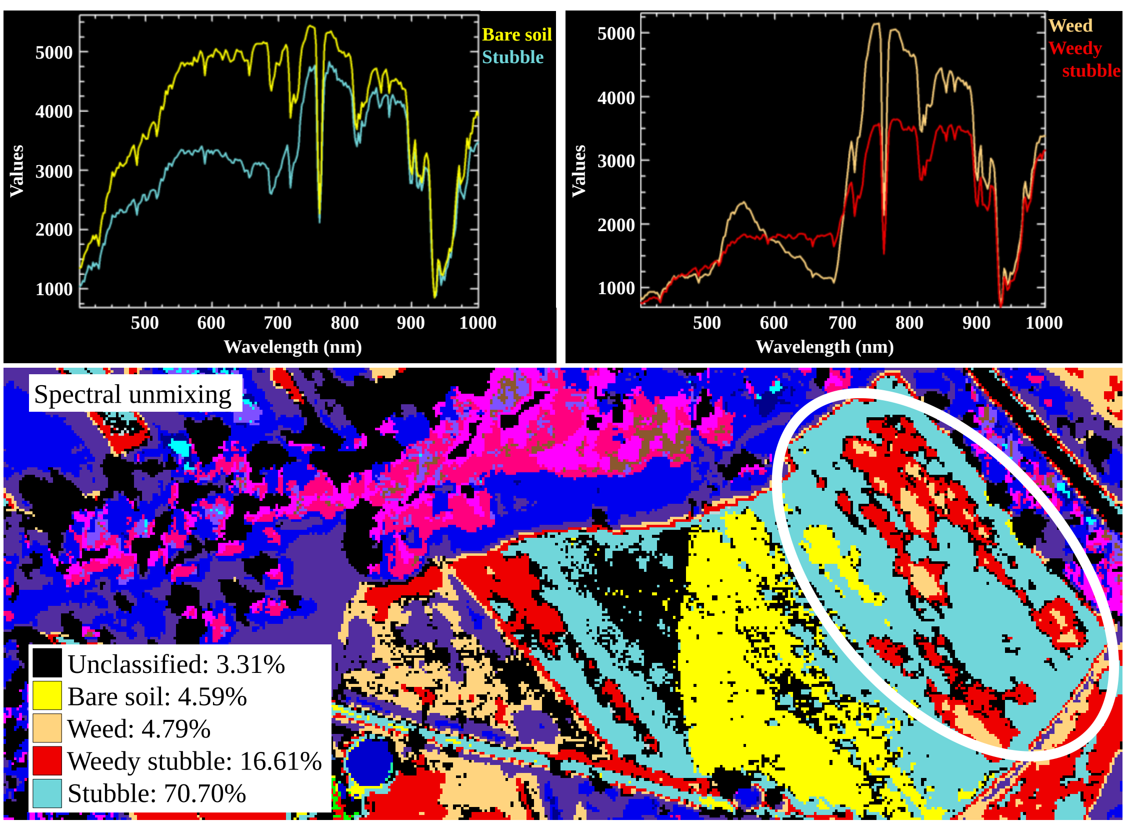

Figure 3. Classification result of MNF transformation and SAM method

Relief properties of the investigated area were examined by the high resolution airborne laser scanning system (Figure 4).

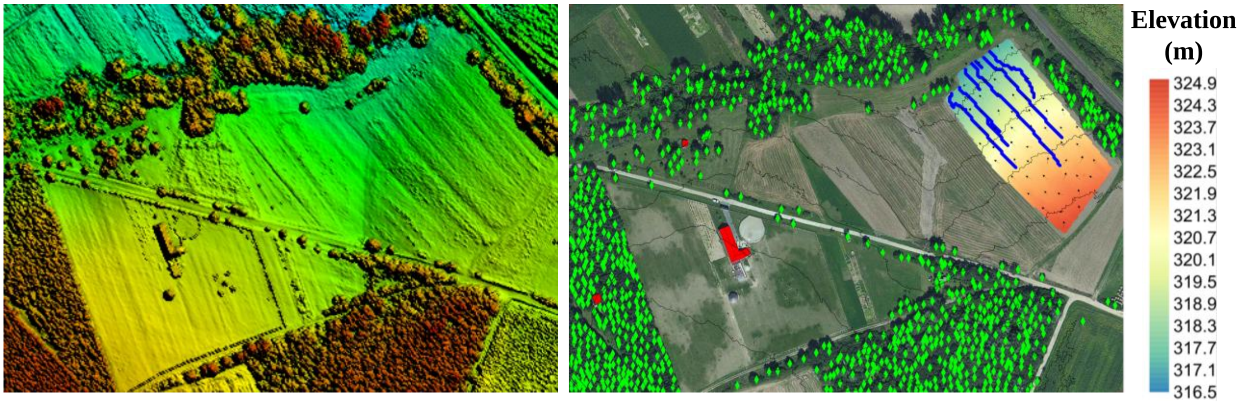

Figure 4. Surrounding area of the test site with relief and runoff conditions

Based on the ground points of pf the LiDAR survey a DEM was created. The height difference of the test site is ca. 8.5 m, with Northwest surface runoff. Due to the relative smaller height of weeds, the automatically classification of those was not possible, but the higher objects (trees and buildings) could have been separated from each other (Figure 5).

In order to distinguish weed species from the soil and each other, a higher resolution terrestrial LiDAR technology could provide more effective opportunities. Terrestrial laser scanners could be effective tool to determine not also the spatial distribution of weeds, but also structural properties of weeds.

Acknowledgement

Our researches were made in the frame of FP7 IAPP Marie Curie ChangeHabitats 2 project supported by European Union, which is gratefully acknowledged. This publication was supported by the OTKA project K 105789.

4. REFERENCES

Aggarwal S. 2004. Principles of Remote Sensing. [In. Sivakumar M. V. K., Roy P. S., Harsen K., Saha S. K. (eds.): Satellite Remote Sensing and GIS Applications in Agricultural Meteorology.] World Meteorological Organisation, Geneva. 23-38.

Asner, G. P., Knapp, D. E., Kennedy-Bowdoin, T., Jones, M. O., Martin, R. E., Boardman, J. and Hughes, R. F. 2008. Invasive species detection in Hawaiian rainforests using airborne imaging spectroscopy and LiDAR. Remote Sensing of Environment. 112 (5): 1942-1955.

Boardman J. W. and Kruse, F. A. 1994. Automated spectral analysis: A geologic example using AVIRIS data, north Grapevine Mountains, Nevada. [In. Proceedings of the Tenth Thematic Conference on Geologic Remote Sensing]. Environmental Research Institute of Michigan, Ann Arbor, MI, I-407-418.

Clay S. A. and Johnson G. 1999. Scouting for Weeds. Site-Specific Management Guidelines. SSMG-15. Potash and Phosphate Institute. Norcross, Georgia. 1-4.

Clode, S. and Rottensteiner, F. 2005. Classification of trees and powerlines from medium resolution airborne laserscanner data in urban environments. [In. Lovell, B. C. and Maeder, A. J. (eds): Proc. of APRS Workshop on Digital Image Computing. 190-196.

Curran, P. J. 1981. Multispectral remote sensing for estimation of biomass and productivity. [In.: Smith, H. (eds.): Plants and the Daylight Spectrum.] New York Academic Press 65-69.

Dammer, K. H. and Wartenberg, G. 2007. Sensor-based weed detection and application of variable herbicide rates in real time. Crop Protection. 26 (3): 270-277.

Forlani, G., Nardinocchi, C., Scaioni, M. and Zingaretti, P. 2006. Complete classification of raw LIDAR data and 3D reconstruction of buildings. Pattern Analysis and Applications. 8 (4): 357-374.

van Heemst H. D. J. 1985. The influence of weed competition on crop yield. Agricultural Systems. 18 (2): 81-93.

Jones, T. G., Coops, N. C. and Sharma, T. 2010. Assessing the utility of airborne hyperspectral and LiDAR data for species distribution mapping in the coastal Pacific Northwest. Remote Sensing of Environment. 114 (12): 2841-2852.

Kale, M. P., Singh, S. and Roy, P. S. 2002. Biomass and productivity estimation using aerospace data and Geographic Information System. Tropical Ecology. 43 (1): 123-136.

Lipecki J. 2006. Weeds in orchards – Pros and contras. Journal of Fruit and Ornamental Plant Research. 14 (3): 13-18.

Means, J. E., Acker, S. A., Harding, D. J., Blair, J. B., Lefsky, M. A., Cohen, W. B., Harmon, M. E. and McKee, W. A. 1999. Use of Large-Footprint Scanning Airborne Lidar to Estimate Forest Stand Characteristics in the Western Cascades of Oregon. Remote Sensing of Environment. 67 (3): 298-308.

Medlin, C. R., Shaw, D. R., Gerard, P. D. and LaMastus, F. E. 2000. Using remote sensing to detect weed infestations in Glycine max. Weed Science: May 2000, Vol. 48, No. 3, pp. 393-398.

Meziere D., Lucas P., Granger S. and Colbach N. 2013. Does Integrated Weed Management affect the risk of crop diseases? A simulation case study with blackgrass weed and take-all disease. European Journal of Agronomy. 47: 33-43.

Mohammadzamani D. and Rashidi M. 2009. Generating a digital management map for variable rate herbicide application using the global positioning system. ARPN Journal of Agricultural and Biological Science. 4 (3): 1-6.

Nagy S. 2004. Development of weed survey methods to planning precision weed control. Ph.D thesis. Mosonmagyaróvár, Hungary 222 p.

Short N. M. 2011, The Remote Sensing Tutorial. Available at: http://www.fas.org/irp/imint/docs/rst/Front/overview.html: Webpage visited: 16.06.2014.

Silleos, N. G., Alexandridis, T. K., Gitas, I. Z. and Perakis, K. 2006. Vegetation indices: Advances made in biomass estimation and vegetation monitoring in the last 30 years. Geocarto International. 21 (4): 21-28.

Smith, R. B. 2006. Introduction to Hyperspectral imaging with TNTmips®. MicroImages Tutorial Web site: http://www.iro.umontreal.ca/~mignotte/IFT6150/ComplementCours/HyperspectralImageryIntroduction.pdf Webpage visited: 11.01.2013. Lincoln, Nebraska. 24 p.

Tucker, C. J. 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. Remote Sensing of Environment. 8: 127-150.

Tupin, F., Inglada, J. and Nicolas, J.-M. 2014. Remote Sensing Imagery. John Willey & Sons and ISTE. 368 p.

Ullrich, A., and Pfennigbauer, M. 2011. Echo digitization and waveform analysis in airborne and terrestrial laser scanning. [In. Fritsch, D. (ed): Photogrammetric Week 2011. Stuttgart, Germany, 217-228.

Vosselman, G. and Hans-Gerd, M. 2010. Airborne and Terrestrial Laser Scanning. Whittles Publishing, CRC Press. Caitness. 320 p.

Wagner, W., Hollaus, M., Briese, C. and Ducic, V. 2008. 3D vegetation mapping using small-footprint full-waveform airborne laser scanners. International Journal of Remote Sensing. 29 (5): 1433-1452.

Wagner, W., Ullrich, A., Ducic, V., Melzer, T. and Studnicka, N. 2006. Gaussian decomposition and calibration of a novel small footprint full-waveform digitising airborne laser scanner. ISPRS Journal of Photogrammetry and Remote Sensing. 60 (2): 100-112.

Wehr, A. and Lohr, U. 1999. Airborne laser scanning: An introduction and overview. ISPRS Journal of Photogrammetry and Remote Sensing. 54 (2-3): 68–82.

Wehr, A. 2008. LiDAR Systems and Calibration. [In. Shan, J. and Toth, C. K. (eds): Topographic Laser Ranging and Scanning: Principles and Processing]. CRC Press. 129-172.

Wells K. L. and Dollarhide J. E. 1998. Precision Agriculture: The Effect of Variable Rate Fertilizer Application on Soil Test Values. Soil Science News & Views. 19 (6): 1-9.

Wiles L. J., Gold H. J. and Wilkerson G. G. 1993. Modeling the uncertainty of weed density estimates to improve post-emergence herbicide control decisions. Weed Research. 33 (3): 241-252.

Yang, C. and Everitt, J. H. 2010. Mapping three invasive weeds using airborne hyperspectral imagery. Ecological Informatics. 5 (5): 429-439.