Localization of pasture maintenance spots by a 2D laser scanner[1]

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Abstract

In consequence of the growing world population an increase in consumption of dairy products and meat is predicted. The challenge lies in meeting the rising demand in a more sustainable manner. Thus, the development of sustainable animal husbandry systems in regard to animal welfare and the environment must be proceeded. Dairying with grazing has a great potential for such a system. However, public opinion and organizations promote naturalness and sustainability and regard grazing cattle as a part of the landscape (‘t Mannetje, 2000). In livestock housing the information and communication technology (ICT) is already present considering milking, cleaning and feeding robots. Modern ICT also enables to increase the economic efficiency of pasture grazing. Quantity and quality losses of pasture forage are especially consequences of insufficient pasture maintenance.

Optimal pasture maintenance includes selective mulching of leftovers and reseeding of damaged swards after grazing. Until now these operations have been done manually, by a tractor driven machine or there was no pasture maintenance at all. Precondition for a selective and careful improvement of pasture is the localization of maintenance spots in real-time, which can also enable an operation by an autonomous pasture robot.

This paper presents a method to carry out the localization of leftovers and damaged swards after grazing within a paddock by a 2D laser scanner. For the experiment the sensor is attached at a mobile wheeled platform, which moves over the paddock area. Leftovers are identified by the grass height difference after grazing. To distinguish soil surfaces from surfaces with vegetation the measure of the received energy by the laser scanner, which depends on surface properties of the reflection area, is used. Results of tests under model and real pasture conditions are shown and discussed.

Keywords: Precision Livestock Farming, Animal production, Agricultural robots

1. Introduction

Facing the increasing world population accompanied by an increasing demand for meat and dairy products, agricultural engineering needs new ideas for food and livestock production to cope with this future situation. It is expected that the world population will grow to 9.3 billion people until 2050. As in the past, the consumption of bovine meat and other animal products will continue to rise, especially with the higher income and living standards in emerging economies. In the mid-1960s the averaged worldwide consumption per capita of meat amounted 24.2 kg. In 2030 it will exceed 45 kg. The same applies to milk and dairy products. The averaged worldwide consumption per capita of milk and dairy products was 74 kg in the mid-1960s. Until 2030 it will increase to 90 kg. (FAO, 2003)

A growing livestock farming sector is the consequence of the increase in demand for bovine meat and milk products. The number of cattle for meat production worldwide increased by 58 % from 170 to 300 million animals in the period from 1960 to 2013. The world population of milk producing cows has increased by 65 % from 180 to 270 million animals in the same period. Most of this increase of the cattle and dairy cow population in the last 50 years has related to Africa, America and Asia. In Oceania the number of cattle and dairy cows has nearly stagnated, in Europe it has even declined. Nevertheless, the area of permanent meadows and pastures on the world remained nearly constant. It has only increased by 2.6 % during the mentioned period. (FAOSTAT, 2015)

Due to these trends the available area of grassland for the fodder production per animal will decline. Methods of animal feeding range from indoor or feedlot feeding to different forms of grazing systems. According to ´t Mannetje grazing is the natural and regarding the fodder losses also the most efficient way in which herbivores take up feed. In earlier times mixed farms with animal husbandry and crop farming came up in most parts of Europe. The farmers kept cattle mainly for manure production and performed indoor feeding, particularly in winter period (‘t Mannetje, 2000). Currently the main products are milk and meat for national and international markets and manure is regarded as a more or less undesirable by-product (‘t Mannetje, 2000). In 2010 the share of grazing livestock in EU-27 was only 58 % (Eurostat, 2012) In Germany only 44 % of livestock farms applied grazing in 2010 (Statistisches Bundesamt, 2011).

1 Issue within the i-LEED project “*Advanced cattle feeding on pasture through innovative pasture management”:* This project is funded within the 2nd ICT-AGRI ERA-NET and financially supported by a grant from NCPs: the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) through the Federal Office for Agriculture and Food (BLE) grant number 2812ERA058 and 2812ERA059, the French National Research Agency (ANR) grant number 12-ICTA-0002-01 and 12-ICTA-0002-02 and the Scientific and Technological Research Council of Turkey (TUBITAK) grant number 112 O 464. Web site: *http://www.lfl.bayern.de/ilt/i-leed/en/index.php*

Public opinion and organizations promote naturalness and sustainability and regard grazing cattle, sheep and horses as part of the landscape (Mannetje, 2000). Actually grazing is a high efficient method of animal feeding. But due to the increase in demand for milk and meat products pasture grazing must be more economically attractive towards livestock housing, especially considering the higher work load for pasture maintenance and cattle handling. Basic factors for profit of grazing are grass quantity and quality. Considering this LfL started a research project with four other partners to optimise the feeding of cattle on pasture as well as the management of the pasture through introduction and fusion of innovative tools. The complete project with all work packages is described by Gobor et al., 2015.

Quantity and quality losses of pasture forage are especially consequences of insufficient pasture maintenance. Optimal pasture maintenance includes mulching of leftovers and reseeding of damaged swards e.g. because of footsteps after grazing (fig. 1).

Figure 1. Maintenance spots on pasture: damaged sward by footstep of cattle (left and central image); leftovers after grazing (right image)

Until now these operations have been done manually, by a tractor driven machine or there was no pasture maintenance at all. To enable automatic pasture maintenance by a robot, maintenance spots have to be detected. Therefore, the aim of this study is to use the modern 2D laser scanner technology to localize maintenance spots in real time and to perform operations selectively. With the use of this technology combined with a Global Positioning System (GPS) for navigation pasture maintenance operations can be performed selectively by an autonomous robot and maintenance spots can be mapped and memorized to optimize pasture management. Thus the application not only reduces workload, it also provides information about the state of the paddock. The farmer is supported in his decisions on operations like grassland renovation or fertilizing based on this information.

2. Materials and Methods

2.1. 2D laser scanner technology for localisation of pasture maintenance spots

Due to the rapid development of the 2D laser scanner technology in the last years the idea was to analyse the suitability of a 2D laser scanner for maintenance spot localisation on pasture areas. Advantage of this method is a relatively high ground resolution, the non-destructive measurement and being able to detect both leftovers (mulching spots) and damages in the sward (seeding spots) after grazing by one sensor. In the field of agriculture other authors used 2D laser scanners almost for vehicle navigation in structured terrain, like (Hamner et al. 2010) and (Hansen et al. 2011) who focused on vehicle navigation in orchard. Generally a 2D laser scanner consists of a laser head which rotates around one axis. Depending on the angular resolution more or less emitted laser beams create the so-called scanning plane. Primarily 2D laser scanners output a value of the distance between the rotating laser head and the surface where the beam is reflected. The difference between measured grass height values indicates leftovers after grazing. Nowadays some commercially available 2D laser scanners also output another value which characterises the received energy of the reflected laser beam depending on the surface properties. This value is used to distinguish grass from soil areas and therefore to localize seeding spots. For these applications the scanner must be attached at the front of a mobile platform in a manner that the scanning plane intersects the ground. The position of the 2D laser scanner has influence on the resulting ground resolution. The required ground resolution is defined based on the pasture conditions, especially the sizes of maintenance spots. Leftovers after grazing result from the excrements of cattle which avoid grazing those areas where they have set urine or feces. Figure 2 illustrates the principle of the maintenance spot localization and shows all relevant parameters.

z_{laser} = attaching height of laser scanner

$h_{leftover}$ = height of leftovers

v = vehicle speed

φ = measuring angle of laser beam

θ_x = pitch angle of the vehicle

θ_x = roll angle of the vehicle

β = inclination of the scanner relative to the vehicle

h_b = height of bumps on pasture

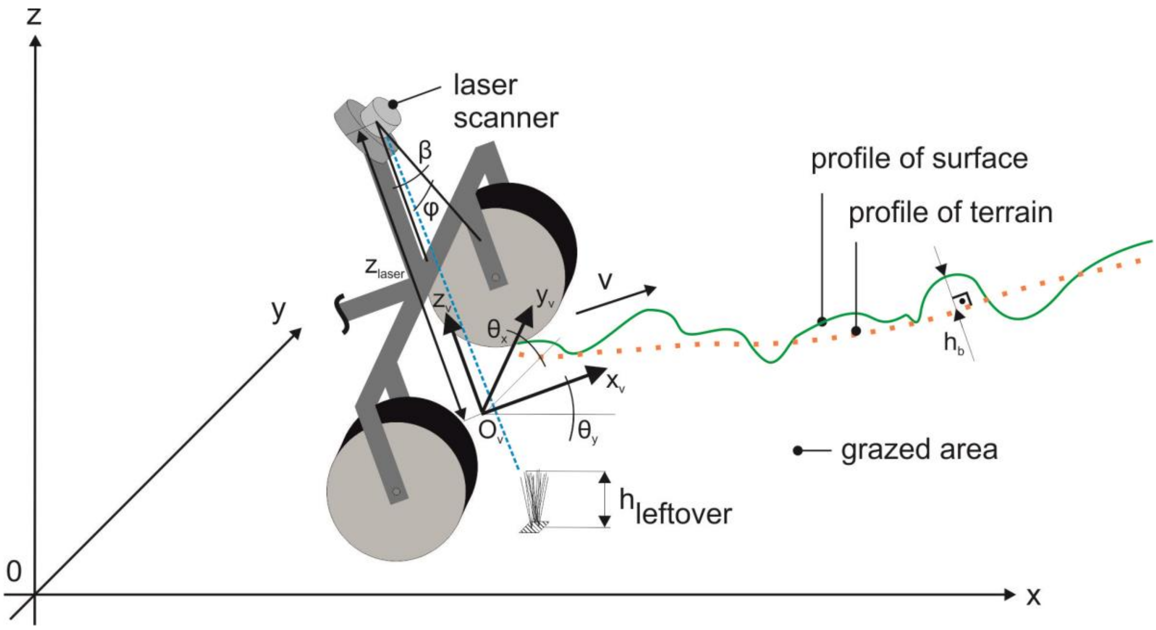

Figure 2. Maintenance spot localisation on pasture

2.2. Theoretical considerations and analysis

Leftovers after grazing should be detected by measuring and calculating their height $h_{leftover}$, the difference of grass height between the grazed and the partially not-grazed spots:

$$h_{leftover} = z_{laser} - \cos(\beta) \cdot \cos(\varphi) \cdot d + \Delta h_{error} \qquad (1)$$

Reference of this value is the y_v axis of the local vehicle coordinate system whose origin is on the central point of the two ground contact points of the wheels. Under ideal conditions, which means smooth grazed ground and constant terrain inclinations (roll angle Θ_x and pitch angle Θ_y of the vehicle do not change at any time) there will be no large errors in measuring the height. But on real pasture the conditions are quite rough, and bumps in the ground cause errors Δh_{error} in measurements. Consequently the suitability of the 2D laser scanner technology for pasture maintenance spot localization had to be checked first. Errors on pastures are especially caused by bumps of the ground itself and the resulting roll and pitch angle of the vehicle. To detect the terrain profile of real pastures or rather the surface profile to finally calculate the height of the bumps h_b of the ground measurements were carried out by a wheeled vehicle with one oscillating axle. It was important to avoid tilting. Depending on the sign of the value h_b there are positive or negative bumps. For these measurements a carriage which was pulled by a small tractor was used. The following figure 3 shows the axle which sensed the ground surface.

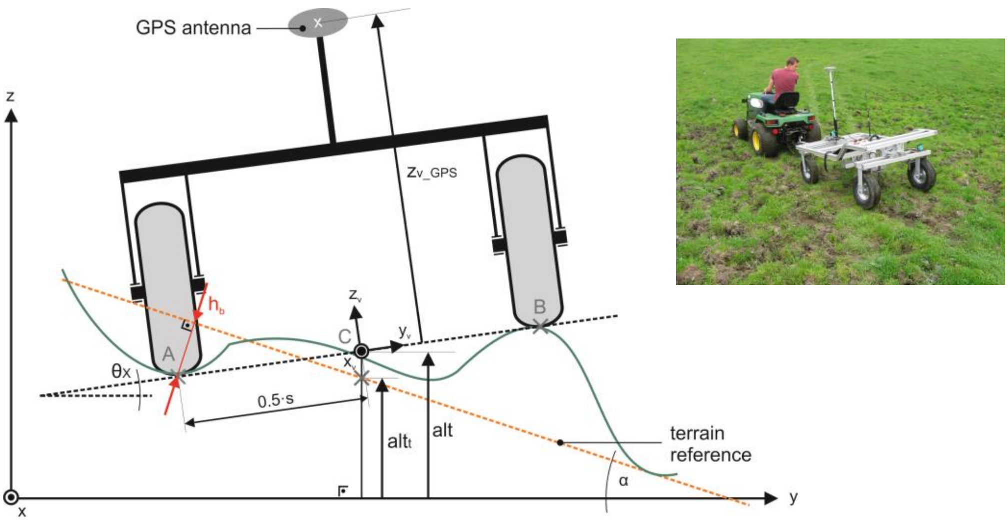

Figure 3. Principle of pasture surface detection

z_{v_GPS} = attaching height of GPS antenna
s = vehicle track gauge
alt = altitude of point C
alt_t = altitude of terrain based on filtered values
α = terrain inclination based on filtered roll angle signal

In principle the soil profile was sensed by the wheels of one axle rolling over the pasture area at the lowest possible speed. This method is sufficient to detect the profile of surface although edges on the surface cannot be detected because of the diameter of the wheels. But these measurements are mainly for measure the height of bumps which cause errors in grass height measurements by the 2D laser scanner. The roll and pitch angles of this measuring axle as well as its GPS positions (real time kinematics) were measured. The frequency of the GPS measurement was 10 Hz so that the resulting resolution is nearly 0.5 points/cm according the travelled distance. After recording these raw data by a laptop and a LabView VI the mathematical anaylsis were performed by post-processing and not in real-time. Because of the height of GPS antenna z_{v_GPS} the first step was to calculate the GPS position of the central point C on the connecting line between the soil contact points A and B of the two wheels (see fig. 3).

Then the ground level (GPS altitude alt_t) and the terrain inclination based on the roll angle of the vehicle were determined by applying a Butterworth filtre of first order to smooth the noisy values caused by surface roughness. The resulting time delay after the filtre application had to be taken into account and compensated for both angle and GPS position values. The smoothed values result in the terrain position (filtered values: inclination α and altitude alt_t) which is the reference of the final bump height h_b, which is drawn in figure 3. These calculated individual points result in the profile of terrain. At the end the bump height h_b is calculated (see equations 2 and 3) for each value of the vehicle roll angle in relation to the current terrain position. Thereby two cases have to be considered:

$alt_t < alt$:
$$h_b = 0.5 \cdot s \cdot \frac{1}{\tan[90° - (\alpha - \theta_x)]} - \frac{(alt - alt_t)}{\sin[90° - (\alpha - \theta_x)]} \qquad (2)$$

$alt_t \geq alt$:
$$h_b = 0.5 \cdot s \cdot \sin(\alpha - \theta_x) + \frac{(alt - alt_t)}{\cos(\alpha)} \qquad (3)$$

The particular parameters are shown in figure 3. Besides the circumstance of error because of roughness of pastures parameters like the position of the scanner in relation to the vehicle, especially the attaching height, inclination, location, width of scan zone, angular resolution and the speed of the mobile platform have influence on the ground resolution Δy_{res} and Δx_{res}. Thereby the so-called laser shadow was also considered (see fig. 4). These parameters were analysed by theoretical calculations.

h_{object} = height of measured object (leftover)
s = vehicle track gauge
Δx_{sha} = length of laser shadow in x direction
Δx_{res} = ground resolution in x direction
Δy_{sha} = length of laser shadow in y direction
Δy_{res} = ground resolution in y direction

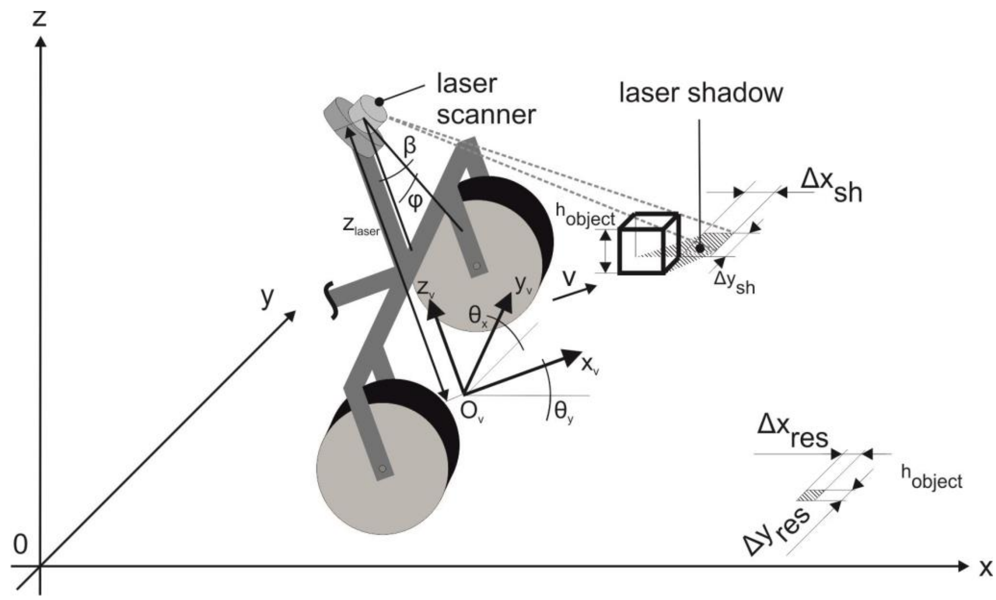

Figure 4. Laser shadow of 2D laser scanner detection

2.3. Tests under model conditions

2.3.1.Leftover localisation

After these theoretical considerations stationary tests under model conditions were performed using a 2D laser scanner of the type “R2000” (manufacturer Pepperl&Fuchs). For this purpose a framework was developed in order to allow appropriate positioning of the sensor (variable height z_{laser}). Therefore the sensor was attached at a framework. For simulation of leftovers a setting constisting of toothpicks positioned on the floor was used to find out an appropriate angular resolution which will be necessary for the detection of leftovers on pasture (fig. 5).

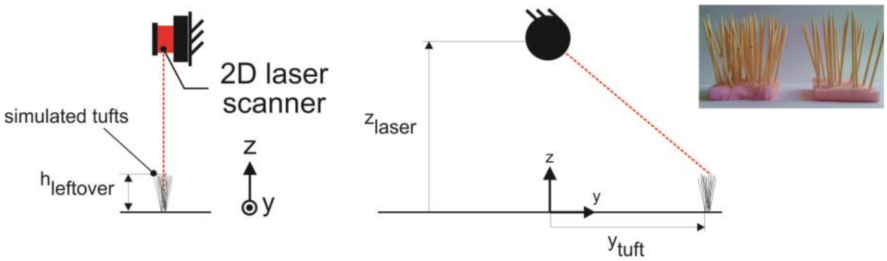

Figure 5. stationary tests with simulated grass leftovers

2.3.2.Seeding spot localisation

With regard to the localization of seeding spots flat trays filled with local topsoil were placed on a cut lawn area to simulate seeding spots on pasture. They were covered with local topsoil so that both zones have the same height level. The trays were totally covered to assure a laser beam reflection on the soil. A scan width w_{scan} of 1300 mm was considered, which corresponds to the working and scanning width of the pasture robot (fig. 6). These tests were carried out both at daytime and at night to analyse the influence of solar radiation.

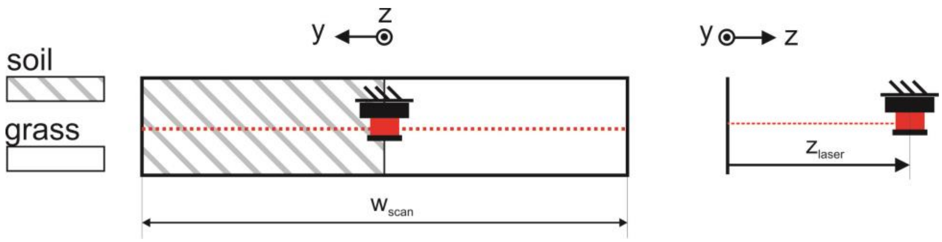

Figure 6. Stationary tests with regard to the localization of seeding spots; top view (left) and side view (right)

3. Results and Discussion

3.1. Theoretical considerations and analysis

The errors of leftover height measurements caused by surface roughness on pasture derive from the bump height h_b itself as well as the consequent transverse tilt of the vehicle. The following figures (fig. 7) describe these two possible error caused by terrain conditions on pasture.

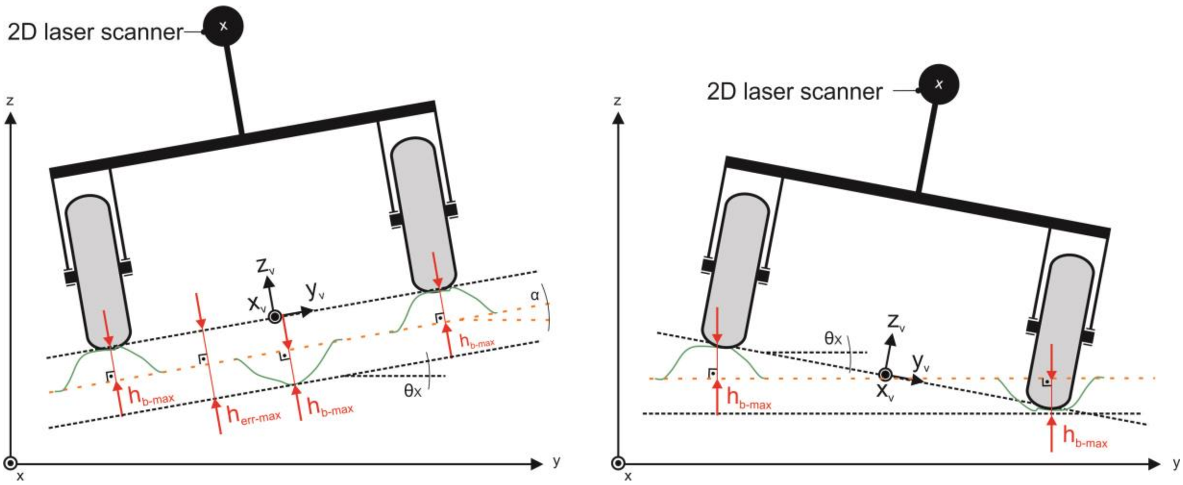

Figure 7. Extreme situations with maximal errors according grass height measurement caused by bumps on pastures

The left sketch shows the vehicle whose role angle corresponds to the angle of terrain inclination. The error of height measurement by the 2D laser scanner is extreme if the vehicle is enhanced by two maximal positive bumps with a height of $h_{b\text{-}max}$ and in the scanning zone between the two wheels is a negative bump with a depth of $h_{b\text{-}max}$ (assumed worst case). Thus the maximal error $h_{err\text{-}max}$ in this case can be twice the maximal bump height $h_{b\text{-}max}$:

$$\Delta h_{leftover\_err1} = 2 \cdot h_{b-\max} \qquad (4)$$

The same applies to the case if the wheels are on negative bumps with maximal bump height according to amount and there is an extreme positive bump in the scanning zone between the two wheels. The error because of vehicle inclination is extreme if one wheel of the axle is on a positive bump and the other in a negative bump. The error is calculated as follows in equation 5.

$$\Delta h_{leftover\_err2} = h_{leftover} \cdot \left(1 - \frac{1}{\cos(\theta_x - \alpha)}\right) \qquad (5)$$

The analysis of the pasture surface enabled to quantify or rather calculate these errors of leftover height measurements after grazing by a 2D laser scanner. A distance of 2000 m was traveled on pasture areas in Bavaria by this test carriage. The maximal calculated height of bump h_b on pasture surface revealed in a height of 80 mm. But the share of bumps with a height larger than 75 mm is very low. The highest percentage of bumps has a height of lower than 25 mm. The percentages of the different bump height values distribute as follows:

Table 1. Results of soil profile measurements on pasture areas

range of $\lvert h_b \rvert$	**percentage**
0 mm < h_b < 25 mm	93.86 %
25 mm < h_b < 50 mm	5,86%
50 mm < h_b < 75 mm	0.25 %
75 mm < h_b	0.03 %

Consequently these figures show that the error because of bumps with a height of more than 50 mm can be neglected, because its share is small. But a bump height of maximal 50 mm with an averaged percentage of more than 5 % must be considered. If the vehicle track gauge is for example 1000 mm the maximal difference between Θ_x and α is 9.1°. Thus the value for the maximal error $\Delta h_{leftover\_err2}$ caused by vehicle inclination is with 3.2 mm negligibly small (if a height of leftovers $h_{leftover}$ of 250 mm is assumed) compared to the error $\Delta h_{leftover\_err1}$ because of bumps which are 100 mm if the maximal height of bumps is 50 mm. Thus bump heights h_b between 25 and 50 mm can be a problem to detect leftovers with a height $h_{leftover}$ of less than 100 mm. But the percentage of this bump height range of less than 6 % is relatively low compared to main portion of bumb heights between 0 and 25 mm.

The position of the scanner in relation to the vehicle, especially the attaching height, inclination and location must also be considered. The attaching height z_{laser}, width of scan zone, angular resolution as well as the inclination β_{laser} (see fig. 2) are important for the resolution Δy_{res} on the ground level. The resolution corresponds to the distance between the successive rotating laser beams. The maximal distance Δy_{max} on ground level is between both external laser beams. The following diagram (fig. 8) shows this distance depending on the parameters w_{scan} and z_{laser}.

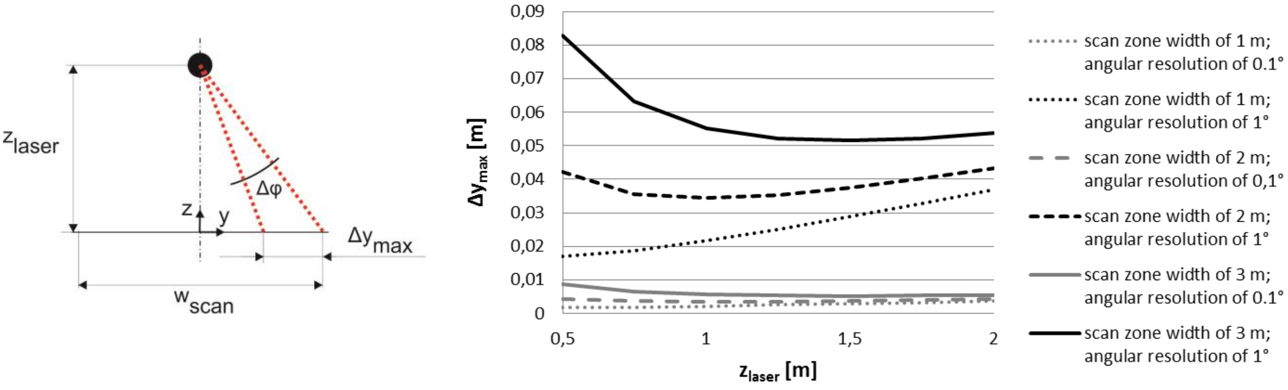

Figure 8. Relations between parameters scan zone width w_{scan} and attaching height of the scanner z_{laser} (angular resolution Δφ is 0.1°)

As expected the larger the width of scanning zone w_{scan} the larger is the distance Δy_{max}, the lower the resolution on ground. The angular resolution has logically big influence on the resolution Δy_{max}. With an angular resolution of 0.1° and an attaching height z_{laser} of 0.5 to 3 m the resolution on the ground Δy_{res} is lower than 10 mm if the scan zone width is slightly more than 3 m.

Considering the laser shadow which is illustrated in figure 4, the size of the shadow Δy_{shadow} is higher in the outer parts of the scanning zone than in the central ones because of the larger irradiation angle. Under simplified conditions (role angle Θ_x similar to terrain inclination α and β = 0°) the length Δy_{shadow} in y direction is calculated in the following equation 6:

$$\Delta y_{shadow} = h_{óbject} \cdot \left(\frac{0.5 \cdot w_{scan}}{z_{laser}} \right) \qquad (6)$$

With a width of scan zone of 1000 mm and an attaching height of 1000 mm the maximal possible laser shadow length Δy_{shadow} is the half of the object height h_{object} or rather of the grass height $h_{leftover}$. To avoid a laser shadow in x direction Δx_{shadow} the attaching angle β should be nearly 0°.

The x direction (direction of travel) was also considered. The measuring points result in curves on the ground level because of both linear motion of the vehicle and the rotational movement of the laser head. One curve is shown in figure 9. If the rotational frequency f of the scanner head is high these curves result in approximately straight lines. The distance between two successive curves which corresponds to the ground resolution Δx_{res} depends on the vehicle speed and the scanning frequency f of the laser scanner. The dependencies are shown in diagram of figure 10.

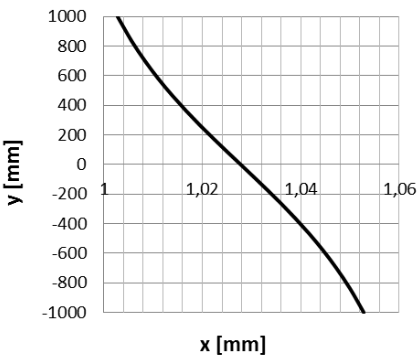

Figure 9. Curve of measurements points of a single laser head rotation (f = 10 Hz, v=1 m/s)

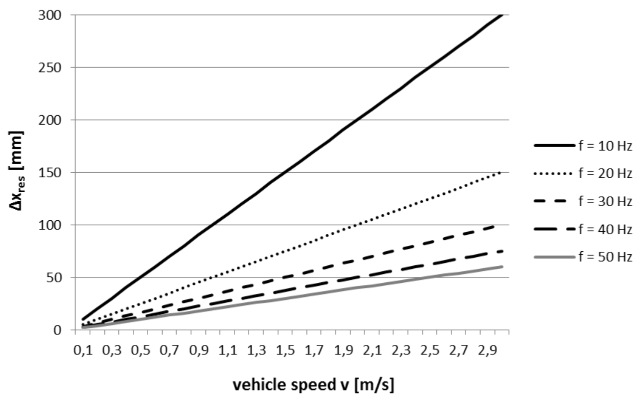

Figure 10. Ground resolution Δx_{res} in relation to vehicle speed for different scanning frequencies f

3.2. Tests under model conditions

3.2.1.Leftover localisation

The definition of the minimal surface area of these mulching spots is 100x100 mm, orientated toward the minimal size of a cowpat which is based on measurements. In regard to leftovers after grazing it is assumed that the minimal grass height difference of leftovers $h_{leftover}$ which should be detected is more than 100 mm. The minimal area of a seeding spot is determined referred to a footstep of cattle which is approximately 100x100 mm. Finally the minimal ground resolution of the pasture maintenance spot localisation must be at least 100x100 mm (Δx_{res} x Δy_{res}) with these assumptions.

The results of measurements which are described in section 2.3 are shown in the following diagrams (fig. 11). The position of the simulated leftover y_{tuft} was 750 mm. The maximal height of the sticks was about 65 mm. The values show that there is a noise in the measurement values of ± 20 mm. As the number of points in the marked circles show, the necessary angular resolution to detect the artificial leftovers must be at least 0.1°. Moreover another conclusion of this test was that one single point is meaningless because of the noise. It is always necessary to use a collective of more measurement points to detect leftovers with a certain height.

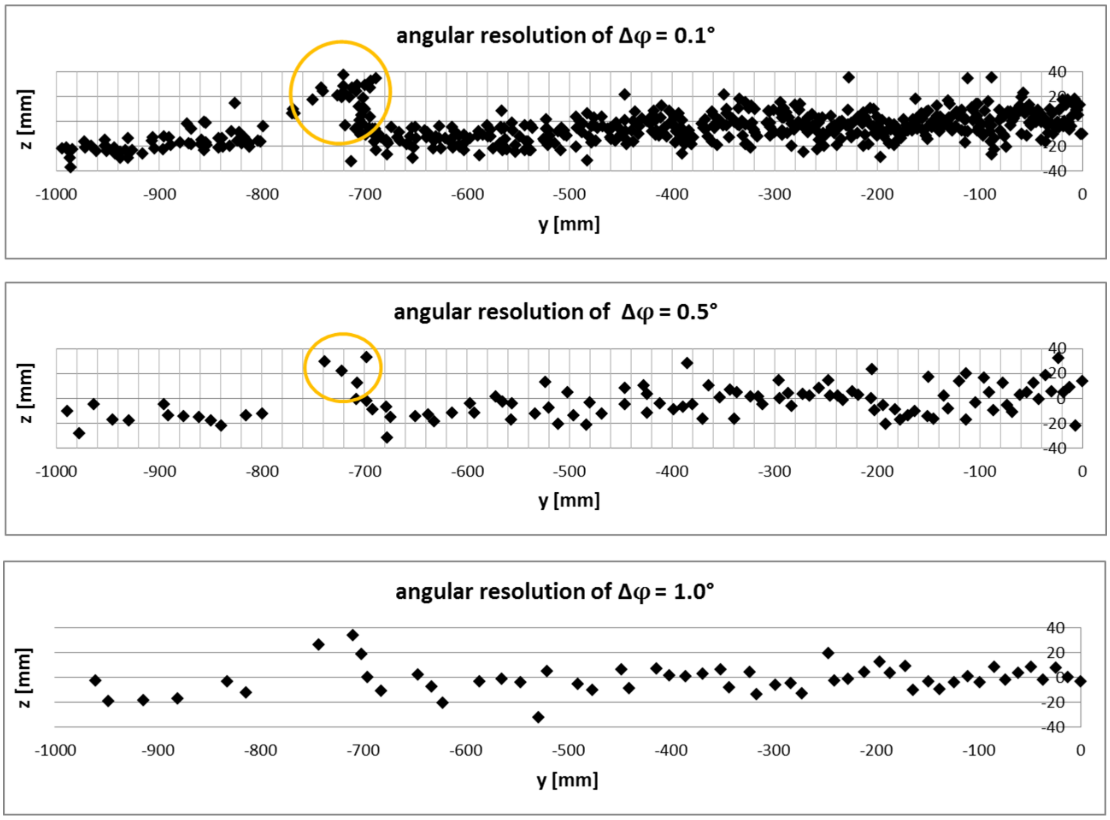

Figure 11. Results of measurements with artificial grass tufts

3.2.2.Seeding spot localisation

As in section 2.3.2 is described measurements were carried out to analyse if the 2D laser scanner "R2000" is able to distinguish between grass and soil spots via the value which characterises the received energy of the reflected laser beam depending on the surface properties. Pepperl & Fuchs calls these values "amplitude values" (Pepper & Fuchs, 2014). The results are illustrated in the following diagram (fig. 11) and table 2. It shows amplitude values for one laser head rotation in relation to the y-position, which is calculated by the distance values of the laser for each measuring point. Table 2 contains the calculated mean values and the coefficient of variation for each zone.

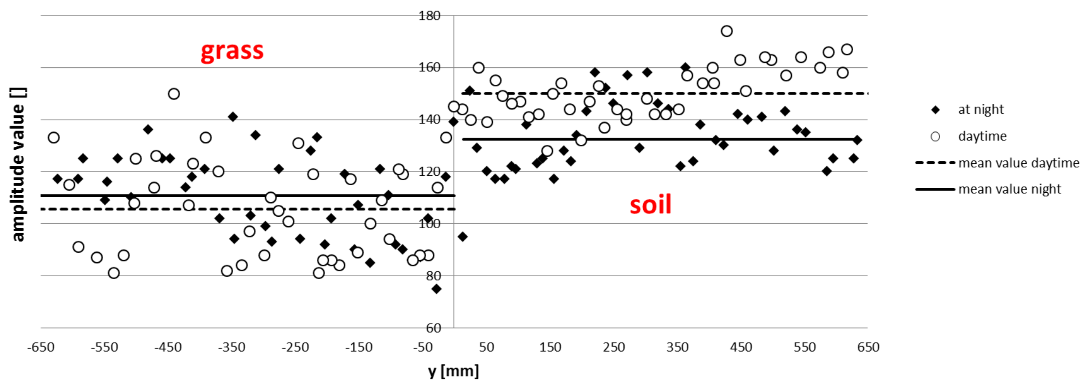

Figure 11. Results of measurements to distinguish soil from grass (measuring values of one laser head rotation)

Without further data analysis the diagram shows higher amplitude values of the soil zone. Moreover a slighter scatter of the values within the soil zone can be seen. The particular coefficients of variation are 17.8 % (grass) and 7.5 % (soil) according the daytime measurement. At night the difference of the scattering values is lower, but almost 6.8 %. With 22500 values on each zone (corresponds to 500 laser rotations), on soil ($0 < y < 650$ mm) the mean value was 148, on grass ($-650 < y < 0$ mm) it was 106 (daytime measurement). The coefficient of variation for the soil zone was 8.5 % and for grass 17.5 % respectively. At night the mean value of 500 repetitions was on soil ($0 < y < 650$ mm) 131 and on grass ($-650 < y < 0$ mm) it was 111. The coefficient of variation for the soil zone was 11.0 %, for grass it was 15.2 %. In general the mean value of amplitude value of the grass zone was lower and the scattering of amplitude values was much higher in comparison to the values of the soil zone. Especially the scattering and the average values of echo amplitude data can be characteristic parameters of soil or rather grass zones.

Table 2. Results of soil profile measurements on pasture areas

type of ground surface	**mean value and standard deviation**		**coefficient of variation [%]**	
	day	**at night**	**day**	**at night**
grass	105.6 ± 18.8	110.7 ± 17.9	17.8	16.2
soil	149.9 ± 11.3	133.3 ± 13.8	7.5	10.4

3.3. Pasture robot

After these preliminary studies finally the parameters of the 2D laser scanner were defined to attach the sensor at the pasture robot platform of the i-LEED project (see Gobor et al., 2015). To avoid a laser shadow in x-direction a scanning plane inclination β of nearly 0° is chosen. To minimize the distance Δx_a between the ground contact points of the front wheels and the intersection line of the scanning plane (see fig. 13) the laser scanner is tilted back slightly, because the wheels are the reference for the grass height measurement. In this context the stiff connection with the oscillating front axle is important. The scanning frequency is 50 Hz which corresponds to a ground resolution Δx_{res} of 20 mm if the vehicle speed is 1 m/s, which corresponds to the maximal operation speed of the pasture robot. The width of scanning zone w_{scan} corresponds to the track gauge and working width of 1300 mm. Furthermore the vehicle is equipped with a flail mulcher to mulch leftovers after grazing as well as with a seeder to seed faults in the sward. In cooperation with the French project partners IRSTEA and Effidence an automatic guidance function by GPS RTK (Real Time Kinematic) signal was developed which allows path following of defined trajectories on pasture areas.

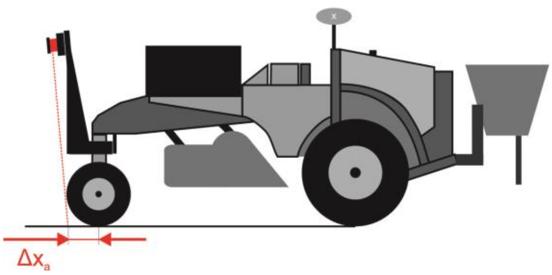

Figure 13. Draft of the i-LEED pasture robot

Figure 13. Pasture robot “i-LEED”

4. Conclusions

These presented tests and analysis were preliminary studies. They served to analyse the suitability of the 2D laser scanner technology for pasture maintenance spot localisation. An approach of detecting bump heights on pasture areas was shown. The analysis of the pasture surface has shown that errors of leftover height measurements by the 2D laser scanner because of ground unevenness won’t be a major problem if the aim is the detection of leftovers after grazing with a minimal height of 100 mm. The output laser scanner value which characterises the received energy of the reflected laser beam depending on the surface properties can be used to distinguish between soil and grass zone under the presented test conditions. The scattering and the average values of so-called echo amplitude data can be used to detect soil or rather grass zones. For both applications (the localization of mulching spots via grass height and the detection of soil zone via so-called amplitude values) the use of a collective of measurement points will be necessary. Further tests, especially under different environmental conditions (solar radiation, moisture of soil etc.) will be necessary to analyse the repeatability of the measurements. The pasture robot and the developed automatic guidance enables further tests on pasture areas in motion and evaluations of the pasture maintenance spot localization. Figure 14 shows the fully equipped pasture robot of the i-LEED project which is the base for further studies.

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