2013 Conference June 23-27, 2013 TORINO, ITALY
EFITA WCCA CIGR
Sustainable Agriculture through ICT innovation

Surface condition determination of sugar beets for a harvester cleaning control system using a NIR hyperspectral imaging system

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ABSTRACT

Hyperspectral Imaging (HSI), also known as “Chemical Imaging” or “Spectroscopic Imaging”, is a powerful technique combining traditional imaging processing and spectroscopic analysis to attain as well spatial as spectral information of an object simultaneously. Caused by improvements in spectrograph technology, new developments in detector designs, reduced costs and better handling of the hard- and software this technique has become increasingly applied in agricultural processes. Thus the count of HSI implementations in agro-food science increases rapidly over the last ten years. The most applied processes of HSI are in field of the food production chain under indoor conditions - determining to quality control of vegetable, fruit, grain, meat and poultry products. In this paper the authors applied a near infrared HSI system for cleaning control of sugar beet directly on a harvesting machine on the field. This is a complete new challenge cause measuring under field conditions during the harvesting process. In this article the potential of this application of HSI for quality monitoring of the sugar beet harvesting process is presented and analyzed

Keywords: NIR hyperspectral imaging, sugar beet harvester, cleaning control system

1. INTRODUCTION

Due to global demands with respect to food, energy, environmental impacts, limited resources and climate changes agricultural processes and technologies have to be optimized with respect to high yield and low input (von Bruinsma, 2009, KTBL, 2009). Until the year 2050 the production of food has probably to be increased about 70 % to satisfy the demand of the world’s population (Cassmann, 2010). Computer sciences together with electronics and sensor technologies have thus become key technologies in agriculture (von Wunder *et al.*, 2012, von Ruckelshausen et al., 2009). The food industry and its different manufacturing sections are attempted to continue the automation of production technologies to be able to increase product quality as well as

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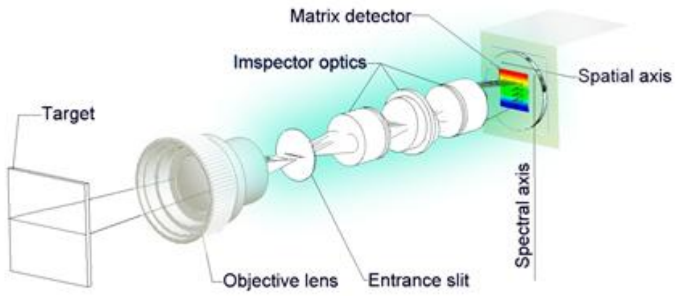
reducing costs. Part of the costs are caused by extensive use of manual work e.g. for visual inspection of quality parameters for sorting products or online adjustments at the process line. Technical innovations of sensor and system technologies offer opportunities for an automatic quality control - especially at the first section of food production chain: the harvesting on the field. This process has the strongest influence to all subsequent processes and therefore offers the highest potential for optimization effects. The measurement and rating of surface conditions at a sugar beet harvester has been identified as one of the well promising applications for further automation using sensor technology. Spectral imaging technology in the NIR waveband has been figured out by the authors as a promising sensor system for food quality analyses and sorting processes that also can be applied to harvesting processes.
The state-of-the art technology for quality and process control in agriculture and the food processing industries are vision systems typically based on traditional trichromatic (red-green-blue) or monochrome imaging. The camera data will be analyzed related to visual quality characteristics of objects such as size, shape, color and appearance (von Frosch *et al*., 2011). The main advantage of the HIS as compared to these standard vision systems is the measurement of a huge count of wavebands (often 200 and more) with a small bandwidth in a defined spectral range. By analyzing this amount of reflectance data precise information of chemical components of the measured object can be identified (Thiel *et al*., 2010, Curran, 1989 and Groell *et al*., 2006). Moreover all image processing feature are also possible by having the combination of the spectral measurement with the spectral information (Frosch *et al*., 2011). This offers a high potential especially for classification processes in quality determinations which results in a growing interest in hyperspectral imaging technologies for safety and quality assessments of agro-food products (Thiel *et al*., 2010).



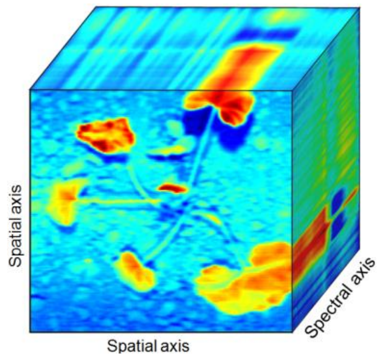


Figure 1. Schematic functional principle of the spectral imaging sensor system (left) (Thiel , *et al*., 2010); NIR hyper spectral data cube of a plant (right) (Thiel *et al*., 2012)

Vision systems in common are very sensitive to external environmental influences coming upon by the use outside on the field – e.g. changes in illumination caused by weather conditions or changes in dynamic properties of the measuring process. Also the HIS system has a strong sensitivity to ambient conditions. To be able to use this system at the field on a harvesting machine, a light shield around the measuring area for reducing ambient light influences has to be mounted. Also a special broadband illumination has to be installed for measuring the object reflectance with high frame rate. The high frame rate is necessary cause of the used push-broom HIS system, which is scanning the scene line by line.

2. MATERIAL AND METHODS

The push-broom hyperspectral imaging system, used for this research project, is a “Helios Core NIR” system developed by the company EVK DI Kerschhaggl GmbH. It consists of a spectrograph with its integrated optical dispersion device and an InGaAS camera detector. The system provides spectral data related to a spatial line in a spectral range from 960 nm to 1680 nm subdivided by sensor resolution of 252 spectral pixels (wavebands). Scanning a moving object line by line this data results in a three dimensional hyperspectral cube consists of two spatial and one spectral axis (fig. 1). For field tests the spectral system was applied to a sugar beet harvester Grimme Maxtron 620. This harvester has a lot of various adjustments for optimizing the cleaning process during the harvesting process. As state-of-art the sugar beets quality control and the hence derived cleaning settings have to be made manually by the harvester driver. Several experiments were performed at various outdoor conditions. The primary objective of the field tests was to determine the ratio of clean, dirty and damaged areas of sugar beets during the harvesting process. For experimental experience a special sensor module has been developed. This module consists of HSI sensor system "Helios Core NIR", an industrial color camera and four active light sources (halogen lamps) mounted in ambient light shielded aluminum frame on sugar beet harvester Maxtron 620 for the measurements on the field (fig. 2).

Figure 2. Grimme Maxtron 620 sugar beet harvester (left), developed HIS system implementation above the conveyor belt on the harvester machine (right)

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The industrial color camera was used for having reference data of the surface conditions of the sugar beets. Based on the color image data a manual classification has been performed which is defined as the reference value. These values have been correlated to the automated classification based on the spectral data from HSI sensor system. The measurements were taken under various intensity settings of the cleaning system on the harvesting machine - the minimum setting of cleaning (less damaged sugar beets and more contamination of soil), standard cleaning setting and high level of cleaning (more damaged sugar beets, less contamination of soil).

Beside dark current correction and white level balancing of the spectral raw data a special pre-processing procedure was performed to eliminate non-relevant and disturbing pixels generated by the reflectance of the background behind the focused area and the transport bars of the conveyor. The background pixels in common have low reflectance intensity at the whole NIR spectrum but especially at the lower wavebands (fig. 3, right). Based on this fact a fixed minimum threshold relating to the reflectance at 1050 nm was established to identify and remove background pixels from the region on interest. To identify and remove also the pixels influenced by the direct reflectance of the metallic conveyor bars, a additional fixed maximum threshold has been established. Cause of the general high reflectance of the bars, but especially at higher wavebands, this threshold was related to the reflectance at 1600 nm.

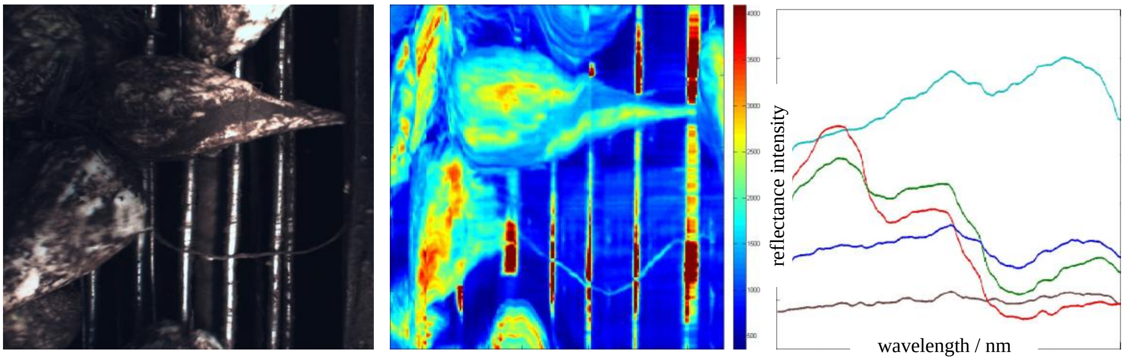

Figure 3. RGB color image for manual reference quality control of sugar beet (left); spectral image of the HIS system at 1200 nm wavelength (middle); typical reflectance characteristic in NIR waveband in range of 970 nm and 1680 nm: of conveyor bars {light blue}, damaged sugar beet {red}, normal sugar beet {green}, soil wasted sugar beet {dark blue} and background reflectance {brown}

For the automated classification of the measured spectral data of region of interest - the sugar beet - the "Spectral Angle Mapper" algorithm (SAM) was used. The SAM algorithm bases on a calculation of the spectral similarity of *n*-dimensional feature space which is formed by the *n* spectral channels (fig. 4). Therefore three spectral characteristics (SAM references) of different conditions (damaged, normal, and soil wasted) of the sugar beet were measured and stored in a data base. A multidimensional

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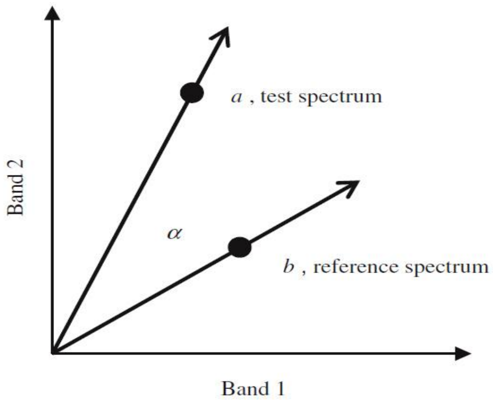
angle between each pixel-spectrum and the classification spectral was calculated by the SAM algorithm to describe the similarity.



$$\alpha = \cos^{-1}\left(\frac{\sum_{i=1}^{n} a_i b_i}{\sqrt{\sum_{i=1}^{n} a_i^2}\sqrt{\sum_{i=1}^{n} b_i^2}}\right)$$

n: count of spectral bands,
a: pixel spectrum,
b: SAM reference spectrum,
α: spectral angle

Figure 4. Scematic of the SAM algorithm for multidimensianal angle calculation (von Park *et al.*, 2007)

The reference data to the machine based analysis was determined manually by analyzing RGB image data (fig. 3, left). These images were analyzed by an experienced expert for adjusting the harvester cleaning system. This way the reference values of the percentile coverage of soil wasted, damaged and normal sugar beet surface have been determined.

3. RESULTS

The pre-processing procedure of eliminating unwanted pixels without any sugar beet information has been tested by data measured on the harvester at the harvesting process. Figure 4 shows the result of the two described filter procedures.

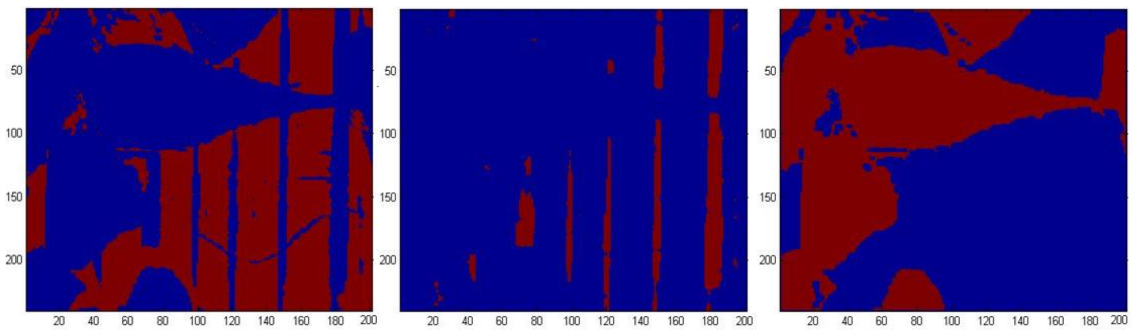


Figure 5. filter result of the minimum threshold at 1050 nm (left); filter result of the maximum threshold at 1600 nm (middle); final outcome of binary sugar beet material determination

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The left image of fig. 5 shows the result of filtering the background pixel behind the conveyor, the image in the middle shows the result of filtering the conveyor bar pixel. At the right image the final outcome after the filtering procedures is shown. The measured sugar beet material is presented in this binary image. These preselected areas are the base (regions of interest) for the surface condition classification.

Exemplarily two sugar beets having typical different surface conditions (fig. 6: A-soil wasted; B-damaged) have been measured and are presented in this paper.

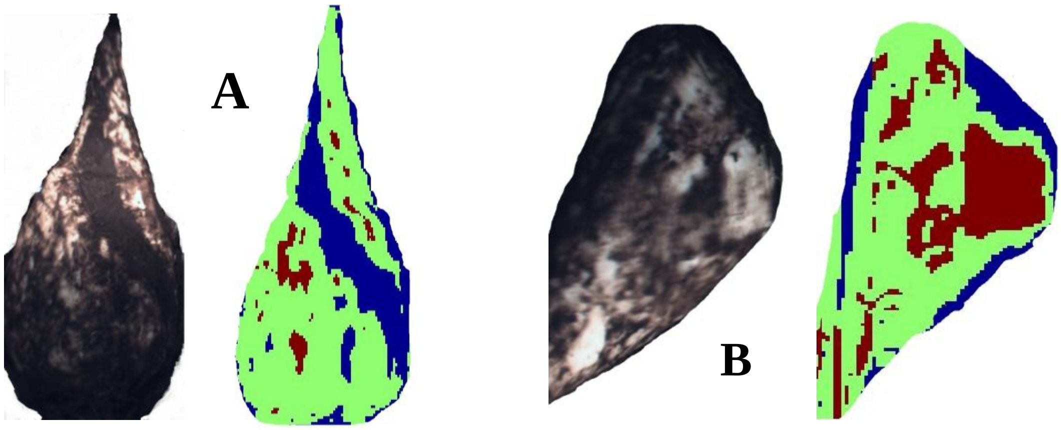

Figure 6. Comparison of two RGB images and the classified sugar beet surfaces by analyzing the HIS data performing the SAM algorithm (red=damaged, green=healthy, blue=soil wasted)

Table 1. Result of sugar beet surface classification – sugar beet “A”

Surface condition	Manual classification	SAM classification
soil wasted	18%	12%
healthy	77%	84%
damaged	5%	4%

Table 2. Result of sugar beet surface classification – sugar beet “B”

Surface condition	Manual classification	SAM classification
soil wasted	9%	7%
healthy	71%	78%
damaged	20%	15%

In figure 6 also the result of the SAM classification compared to the RGB-Image of two different sugar beets is shown. The different surface conditions areas are being clearly pointed out. Table 1 and table 2 shows the percentile proportion of the three classifications done manually by interpretation the RGB and the calculations realized by the SAM algorithm. The high compliance of these values confirms the potential of the spectral measurement for surface condition classification. The analysis of the hyperspectral data using the SAM algorithm offers a comfortable solution for classification.

4. CONCLUSIONS

A method to measure and filter the influence of the transport pipes and the background of the harvester machinery below the scanning area of the spectral system has been developed. Performing these filtering procedures the disturbing areas of the hyperspectral image could be removed from the measured data. Based on the field data different spectra of the sugar beet have been extracted and a database with reference values of three corresponding surface conditions (healthy, soil wasted, damaged) has been set up. By using the SAM algorithm a classification of the sugar beet surfaces has been realized. This automated classification results were compared to the manually classified RGB images. The results of the classification were in high accordance to the manual reference classification. The results showed, that the spectral reflectance measurement has a high potential for the objective of surface classification for e.g. quality control of sugar beet under field conditions to adjust clearing parameters of the harvesting machine.

5. ACKNOWLEGEMENTS

This work is a part of EU project "SmartBot" and is funded by EU Interreg (Region's EDR and Euregio)

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