Agro-sensor systems for outdoor plant phenotyping platforms in low and high density crop field plots

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1. Abstract

Sensors and the corresponding system technology are key components in the automated treatment of individual plants as well as for plant phenotyping in field trials. Based on varying dimensions of plant structures between different kinds of plants in combination with the spatial resolution of sensor systems, the authors introduce a differentiation between "high" and "low" density crop field plots related to the automated phenotyping process. Based on experiences in research and application of sensor systems in agriculture the authors are developing phenotyping platforms for both of the above mentioned categories. The multi-sensor-platform "BreedVision" specialized for "high density crop field plot"-phenotyping of Triticale (x Triticosecale Wittmack) and the autonomous phenotyping robot "BoniRob" as an example for "low density crop field plot"-phenotyping with a first field of application in maize.

The platforms use several different sensor systems for the detection of morphological and spectral signatures. In this paper two of them, light-curtain imaging and laser distance sensors with first outdoor measurement results, were described in detail.

2. Introduction

The permanently increasing world population (40% until the year 2050) and a cumulative reorientation of food pattern to a higher meat consumption in newly industrializing countries lead to a higher demand of agricultural products. To be in line with this growing demand the agricultural output has to be increased for about 70% up to the year 2050. About 90% of the progression in production has to be achieved by a raise of crop yield on areas which are already in use because the exploitation of arable land is limited. [1]

To obtain this increase of crop yields in the future the commitment of intelligent sensor systems becomes more and more important in the automation of the agricultural production process. The usage of intelligent sensors can lead to ecological and economical advantages, e.g. to an optimized use of fertilizer or herbicide in “day-to-day business” or to a reduction of breeding periods for optimized plant species in the field of seed breeding [2].

3. Plant phenotyping in low and high density crop field plots

Plant phenotyping is a complex challenge and is influenced by the dimensions of the plant structures or rather the spatial resolution of the sensor systems. In this context the authors differentiate between

- “low density crop field plots” (LDP) and
- “high density crop field plots” (HDP).

In LDP the plant coverage density is low and the dimension of plant structures in comparison to the spatial sensor resolution is high respectively. This fact enables the detection and redetection of individual plants. Maize, as an example for LDP with the sensors applied by the authors, allows the detection of each single plant and the cultivation in rows with typical intervals of 5-10cm between the plants offers the opportunity to redetect the plants in repeated measurements using RTK-DGPS [3]. This approach enables the automated monitoring of the individual growth stage history from every single plant. For LDP - phenotyping the authors are developing the autonomously navigating field robot “BoniRob” (Figure 1 left and [4]).

Figure 1 Sensor integration into the phenotyping-platforms “BoniRob”(left) and “BreedVision”

Plants having structures smaller than the spatial resolution of the applied sensors and with plant coverage densities which avoid a redetection of single plants with available instruments like the RTK-DGPS could be merged in the category of HDP. Triticale is an example for HDP with the sensors applied by the authors. In data processing of HDP more statistical algorithms are used. The results do not advert on single plants but on field divisions. As an example for HDP - phenotyping the authors are developing the multi-sensor-platform “BreedVision” (Figure 1 right).

4. Light-curtains and laser distance sensors for outdoor plant phenotyping

Even though there are several sensor systems used for the detection of morphological and spectral signatures like 3D-Time-of-flight cameras [5], spectral imaging systems [6], RGB-cameras, light-curtain imaging systems and optical distance sensors, this paper is focused on the presentation of light-curtain imaging and laser distance sensors.

Laser distance sensor: The distance determination is based on triangulation or on time-of-flight of a single laser beam. Due to this working principle the sensor is able to perform high measurement frequencies up to 1 kHz and reaches a satisfying performance concerning robustness during outdoor operations. Applying such a high frequency sensor from top view results e.g. in a high resolution height profile of the plants which can be used to predict the average plant height or as a statistical parameter to correlate with other morphological plant parameters of interest [7]. The application of laser distance sensors from side view can serve, in case of maize, e.g. as stalk detection of single plants and is useful to determine the stem thickness. Thus maize becomes a „low density crop field plot“, using this kind of sensor in combination with RTK-DGPS. The horizontal application in case of Triticale, or more generally in case of grain, delivers statistical parameters which can be correlated e.g. with the density of plant cover.

Light-curtain: The left part of Figure 2 shows the functional principle of light-curtains measuring maize.

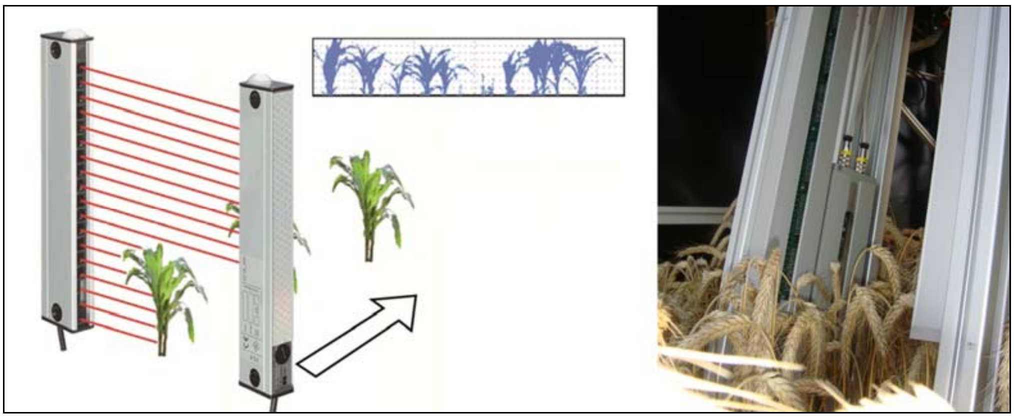

Figure 2 Light - curtain; left: functional principle; right: measuring crop

A light – curtain consists of stacked light barriers and delivers binary data of the height – profile from the measured object. The fastest available system on the market (Infrascan 5000 Series) reaches frame-rates about 300Hz (288 light – barriers; interspace of 2.5mm) which leads to a spatial resolution in horizontal direction of about 2mm (based on a scanning-speed of 0.5m/s). This spatial resolution allows e.g. a stalk detection of maize plants and thus, next to other sensors, it is supporting the detection of single plants. As a consequence the usage of fast light-curtains in combination with RTK-DGPS turns maize into the category of „low density crop field plots". In case of Triticale the spatial resolution is not high enough to detect the stalks of single plants with sufficient certainty. However the sensor is able to display the spikes of the plants and hence it is possible to get information e.g. about the average spike angle for a plant parcel with image analysing algorithms. Furthermore the data can give information about the plant height and the plant coverage density which are important characteristics, in combination with other sensors, for the prediction of plant biomass.

5. First outdoor measurement results and outlook

First systematic outdoor measurements were performed with the phenotyping-platform BreedVision at the regional office for seed breeding in Eckartsweier/Germany. The sensors monitored round about 1000 plant parcels (1.2m x 4m per parcel) with a high variation of plant parameters between the parcels to calibrate the sensor systems.

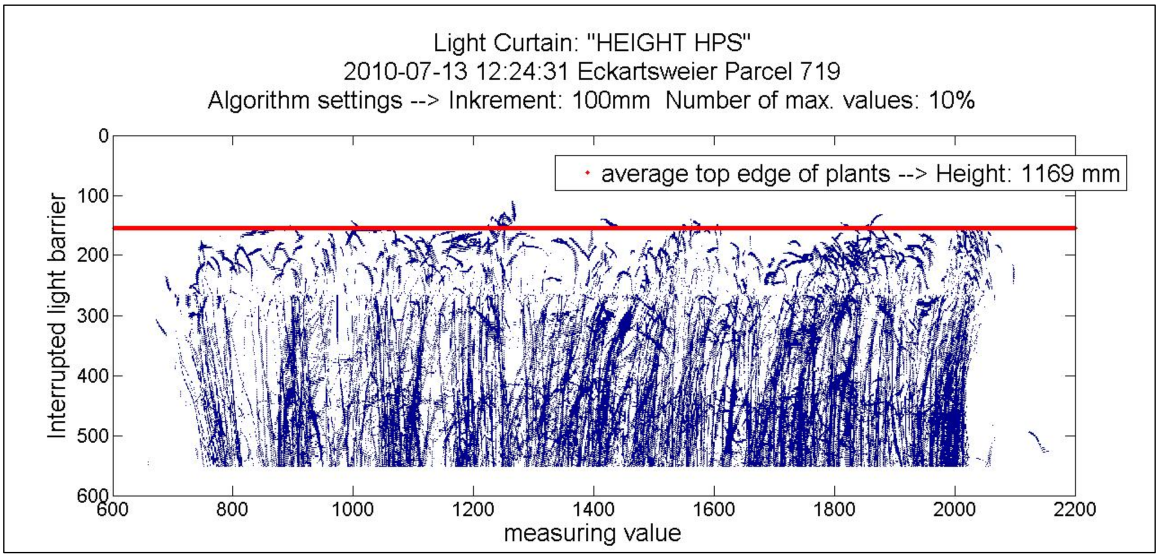

Figure 3 Height determination with light - curtain data of phenotyping platform BreedVision

As a first step of raw data reduction, the authors developed algorithms to calculate the averaged plant height of the parcels, one for the light-curtains and another for the distance sensor. In addition to the height determination the algorithms also create an image of the sensor data with the corresponding averaged height. This visualization of raw data, shown in

Figure 3 and Figure 4, combined with the visualization of the determined height is necessary to detect abnormities of data and thus for the optimization of the developed algorithms.

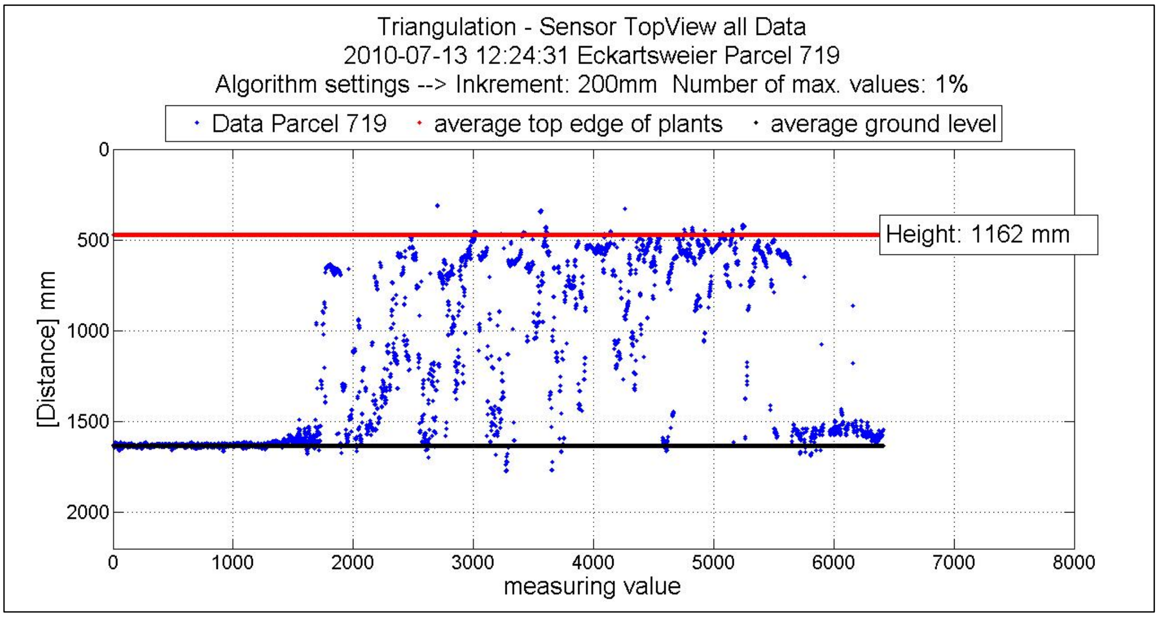

Figure 4 Determination of crop height with laser distance sensor from platform BreedVision

For the first evaluation of sensor selectivity concerning the determination of plant height, the authors analysed about 60 plant parcels of the calibration measurement data. The correlation between the plant height measured with the light-curtains and determined by the conventional manual method is shown in the following figure.

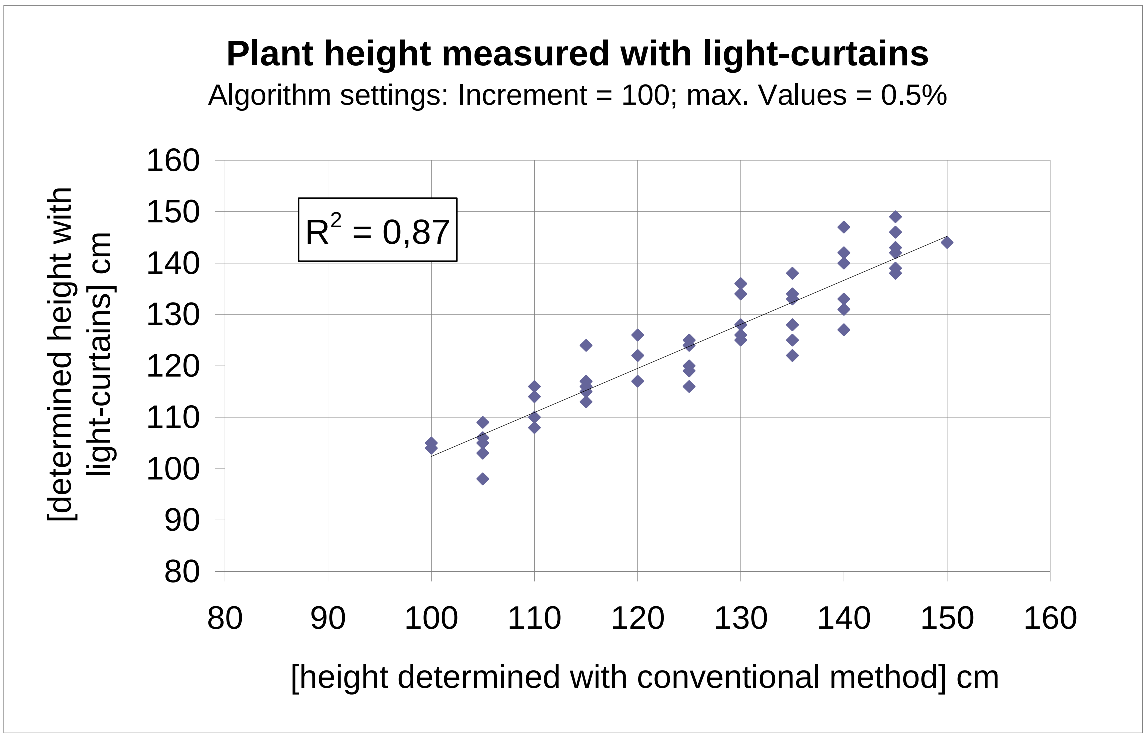

Figure 5 Correlation between light-curtain data and manual method

As a first result the light-curtains with a coefficient of determination of about 0.87 (Figure 5) show a higher selectivity as the distance sensor with a coefficient of about 0.75.

To summarize, phenotyping platforms with agro-sensor systems for "low" (LDP) and "high density crop field plots" (HDP) have been developed on a high level of technology with respect to sensors as well as system integration, software and mechanics. It turned out that the main difference between both concepts is founded in the goal of phenotyping output, depending on the dimensions of plant structures and the spatial resolution of the sensor systems. Whereas in LDP the phenotyping output is related to single plants, the output in HDP is related to field divisions, resulting in different approaches of algorithms to determine the plant parameters. Furthermore first outdoor measurements have been performed and first algorithms to determine the plant height were tested with real outdoor generated data-sets. The next steps will be the optimization of sensor fusion algorithms based on the calibration data sets and optimizations to increase platform robustness.

6. References

[1] Bruinsma, J: The Resource Outlook to 2050. Paper of FAO Expert Meeting, Rome 2009

[2] Peleman, J.D., Van der Voort, J.R.: Breeding by Design. TRENDS in Plant Science, Vol.8 No.7, July 2003, pp. 330 - 334

[3] Fender, F., Hanneken, M., In der Stroth, S., Kielhorn, A., Linz, A., Ruckelshausen, A.: „Sensor Fusion Meets GPS: Individual Plant detection". Proceedings of CIGR EurAgrEng/VDI-MEG, 2006

[4] Ruckelshausen, A., Biber, P., Dorna, M., Gremmes, H., Klose, R., Linz, A., Rahe, F., Resch, R., Thiel, M., Trautz, D., Weiss, U.: BoniRob – an autonomous field robot platform for individual plant phenotyping. JIAC, Wageningen, 2009

[5] Klose, R., Penlington, J., Ruckelshausen, A.: Usability study of 3D Time-of-Flight cameras for automatic plant phenotyping. Bornimer Agrartechnische Berichte, Heft 69, 2009

[6] Thiel, M., Rath, T., Ruckelshausen, A.: Plant moisture measurement in field trials based on NIR spectral imaging a feasibility study. CIGR Workshop, Budapest 2010 (to be published)

[7] Preckwinkel, J., Thösink, G., Linz, A., Marquering, J., Ruckelshausen, A.: Methode zur optoelektronischen Online-Bestandsdichtemessung in der teilflächenspezifischen Bewirtschaftung. Bornimer Agrartechnische Berichte, Heft 37, 2004, pp. 153- 158