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Measuring Properties of Laser Rangefinders

For laser rangefinders to representatively sense crops, the stands must be scanned with foresight and with a sufficient width. Measuring ranges must be greater than 2.5 m to accomplish this. Because laser beams have a device-specific cross section, which increases at higher distances, it can be expected that crops with filigree structure (e.g. cereal crops) will not be measured accurately. Repeated scans under identical conditions have shown that high repetitive accuracy was achieved even with larger distances.

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Precision Agriculture, laser rangefinder, measuring properties

Market available laser rangefinders use the measuring principles: light time-of-flight, phase modulation, interferometry and triangulation. In many cases the first three principles are summarised denominated as time-of-flight measurement. Triangulation sensors measure short ranges (maximum a few meters) with high accuracy while time-of-flight sensors are suitable for both short and far ranges.

Idealised a laser beam can be characterised as a three dimensional normal (Gauss) beam. The beam emitted from the sensor has a device specific cross section area and depends on the measuring range [1]. From this can be concluded that the range influences the measuring properties. Because of them, the measuring properties are sensor specific and must be investigated for the intended application intensively.

In contrast to industrial purposes which almost take place under indoor conditions, the working conditions under field conditions are more difficult. Besides impacts from vibrations and dust, further problems result from out-door operation under very different weather and illumination conditions. In order to measure during intensive sunlight, from the manufacturers sensors with the classification 3b are applied. This results in problems with the safety of labour.

Furthermore, in cop production it is necessary to measure ranges during vehicle movement to crop target areas with very different shapes, inclinations and relative small dimensions. Characteristic examples for these conditions are measurements in stands of grass and cereals, which show a filigree structure. Under such conditions it is unanswered how the readings behave when the beam targets on different ranged crop or soil surfaces. It can be expected that this situation exists particularly for far ranges and large beam cross section surfaces.

Laser rangefinders in agricultural engineering

Laser rangefinder have a substantial potential for application in crop production. Resulting from current state of knowledge, laser rangefinder can be used successfully on techniques for site specific application of fertiliser and crop protection agents and on harvesting machines also. In the sector of market available agricultural machinery, laser rangefinder are installed on combine harvesters. E.g. the company Claas attaches a laser rangefinder (Laserpilot) on the Lexion combine harvesters for detection of crop edges. Based on this information the steering mechanism keeps the optimum cutting width constant. A similar solution can be found on the newest CX-combine harvester from Case-New Holland, named Smart-Steer. Beside optimum cutting width, the accuracy of yield mapping can be improved.

In the field of research, market available laser rangefinders were investigated with regard to vehicle based measuring of crop parameters [2]. High functional correlations were found between reflection height (m) - calculated from measured reflection range and sensor height- and crop biomass density (kg m^{-2}). In the crops winter rapessed, winter rye and winter wheat, the goodness of fit for

Table 1: Combination variants of arrangements of the swivel axle and laser beam for vehicle based measurement of crop parameters

Arrangement of the swivel axle	arrangement of laser beam related to the swivel axle	by beam generated figure	figure of intersect with ground	measurement of swivel angle
horizontal	perpendicular ($\varphi=0°$; $\gamma\neq0°$)	circle sector	straight line	necessary
	inclined($\varphi\neq0°$; $\gamma\neq0°$)	cone mantle	hyperbola	necessary
inclined	perpendicular($\varphi\neq0°$; $\gamma\neq0°$)	circle sector	straight line	necessary
	inclined ($\varphi\neq0°$; $\gamma\neq0°$)	cone mantle	parabola, ellipse, hyperbola	necessary
perpendicular	perpendicular ($\varphi=90°$; $\gamma\neq0°$)	circle sector	none	-
	inclined ($\varphi\neq0°$; $\gamma\neq0°$)	cone mantle	circle	not necessary

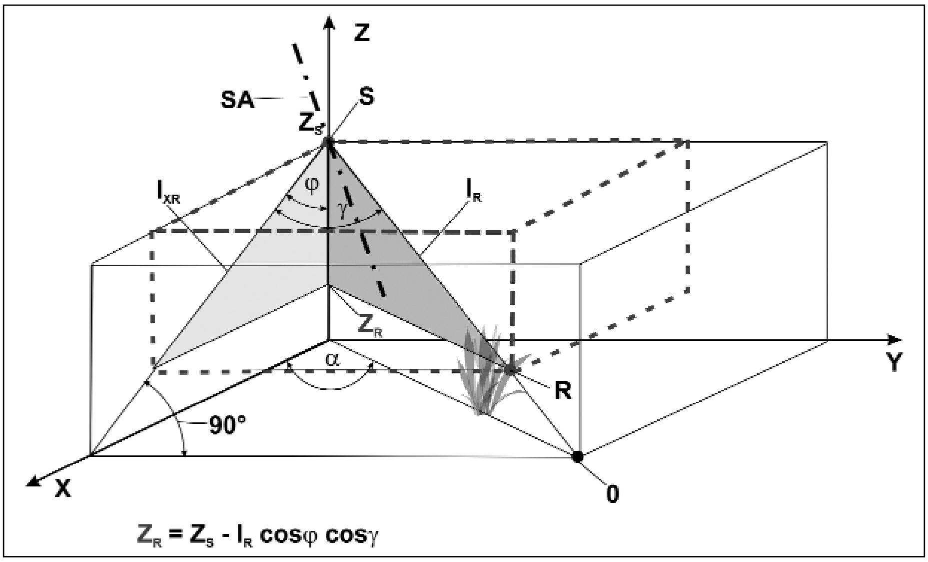

Fig.1: Geometry of the laser beam in the space

a linear regression was more than 0.90 (R^2 > 0,9). In grassland the quality was lower, because of the variable morphology of plant species. During these measurements the beam was directed down in the crop stand or was pivoted around a horizontal axle of ±15°. The mounting height of the sensor and resulting from this the measuring range was less than 2.5 m. Under these conditions the diameter of laser beam was in the range of millimetres. The arrangement of measuring points followed either a straight line or a sinusoidal line with an amplitude of less than 1.34 m.

Agricultural equipment for application of fertilisers and plant protection agents has normally working widths of more than 20 m. To measure in a representative manner for these working widths the measurements have to perform over a broader strip and resulting from this in higher ranges which results in the above described problem.

From the aspect of a beamguide it can be distinguished between sensors with a fixed beam and those with a scanning beam. While on the part of the users for laser scanners limited opportunities exist to influence the movement of the beam, for lasers with a fixed beam individual solutions can be developed by moving the entire sensor housing with a corresponding kinematics.

Scanning with fixed beam sensors

To generate a scanning motion with a fixed beam, the sensor must swivel around an axis or must rotate. Depending on how the axis is oriented in space, there are completely different characteristics of scanning properties (*Fig. 1*). Since for agricultural machinery the area in front of the vehicle or below must be sensed, full rotations of the sensor and swivel angles γ of more than ± 90 degrees to the moving direction (X-axis) are generally not required.

Table 1 shows possible arrangement combinations of the swing axis SA and orders of the laser beam to swing axis for the vehicle based measurement of crop parameters. In the majority of combinations the measured reflection distance l_R depends on the swivel angle γ and must be corrected to determine the reflection height Z_R. A prerequisite to perform this correction is that the swivel angle γ is measured in sync with the reflection distance l_R.

Measuring of the swivel angle is not required if- as *Table 1* shows - the swing-axis is arranged perpendicular to the footprint of the basic vehicle, and the sensor beam is inclined to swivel axis of angle φ. In this case the sensor beam describes a vertical cone mantle. In the idealized case, in this configuration and non-existing crop mass for each swing angle γ a reflection height Z_R of zero would be calculated. This independence of the reflection distance from the swivel angle γ is given in the same way to measurements in the crop stand.

Repeatability of the scans under field conditions

In the case of large measuring distances and swivel angles, it is very difficult to investigate the functional relationship between the reflection height and crop biomass mass density. An exact site reference to the scanned area can be found only with a high expense. Laser rangefinders can be assessed however in terms of their measuring properties at greater distances if they scan unknown but always the same crop plants.

Under field conditions, those conditions can be created by a laser sensor mounted on a base vehicle in such a way, that its swivel axis is oriented perpendicular to the base vehicle. If the base vehicle is parked in a crop field, for each scan exact the same crop biomass can be ensured. In this case, the laser sensor should measure the same mean reflection height for each scan. Based on the variance of the mean reflection height of each scan it is possible to assess the repeatability of measurements under constant crop conditions.

Another form to assess the sensor properties for larger measuring distances is to scan the characteristics of the crop stand as tram lines or stock edges. This should be marked by leaps in reflection distance in the individual scans clearly according to the corresponding swivel angles γ.

The laser sensor used was a fixed beam sensor ACUITY, already has been described in terms of its technical data [3]. The sensor was moved with a special swivel body (*Fig. 2*). The swivel axis was arranged perpendicular to the base vehicle (Hege tool carrier) and it was swung with a crank arm on a swivel angle of 73 ° and a frequency of about 1 Hz. The time-synchronous measurement of the swivel angle was performed with the rotation angle sensor P500A.160 L300 of the company Positek Ltd.. UK. For inclination angle φ of the sensor, 45 °, 60 ° and 75 ° were chosen.

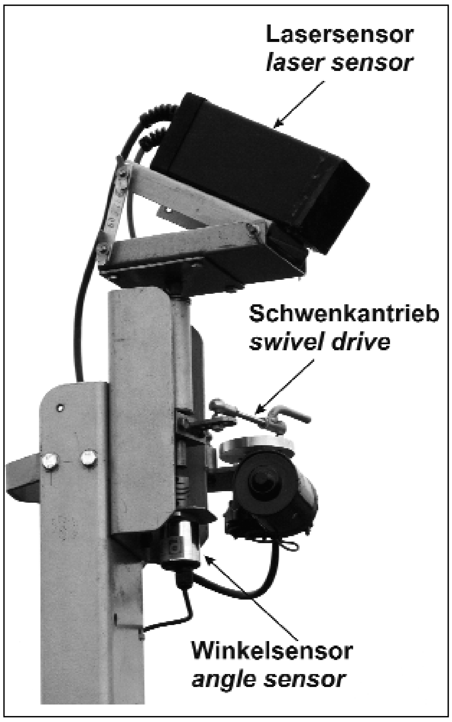

Fig. 2: Swivel unit with fixed beam sensor and vertical axle arrangement

Table 2: Comparing mean values, standard deviations and coefficients of variations of the reflection range in winter wheat

Inclination angle φ grad	number of scans -	mean value m	caster / return standard dev. m	CV %
	winter wheat, ripe 13.07.2007 , sensor height 3.65 m			
45	43 / 43	4.543 /4.564	0.0095 / 0.0084	0.21 / 0.18
60	60 / 60	6.061 / 6.065	0.0118 / 0.0116	0.19 / 0.19
75	56 / 56	10.093 /10.087	0.0538 / 0.0512	0.53 / 0.51
	winter wheat, BBCH 33, 15.5.2008 , sensor height 2.75 m			
45	24 / 22	3.214 / 3.188	0.0094 / 0.0086	0.29 / 0.16
60	25 / 23	4.064 / 4.080	0.0062 / 0.0086	0.15 / 0.21
75	26 / 25	7.213 / 7.127	0.0067 / 0.087	0.09 / 0.12

Results

To demonstrate the conformity of readings from the individual scans in visual form, the measured reflection distances together with the corresponding swivel angles were drawn (*Fig. 3*). As *Figure 3* expresses exemplary, the characteristic patterns of each scan were reflected. Particularly striking are the jumps, caused by the tram lines. To assess the scans more different, the readings for both scanning directions were compared. This comparison in *Table 2* shows that the mean reflection distance of the individual scans have a standard deviation in the range of centimetres only.

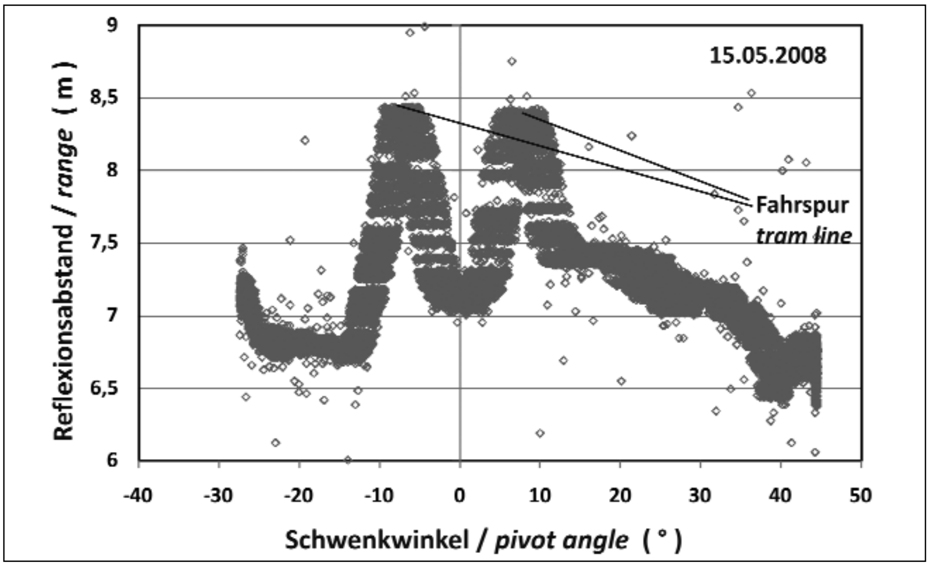

Fig. 3: Demonstration of the reflection range in winter wheat (BBCH 33; 25 scans; sensor height 2.75 m; inclination angle 75°)

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