ASSESSMENT OF A LASER SCANNER ON AGRICULTURAL MACHINERY

Detlef Ehlert, Michael Heisig, Rolf Adamek
Leibniz-Institute for Agricultural Engineering Potsdam-Bornim, Germany
dehlert@atb-potsdam.de, mheisig@atb-potsdam.de, radamek@atb-potsdam.de

Abstract. For industrial purposes and remote sensing, laser rangefinder scanners are wide established already. In the sector of agricultural machinery laser rangefinders are installed onto a few market available combine harvesters for detection of crop edges to optimise the cutting width and to perform auto guidance. A new laser rangefinder scanner (ibeo-ALASCA XT) was developed specifically for drivers' assistance and autonomous guiding in road vehicles. This sensor system was tested in 2008 and 2009 regarding the potential for agricultural engineering purposes. The tests were focussed on the assessment of measuring properties under field conditions. Strong functional correlations were found between crop biomass and mean heights of reflection points (crop height) in winter wheat (R^2=0.96) and maize (R^2=0.95). Furthermore, tram lines, crop stand edges and swaths were detected clearly to support the autonomous guidance of sprayers, spreaders and harvesting machines.

Keywords: crop production, sensors, laser scanner, environment detection.

Introduction

Looking on fundamental trends in agriculture, clear trends toward more precision, reduced environmental impacts and automation up to robots can be perceived. The technical realization of these trends is only possible with progresses in sensor development and their wide use for future agriculture. For industrial purposes and remote sensing, laser rangefinder scanners are wide established already, whereas the potential of laser rangefinders for agricultural applications was presented in first publications. In the sector of agricultural machinery, laser rangefinders are installed onto a few market available combine harvesters. The company CLAAS offers the "Laserpilot" for the Lexion series to detect the edge of crop stands for auto-guidance. This results in optimum cutting width and threshing performance. A similar solution "SmartSteer" can be found on CX combine harvesters from CASE-NEW HOLLAND. However, these laser rangefinder sensors are not able to detect specific crop stand parameters like crop biomass and swath volume for controlled ground speed and obstacles to avoid crashes. Today's market available laser rangefinders are very different in prices and performance parameters. Simple laser rangefinders cost less than 1000 € and airborne high end laser scanner systems are about up to 1 000 000 €.

There are potential detection objects in agriculture which can be used for supporting production processes in crop production (Figure 1).

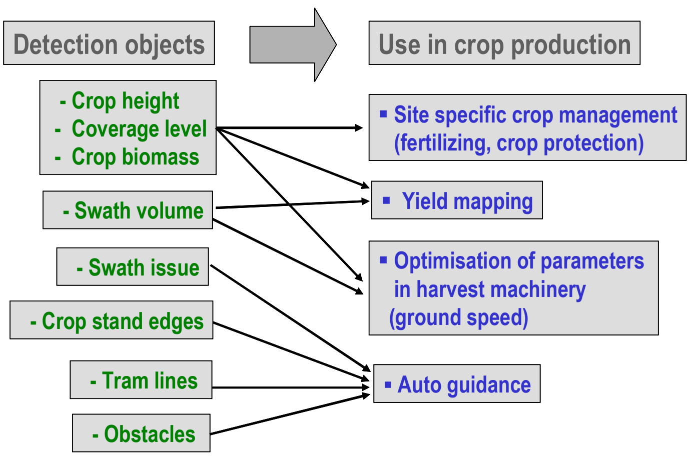

Fig. 1. **Detection objects and their use in crop production**

Crop height, leaf cover, and biomass are important parameters for the assessment of crop stands. Based on these parameters, expected crop yields can be appraised and the amount of fertilisers and pesticides for site-specific crop management can be optimised [1]. Moreover, during harvesting, process parameters on combine – as ground speed or the rotation speed of functional units (rasp-bar cylinder, cutter head) – can be adapted to crop conditions. Furthermore, autonomous guidance of agricultural machinery along tramlines and crop edges is of great interest to increase the machinery performance and to reduce the workload for the driver (auto guidance). For gathering these parameters, suitable sensors are needed with high robustness and at low cost. In the recent years, first research was carried out to investigate the potential of laser rangefinders for vehicle based measuring of physical properties in crop stands.

In the field of agricultural engineering research, market available low cost laser rangefinders were investigated. Ehsani and Lang [2] used a laser scanner to estimate the volume of geometric objects with defined shape (cylinders) and of soybean plants under laboratory conditions. The aim was to develop a method for measuring plant volume or biomass in order to monitor plant growth rate in the field at early growth stages. Quantitative relationships between laser scanner readings and crop biomass were not presented. Thösink et al. [3] made the first test to measure the height of oat plants. To calculate the crop height, the level of soil surface was discriminated from the distribution of height classes. In a comparative study Kirk et al. [4] estimated the canopy structure from laser range measurements and computer vision. Saeys et al. [5] modelled small crop stands and predicted crop plant density using two LIDAR sensors. Ehlert et al. [6] measured crop biomass density by laser triangulation and time-of-flight principles in oilseed rape, winter rye, winter wheat and grassland. For measuring ranges up to 2.50 m, high functional correlations were found between mean reflection height h_{Rmean} (m) – calculated from measured reflection range and sensor height – and fresh crop biomass FMD ($kg \cdot m^{-2}$). In oilseed rape, winter rye and winter wheat, the coefficient of determination for linear regression was more than 0.90 ($R^2 > 0.9$). Caused by varying plant species in grassland (pasture) the accuracy was lower.

In all literature cited from agriculture engineering research, the distance between the sensor and the crop or soil was mostly less then 3.5 m; and therefore, small strips were scanned. Agricultural spreaders and sprayers have working widths up to 36 m. To ensure a high representativeness of measurements, the scanned strip should be in an adequate relation. The same problem exists for scanning the area in front of harvesters, because the crop biomass, crop stand edges or obstacles must be detected in sufficient distance to adapt the speed above ground, to navigate the harvester or to stop the machine in time before contacting obstacles. To meet these demands, laser rangefinder sensors should measure up to 20 m with high reliability. Therefore, the objective of the paper was to find and to test a laser scanner for such purposes.

Materials and methods

Description of the laser scanner. Based on own experiences [6] and on analysis of market available laser rangefinders, a laser scanner – developed for automobile driver assistance (ibeo-ALASCA XT, Automobile Sensor GmbH, Hamburg, Germany) – was chosen (Table 1, Figure 2).

Table 1

Technical data of laser scanner ibeo-ALASCA XT (Time-of-flight-principle)

Measuring range	0.3-200 m
Wave length	905 nm
Scan frequency	12,5 Hz
Angle resolution	0.125˚/0.25˚/0.5˚
Voltage	12-15 V
Power requirement	20 W
Safety class	1
Length/ height /width	204/215/377 mm
Mass	ca. 3.0 kg

The ibeo-ALASCA XT laser scanner is an instrument based on LIDAR (LIght Detection And Ranging) technology measuring the pulses' time of flight. The built-in laser generates short rapid-fire pulses, which are transmitted by a tilted rotating mirror. The intensity of the reflected laser pulse is recorded by a photo diode inside the scanner. If the intensity is below a threshold, the measured value is discarded. The laser scanner transmits and analyses up to four echo pulses of different target distances over a period of one measurement pulse. That means that from a single pulse up to four individual echoes are recorded. Because of this, the crop stand can potentially be measured in the depth and interfering effects like raindrops or dust can be eliminated to a certain extent. Furthermore, the sensor measures in four layers which have an angle of divergence of 0.8° with respect to each other. A single beam has a divergence of 0.8° in vertical and 0.08° in horizontal direction (user's manual). The beam has the cross section area of 140 mm (height) x 14 mm (width) at a distance of 10 m. The layers are arranged on top of each other. With this structure the four layers together scan a band of 0.56 m in height in the range of 10 m.

Fig. 2. **Laser scanner (ibeo-ALASCA XT)**

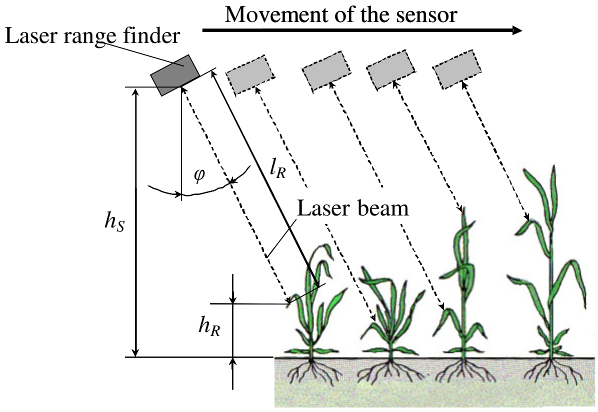

Fig. 3. **Measuring principle and parameters for calculation of reflection height h_R**

In our investigations the sensor worked with a rotation frequency of 12.5 Hz. From that the following scan angular resolutions results: 0.125° for scanning angle $\gamma < \pm16°$, 0.25° for $\gamma = \pm16°$ to ±60°, and 0.5° for $\gamma = \pm60°$ to ±90°.

During scanning, the laser beam rotates in a plane. The sensor does not deliver the measured range l_R and the corresponding scanning angle γ (polar coordinates) but Cartesian coordinates x and y. The coordinate of reflection point related to the sensor axis (scanning angle $\gamma = 0°$) is x and y is the lateral distance of the reflection point to the x-axis. The potential scanning width is determined by the sensor hardware, the inclination angle φ and the sensor height h_S (Figure 3). Furthermore, the scanning width can be adopted according to the measuring task by user software.

Modelling of crop stands. For laser scanner based modelling of crop stands, the basic vehicle was moved along of crop edges and tram lines. Because the laser scanner is mounted on a vehicle, the measured range l_R depends on the height of the laser scanner h_S above the ground and the inclination angle φ of the sensor. As shown in Figure 3, the measured range l_R is not suitable to describe crop stands in a plausible manner. Therefore, the mean height of reflection point h_R was calculated to improve the interpretation of the results. From the measured reflection distances and the adjusted inclination angle of the laser scanner, the reflection height for each reflection point was calculated according to formulae:

$$h_R = h_S - l_R \cos \varphi, \tag{1}$$

where h_R – height of the reflection point;
h_S – height of the laser scanner;
l_R – measured range;
φ – inclination angle of the sensor.

In our investigations crop stands from oil seed rape, winter wheat, winter rye, and maize were scanned. Based on the range measurements, spatial distributions (arrangements) of reflection height were calculated. Using a Geographic Information System (GIS, ArcView 3.2) crop stands were modelled.

Estimation of crop biomass. A basic vehicle (tractor, tool carrier) was used for estimation of crop biomass to simulate the typical conditions on agricultural machinery under field conditions. For measuring crop biomass in winter wheat and maize, the basic vehicle was positioned beside plots with varying crop biomass in the field (Figure 4). After scanning the individual plots, the biomass was harvested and weighted with a scale. Taking into account the harvested area, the specific crop biomass in $kg \cdot m^{-2}$ or $t \cdot ha^{-1}$ (crop biomass density) was calculated. In the second run, the harvested area with the stubbles was scanned for calculation of the reduction of mean reflection height. In the last step the crop biomass harvested and the reduction of mean reflection height was used for calculation of the quality of the functional relation between both parameters.

Results and discussion

Modelling of crop stands. Figure 5 demonstrates a small part of a plot with maize while harvesting with forage harvesters. Clearly the not yet harvested maize stand, the stubbles and also the row structure are reflected. Furthermore, the model demonstrates quantitatively the height of reflection points for assessment of the crop stand. Taking into account such information, a map for dimension of crop stand (yield map) can be generated. This information could be used also for ground speed control of a forage harvester in real time for optimization of harvested area. That means: in field zones with high biomass density the forage harvester could reduce the ground speed and in zones with sparse vegetation the ground speed could be increased automatically. This automatic ground speed adaption would result in a better productivity of the harvester. The same effects can be expected for combine harvesters.

Fig. 4. **Test setup for measuring crop biomass in maize**

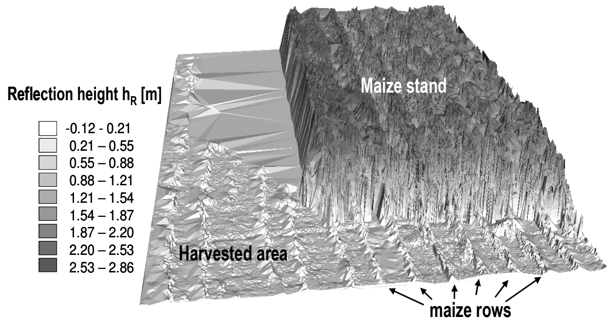

Fig. 5. **Modelled crop stand from maize**

Estimation of crop biomass. The calculations for functional relation between crop biomass are characterized by high coefficients of determination R^2=0.96 in winter wheat and R^2=0.95 in maize (Figure 6). Both functions have a progressive shape. This means that the biomass detection is more sensitive in early grow stages respectively for less biomass density. The opportunity of laser based estimation of crop biomass from mean reflection height can be also used – like modelling – for real time ground speed control of forage and combine harvesters.

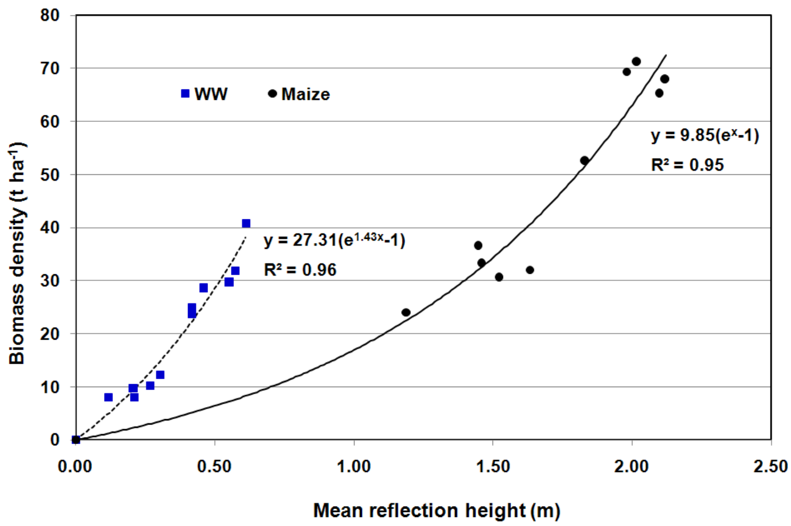

Fig. 6. **Functional relation between mean reflection height and crop biomass density in winter wheat and maize**

Conclusions

1. There are manifold geometric objects in crop production that can be used for site specific fertilization and crop protection, for yield mapping, for optimization of the process parameters on harvest machines and for auto-guidance.
2. Scientific investigation should give an answer whether laser scanners have the potential to detect these objects.
3. Laser scanners can be installed without problems on agricultural vehicles for environment detection.
4. Based on readings from a laser scanner, crop stands can be modelled, e.g., in winter wheat or maize.
5. Crop biomass can be detected (indirectly) from a laser scanner with a high accuracy $R^2 \leq 0.9$.
6. Further scientific investigations are necessary for acquiring more potential of use for laser scanners in agriculture.

Acknowledgement

We would like to thank Antje Giebel for her support in data analysis.

References

1. Ehlert D., Dammer K.H. Wide-scale testing of the Crop-Meter for site-specific farming. Precision Agriculture, 2006, vol. 7, No 2, pp. 101-115.
2. Ehsani R., Lang L. A sensor for rapid estimation of plant biomass. Proceedings of 6th International Conference on Precision Agriculture, July 14-17, 2002, Bloomington, MN, pp. 950-957. (on CD).
3. Thösink G., Preckwinkel J., Linz A., Ruckelshausen A., Marquering J. Optoelektronisches. Sensorsystem zur Messung der Pflanzenbestandesdichte (Optoelectronic sensor system for crop density measurement). Landtechnik, 2004, Nr. 2, S. pp. 78-79. (In German).
4. Kirk K., Thomson A., Anderson H.J. Estimation of canopy structure from laser range measurements and computer vision: A comparative study. Book of abstracts of International Conference on Agricultural Engineering, Leuven, Belgium, 2004, pp. 420-421.
5. Saeys W., Lenaerts B., Craessaerts G., De Baerdemaeker J. Estimation of the crop density of small grains using LiDAR sensors. Biosystems Engineering, 2009, vol. 102, No 1, pp. 22-30.
6. Ehlert D., Adamek R., Horn H.J. Laser rangefinder-based measuring of crop biomass under field conditions. Precision Agriculture, 2009, vol. 10, No 5, pp. 395-408.