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Development of a Near Infrared Sensor for Agricultural Machines

Based on common Near Infrared Spectroscopy (NIRS) systems for lab use, a sensor was developed, which can be employed in agricultural machines and for process control. First, basic lab tests were carried out to determine the suitability of several detectors for scanning constituents in organic materials. Next, various crops were calibrated and validated. Simultaneously various chemometrical methods could be investigated.

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Keywords

Sensor, NIR, constituent's measurement, agricultural machinery, quality control

Necessary improvements and automation of production processes in agriculture and the quality documentation of agricultural products and residues require a continuous detection of the constituents, both in stationary facilities and on mobile agricultural machines. As it is known, near infrared spectroscopy (NIRS) provides various opportunities for analysis of constituents in organic materials, but the current available NIRS-systems do not withstand the extreme conditions on agricultural machines. In addition, investigations revealed the following requirements [1, 2, 3, 4]:

- a suitable detector depending on the required accuracy
- mechanical and electrical interfaces for integration on agricultural machines (e.g. CAN-network) and for stationary use in labs, plants or conveying systems
- wear resistant surface of the measuring window for installation in the material flow
- wide temperature range for the measurements
- low number of necessary external black-/white – referencing
- integrated analysis unit in order to become independent from a PC
- robust calibration models for several crops and varieties

Surveys showed that currently no sensor is available, which fulfils these requirements. Therefore, the objective of a joint research project with Carl Zeiss MicroImaging GmbH was done to develop a sensor with the desired qualities.

Material and Methods

First, functional models have been built with available components. With them a decision should be made whether a silicon (Si)- or Indium-Gallium-Arsenide (InGaAs)– based detector would be working. Because the same sensor type should be used for various organic materials, diffuse reflection was deployed. The final test set up allowed not only to investigate the same sample in the harvesting machine but also in the lab. In the harvesting machine a sample was scanned only once, while in the lab it was done five times, whereas after each measurement the sample was repacked thoroughly. An average spectrum was calculated from the spectra collected during one measurement (5 s). Because the focus for this first stage was on moisture content detection the actual moisture contents have been determined with a drying oven (24 h drying time with a temperature of 105°C).

Before the processing of the gained spectra, they have been undertaken a visual inspection and all abnormal spectra have been manually removed from the data pool. The share of the deleted spectra was less than 2 %. All calibrations and validations have been carried out with the software package "The Unscrambler" (CAMO Corporation, Trondheim, Norway). For establishing the calibration models, partial least squares (PLS) – regressions have been used. Also, this software executed the data transformations and mathematical pre-treatments, which have be-

Fig. 1: "HarvestLabTM"-sensor mounted on a forage harvester and in stationary set-up

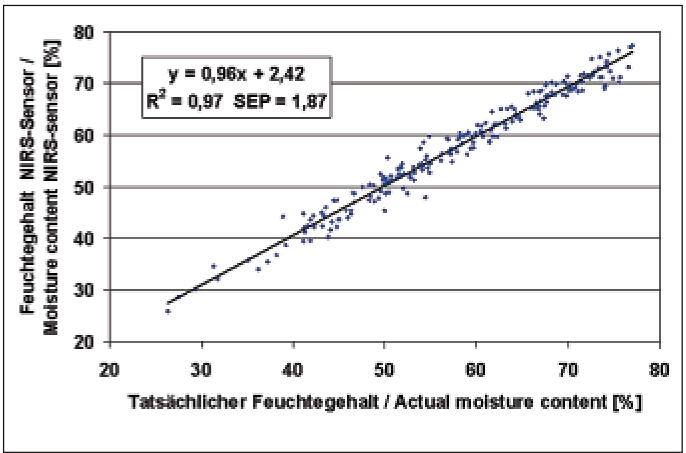

Fig. 2: Determined moisture contents for grass samples in 2005 and 2006 (static measurement; n = 210)

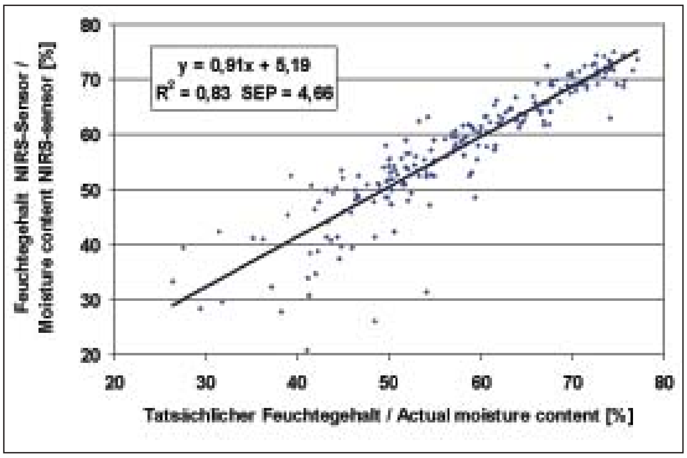

Fig. 3: Determined moisture contents for grass samples in 2005 and 2006 (mobile measurement on forage harvester; n = 210)

en necessary because the spectra are based on diffuse reflection. For evaluating the calibration models and the validations the coefficient of determination (R^2) and the standard error of cross validation (SECV) or the standard error of prediction (SEP) have been applied. At the same time the focus was on keeping the number of PLS-factors low in order to gain robust models.

Results

The basic investigations with the Si- and InGaAs – based detectors in stationary setup revealed a much higher accuracy in determining the moisture content for the InGaAs – based detector (*Table 1*).

For gaining the required accuracy, an InGaAs-detector with a wavelength range from 950 nm to 1530 nm and a resolution of 256 pixels was selected. With it the "HarvestLabTM" sensor was developed. It is robust enough to withstand the extreme conditions in field use and it performs an internal black-/white- referencing automatically. Therefore, the number of external referencing could be lowered to once per year or once per installation service. The circuit board of the sensor features 64 MB of memory, which is sufficient for storing software and multiple calibrations. The integrated processor converts the raw spectra into the moisture content value and provides it via the CAN - network. In addition, the sensor offers an Ethernet and a USB interface for data transfer. The sensor can be used both on agricultural machines and in stationary setup (Figure 1). Tempered steel in combination with a sapphire glass plate ensure the necessary wear resistance.

Conclusions on the achievable accuracy for moisture detection in field use can be drawn from *Figure 2*. It shows the results of a validation for data gained in stationary mode.

With a coefficient of determination of 0.97 and a SEP of 1.9 % the requirements are met. During pre-treatments these data passed a Kubelka-Munk transformation, a scatter light correction (standard normal variant) and a 2nd derivative. Among the multiple tested pre-treatment methods these combination provided in most cases the best results. Without pre-treatment the results of the above example degrade to 0.89 for R^2 and 3.3% for SEP.

Despite the highly unfavourable conditions for measurements, the sensor provides good results on a forage harvester (*Fig. 3*).

If the three obvious outliers are removed from the data pool then SEP decreases from 4.7 % down to even 3.8 %.

Type of detector	Wavelength range [nm]	Number of PLS*-factors	Coefficient of determination R^2	SECV** [%]
Crop: rape seed / number of samples: 390 / moisture range 6.4 - 21.0%				
Silicon	850 - 1050	5	0.987	0.442
InGaAs	1100 - 1600	3	0.994	0.290
Crop: alfalfa fresh / number of samples: 755 / moisture range 5.0 - 81.9%				
Type of detector	Wavelength range [nm]	Number of PLS*-factors	Coefficient of determination R^2	SECV** [%]
Silicon	800 - 1080	7	0.917	5.78
InGaAs	1000 - 1600	7	0.984	2.55

* Partial Least Square; ** Standard Error of Cross Validation

Table 1: Results from moisture measurements using different types of detectors (static measurement)

Conclusions

During the tests and the first year of serial production for a self propelled forage harvester the "HarvestLabTM" sensor has proven to fulfil all desired requirements. A key component for the use of NIRS technology is the adequate chemometric data processing method for the spectra data. For robust calibration models it is indispensable to collect sufficient representative spectra from different varieties, grown on different soils and with different degrees of ripeness.

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