APPLICATIONS OF A LASER SCANNER IN CROP PRODUCTION

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Abstract: *New laser rangefinder scanners were developed specifically for drivers' assistance and autonomous guiding in road vehicles. These sensor systems were tested in the past years regarding the potential for agricultural engineering purposes. In a first part of the paper a 2D laser rangefinder scanner was tested for detecting round bales on a harvested field from winter rye. In a second part the laser scanner was used for modelling crop stands and measuring crop biomass in winter wheat (R^2=0.96) and maize (R^2=0.95). In a third part, it was demonstrated that the height of the reflection point increased in a considerable manner depending on the detecting angle of the laser beam; resulting in an overestimation of crop height respectively of crop biomass.*

Keywords: LASER SCANNER, MEASUREMENTS, OBJECT POSITIONING, CROP STAND MODELLING, CROP BIOMASS, ERROR SOURCES

1. Introduction

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 1000000 €.

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

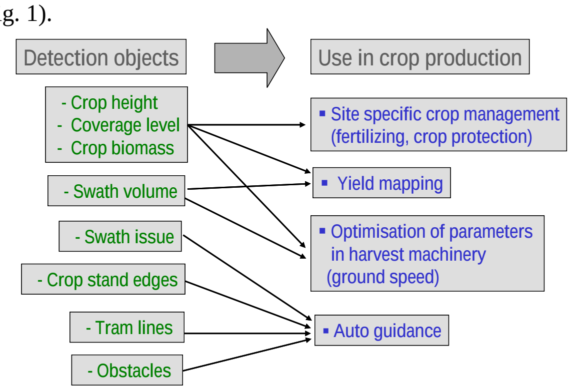

Fig. 1 *Detection objects and their use in crop production*

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. 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 are 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 (Thösink et al. 2004, Ehsani & Lang, 2002, Hosoi & Omasa, 2009, Kaizu & Noguchi, 2009, Saeys et al., 2009, Dworak et al, 2011). The objective of the paper was to demonstrate the suitability of a 2D laser scanner (Fig. 2) for detection of round bales, for measuring crop biomass and its specific measuring features.

Fig. 2 *Laser scanner ibeo ALASCA XT.*

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	12-15V –
- Power requirement	20 W
- Safety class	1
- Length/height/width	204/215/377 mm
- Mass	ca. 3.0 kg

2 Methods and Materials

2.1 Detection of round bales

Based on own experiences 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. In summer 2009, the laser scanner was mounted on a mast in front of a tractor (Fastrac) for scanning round bales (diameter 1.55 m, width 1.25 m) on a harvested field from winter rye (Ehlert et al. 2010). For positioning, a DGPS-antenna (Trimble AgGPS 132 receiver with Omnistar VBS correction service; position accuracy about 1 m) was installed on the roof of the tractor (Fig. 3). While tests, the tractor was moved with a ground speed of about 2.8 ms^{-1} between the bales at different courses. In our investigations the sensor worked with a rotation frequency of 12.5 Hz.

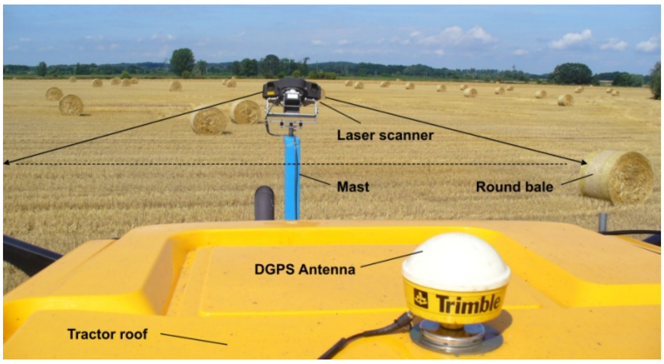

Fig. 3 *Test arrangement for bale scanning*

2.2 Measurement of crop stands

Mounting the laser scanner 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 (Fig. 4). The measured range l_R is not suitable to describe crop stands in a plausible manner.

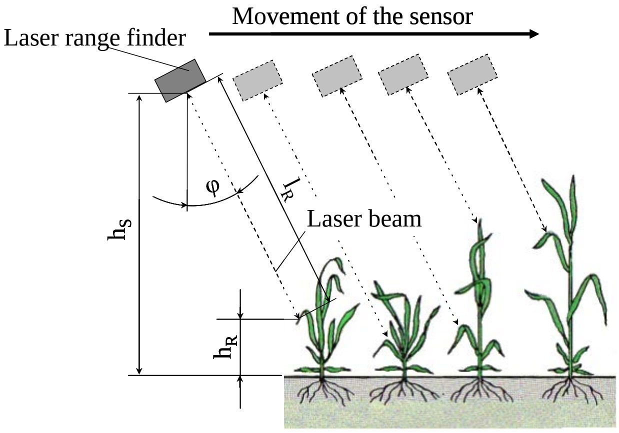

Fig. 4 *Measuring principle and parameters for calculation of reflection height (h_R).*

Therefore, the mean height of reflection point h_R was calculated to improve the interpretation of results. From measured reflection distances and the adjusted inclination angle of the laser scanner, the reflection height for each reflection point was calculated according formulae:

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

where, h_R - height of reflection point,

h_S - height of the laser scanner

l_R - measured range, φ - inclination angle of the sensor

For measuring crop biomass in winter wheat and maize, the basic vehicle was positioned beside plots with varying crop biomass in the field. 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 m^{-2} or t ha^{-1} (crop biomass density) was calculated. In a second run, the harvested area with the stubbles was scanned for calculation of the reduction of mean reflection height. In a 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.

2.3. Measuring behaviour of a laser scanner

In investigations performed under field conditions, it was recognized that the height of the reflection point for crop stand assessment depends on the beam parameters, reflection distance, and detecting angle of the sensor. It was observed that increased resulting angles α cause an increased mean height of the reflection points (Ehlert et al., 2013). This phenomenon indicates that farther crop plants generate higher reflection points, thereby resulting in an overestimation of the crop biomass. For crop sensing on agricultural machinery, this measuring behavior would be a relevant problem, e.g., in the variable rate application of agro-chemicals and process-optimized forage harvesters and combine harvesters.

In face of these unsolved problems, the objectives were as follows:

- To investigate the measuring properties of a chosen laser scanner depending on the inclination angle φ and scanning angle γ in crop stands.
- To analyze the error sources for vehicle-based laser scanner measurements in these crop stands.

In June 10, 2009, the scanner was tested along a plane transect (tramline) with a length of approximately 700 m in a field with winter rye (BBCH 85). Taking into account the arrangement on agricultural machinery, a specific mast construction was performed (Fig. 5).

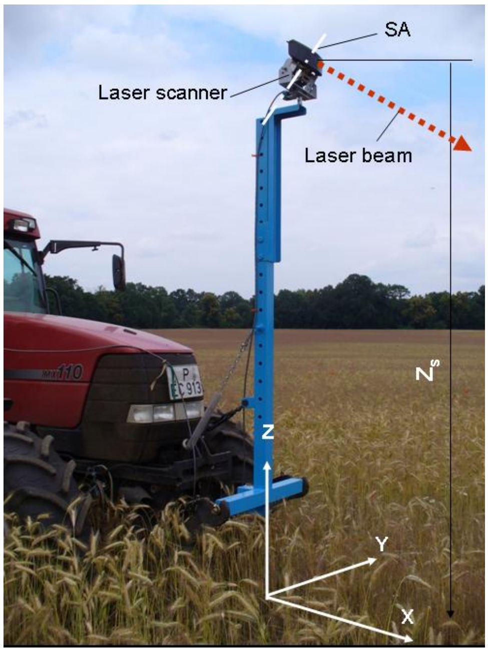

Fig. 5 *Test arrangement in the winter wheat field*

The sensor inclination angles were φ = 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, and 80°. The sensor was attached in a middle position of the tractor in a height of Z_S = 3.29 m, and the ground speed was approximately 2.6 ms^{-1}. To avoid other error sources resulting from mounting the sensor not precisely and due to asymmetric crop growth, the transect was passed in both directions.

In the test, a Differential Global Positioning System (DGPS) (Trimble AG132 [Trimble Navigation Limited, Sunnyvale, California, USA] with reference signal OmniSTAR VBS Germany; accuracy 1 m) was used for positioning.

The lag of the scanned area in relation to the DGPS antenna of the tractor, which resulted from different inclination angles φ, was compensated by a specific transformation program for coordinates produced in MatLab R2011b (The MathWorks, Inc., Natick, Massachusetts, USA).

Parameters (Fig. 6) of the transformation program were: The inclination angle φ, the scanning angle γ, the measured range l_R, the height of the scanner above the ground Z_S, the scanning frequency, the DGPS position, the update rate of the DGPS position, the offset between the GPS-antenna and the laser scanner, and the ground speed of the tractor.

During driving the tractor makes pitching, rolling, and yawing movements around a zero position. Related on short measuring times and ways, resulting errors can be relevant. Because the path length was 700 m for every inclination angle, the calculated tendencies are based on a long measuring time with millions of single points.

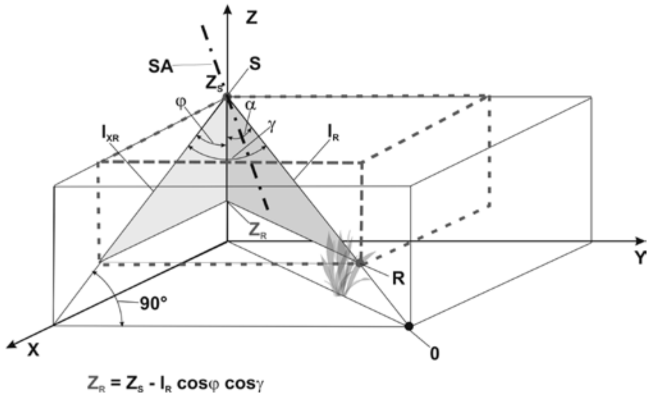

Fig. 6 *Space geometry of the laser beam*

3. Results

3.1. Detection of round bales

The assessment of position accuracy was based on 49 bales (Fig. 7). The laser scanner achieved different results in detecting; ranged from 0 up to 267 hits per bale.

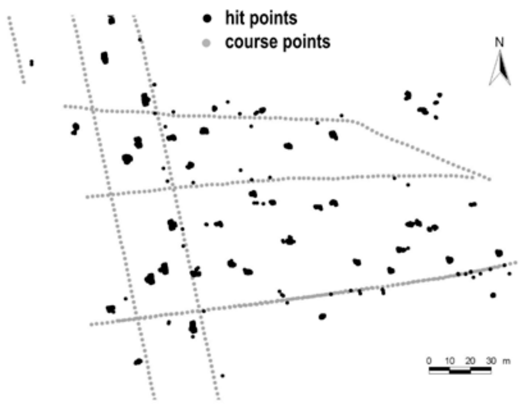

Fig. 7. Map of calculated hit points and course of the tractor

To assess the variance of hit points for each single bale, the definition of a bale related reference point was necessary. A first option was the calculation of the mean values for geographic x and y coordinates of the hit points for each bale; a second the median. A third option was to take into account the maximum and minimum value for bale coordinates for all single bales. The addition of maximum and minimum value divided by 2 resulted in a "space related midpoint (SRM)". As an example, the three options are presented in Fig. 8.

Taking into account the advantages and disadvantages of each option, the SRM method was chosen for further accuracy assessment. The mean value of distance difference between hit point positions on bale surface and SRM reference point was round about 1 m and the standard error was about 0.5 m. Taking into account that a bale has a geometric dimension of 1.55 m x 1.25 m, a sufficient accuracy of positioning can be stated for the method used.

All together, it was shown that the combination of DGPS position of an antenna on a basic vehicle and laser rangefinder readings can be used for generation of distribution maps for objects on agricultural areas (Fig. 7) The mean difference of hit points from round bales was about 1 m and the standard deviation 0.5 m. With that positioning accuracy the presented method is sufficient for object detection in agriculture. Gathered positions of objects could be used, e.g. for transport optimization to remove the bales. Furthermore, the object detection and monitoring could be used on sensitive areas, on areas with a high danger potential or on non agricultural areas. Further investigations are necessary to assess the whole potential of laser supported object detection in agriculture regarding kind of detection objects, type of laser scanner, mounting height on basic vehicle and inclination angle of the scanners.

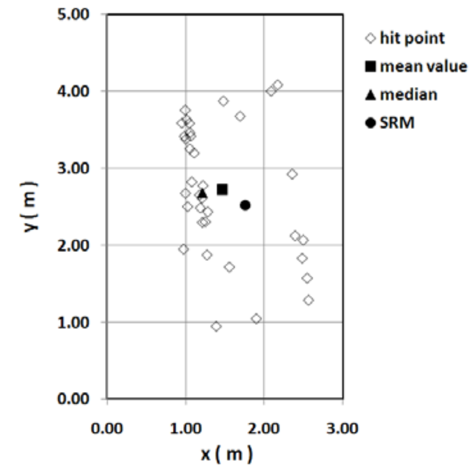

Fig. 8 *Example for hit points on a round bale and demonstration and three variants of reference points*

3.2 Measurement of crop stands

- Modelling of crop stands

Fig. 9 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.

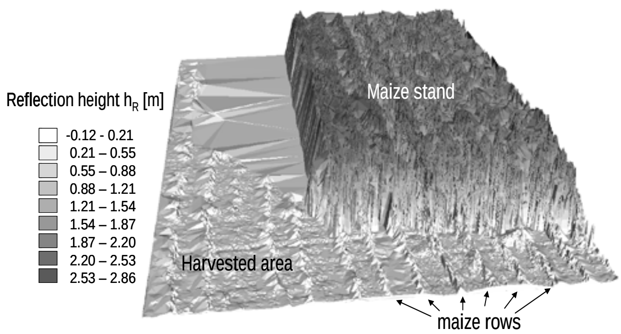

Fig. 9 *Modeled crop stand from maize*

- Calculation of crop biomass

The calculations for functional relation between crop biomass are characterized from high coefficients of determination R^2=0.96 in winter wheat and R^2=0.95 in maize (Fig. 10). 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.

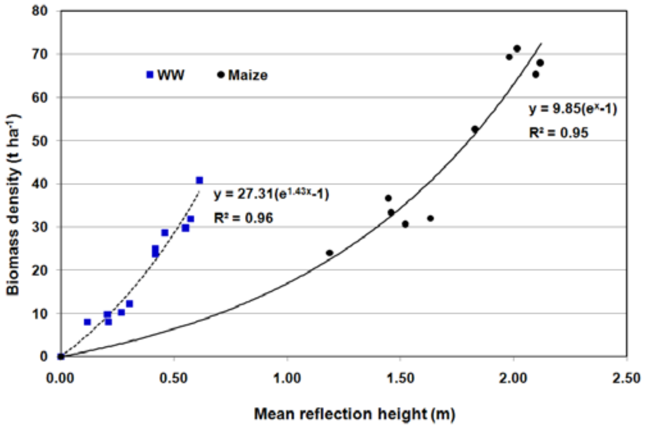

Fig. 10 *Functional relation between mean reflection height and crop biomass density in winter wheat and maize*

3.3 Measuring behaviour of the laser scanner

In test series in 2009, the readings of a strip from y = ± (2 - 5) m (strip length 0 m ≤ x ≤ 700 m) were employed by post processing software to determine how the reflection height depends on the inclination angle φ and the scanning angle γ in the winter rye. The readings of the strip y = ± (0 - 2) m were not taken into account because the tramlines would affect the assessment in an undue manner. The calculated reflection heights for single points in the strip y = ± (2 - 5) m are shown in Fig. 6. For each inclination angle all calculated heights of reflection points in the two strips of 3 m x 700 m are plotted (independent of the path position).

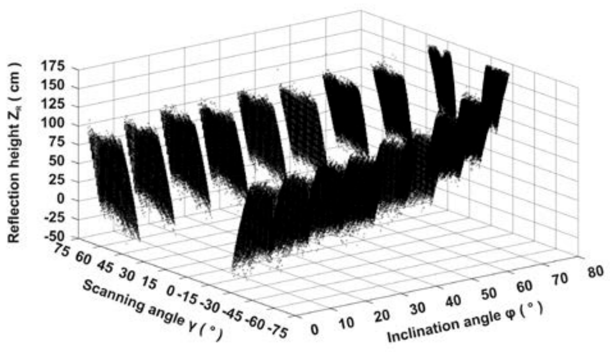

Fig. 11 *Calculated height of reflection points in winter rye for different inclination angles. (Strip size: 2 x [3 m x 700 m])*

Based on 4,792,655 readings shown in Fig. 11, a square regression (2) was calculated to demonstrate the basic trends of the reflection height Z_R depending on φ and γ.

The obtained fitting was:

$$Z_R = 27.92 + 1.76 \cdot \varphi + 41.88 \cdot \varphi^2 - 3.52 \cdot \gamma + 35.10 \cdot \gamma^2 \quad (2)$$

(R^2 = 0.634)

(Z_R in cm; φ and γ in rad)

To support the interpretation of equation (2), the result is also drawn as a 3-D representation (Fig. 12). According to Fig. 12, the reflection height increased significantly depending on the inclination angle φ and the scanning angle γ. There is a clear trend for higher inclination and scanning angles causing an increased mean height of the reflection points that apparently indicates more grown crop biomass.

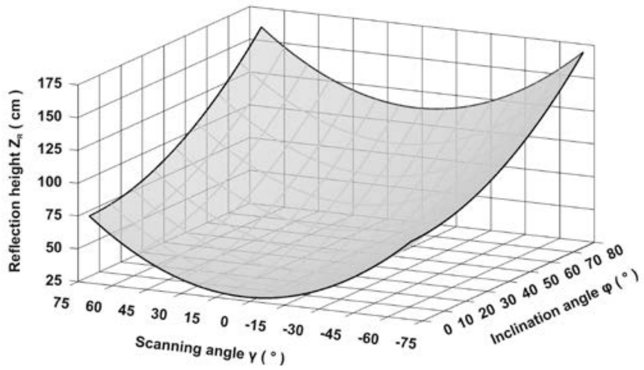

Fig. 12 *Reflection height Z_R depending on inclination angle φ and scanning angle γ in winter rye.*

4. Conclusions

It was shown that 2D laser scanners can be used in crop production for object detection, for modelling crop stands, and for efficient vehicle based estimating of crop biomass. Though, error sources should taken into account, e.g., that the readings depend on parameters like detection angle, distance, and beam divergence. It was demonstrated that the overestimation is low for small detection angles and high for increasing angles. Therefore, it can be concluded that for practical use of laser scanners on agricultural machinery high detection angles would be not useful. Furthermore, this conclusion is in accordance with the insight that the problem is increased by movements of the basic vehicle (pitching, rolling, and yawing) which would heighten the inaccuracies additionally.

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