Control and guidance system for optimal maintenance operations on pastures by an autonomous mobile machine

Development of a pasture maintenance robot

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Abstract: Over the next decades, it is expected that the world population will continue to grow and cause an increase in the consumption of meat and dairy products. The challenge is to manage this growing demand in a sustainable manner. The cattle population increased worldwide in recent years while the area of permanent grassland in the world stagnated. Consequently, the efficiency of the production on grazing pastures needs to be improved. Quantity and quality losses of pasture forage are especially consequences of insufficient pasture maintenance. Optimal pasture maintenance includes the mulching of leftovers and the reseeding of damaged swards after grazing. Typically, these operations are carried out once a year with suitable machinery on the whole area or there was no pasture maintenance at all. The available information and communication technologies (ICT) become suitable for improving the pasture maintenance e.g. spots of interests can be identified by the 2D laser scanner technology. Combining this technology with the global positioning system (GPS) for navigation, scouting an maintenance operations can be carried out by autonomous robots. This paper presents the result within the ICT-AGRI project i-LEED* considering testing of a pasture robot developed based on a commercially available machine.

1 INTRODUCTION

Agricultural engineering needs new ideas for livestock production to meet demands of the increasing world population in the future, as well as the accompanying increase for producing meat and dairy products (Seiferth et al., 2016). Until 2050 it is expected that the world population will grow from 7.3 to 9.3 billion people.

As in the past, the food consumption of bovine meat will probably continue to rise. In the mid-1960s the averaged worldwide consumption per capita of meat amounted 24.2 kg. In 2050 it will reach 50 kg. The same can be presumed for milk and dairy products. The averaged worldwide consumption per capita of milk and dairy products was 74 kg in the mid-1960s. By 2050 it will have increased to more than 90 kg. (FAO, 2003) (FAO, 2015)

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

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(FAOSTAT, 2015). Due to these trends the available area of grassland for the fodder production per animal will reduce. Methods of animal feeding range from indoor or feedlot feeding to different forms of grazing systems. According to (Mannetje, 2000) grazing is the natural 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 crop farmers kept cattle mainly for manure production in barn (Mannetje, 2000). Currently the main products are milk and meat for national and international markets and manure is regarded as an undesirable by-product (Mannetje, 2000). In 2010 the share of grazing livestock within the EU-27 was 58 % (Eurostat, 2012). In Germany only 44 % of livestock farms applied grazing in 2010 (Statistisches Bundesamt, 2011).

Public opinion is oriented towards naturalness and sustainability and as well as grazing cattle, sheep and horses as part of the landscape (Mannetje, 2000). Indeed, grazing is a high efficient method of animal feeding. However, due to the increase in demand for milk and meat products pasture grazing must be more beneficial for farmers towards livestock housing. The basic factors for profitable grazing are grass quantity and quality. Considering this fact, LfL started the project i-LEED* (see footnote on page 1) with four partners to optimise the feeding of cattle on pasture as well as the management of the pasture through the introduction and fusion of innovative tools. The complete project with all work packages is described by Gobor (Gobor et al., 2015).

Quantity and quality losses of pasture forage are particular consequences of insufficient pasture maintenance. Optimal pasture maintenance includes mulching of leftovers and reseeding of damaged swards caused through footsteps after grazing.

Typically, these operations are carried out once a year with suitable machinery on the whole area or there was no pasture maintenance at all. To enable automatic pasture maintenance by a robot, spots have first to be detected. Using the modern 2D laser scanner technology, maintenance spots can be identified in real time and operations can be performed selectively. Combining this technology with the global positioning system (GPS) for navigation, allows carrying out scouting and maintenance operations by autonomous robots before and after each grazing period. Maintenance spots can be mapped and memorized to optimize pasture management. Thus the application not only reduces workload, but it also provides information about the state of the paddock. The farmer is supported in taking decisions on operations such as mulching, seeding or fertilizing based on this information.

2 PASTURE ROBOT

Within the i-LEED project, after analysing environmental conditions on pastures and grazing systems, technical constraints, e.g. requirements according chassis design of the robotic platform and machine capabilities were defined. The pasture maintenance robot was developed based on a commercially available mobile platform, which corresponds to the defined requirements in order to avoid a completely new development. Within the frame of the project an acquisition of an existing mobile platform (Energreen, 2014) was the most suitable to equip it with additional mechanical and electronic components, which are described in the following sections.

The main requirement of the basic machine was the suitability for difficult terrain to ensure stable motion on pasture while not damaging the sward. Consequently a skid steered vehicle and a solution with tracks was excluded *a priori*.

The research on the market was focused on remote controlled machines without a driver's seat or cabin equipped with a mulcher or to which a mulcher and additional implements can be attached.

2.1 Principle of optimal pasture maintenance

Several scientists focus on topics concering the use of laser scanner technology in agriculture for e.g. navigation or plant phenotyping [(Barawid, 2007), (Ruckelshausen, 2008), (Rosell, 2009)]. Due to this fact the idea was to attach a 2D laser scanner at the front of the mobile platform in such a way that the scanning plane is almost perpendicular to the ground (see figure 1) in order to carry out measurements considering grass quantity in real time. Primarily 2D laser scanners output a value of the distance between the rotating laser head and the surface from which the beam is reflected. This measured value is used for detecting leftovers after grazing and the quality of the fresh material. 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 localise spots on which seeding could be required. Through localising the spots of interest selective maintenance such as seeding, mulching or fertilising can be achieved.

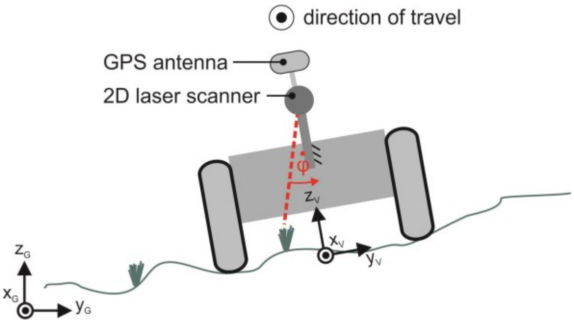

Figure 1: schematic sketch of the pasture robot with attached 2D laser scanner at the front

2.2 Basic vehicle and implements

The pasture robot was developed based on a originally remote controlled mulcher which was intended for mowing public green areas (see figure 3). To guarantee stable movement on pastures the vehicle is equipped with an oscillating front axle. It is a front-steering vehicle. The front wheels are steered via a steering linkage which is driven by a double acting hydraulic cylinder. The steering angle of the front wheels is measured by the angular sensor standardly implemented to the mulcher. The lever of the analogue sensor moves if the hydraulic cylinder displaces the tie rod. Figure 2 shows the steering kinematics of the vehicle.

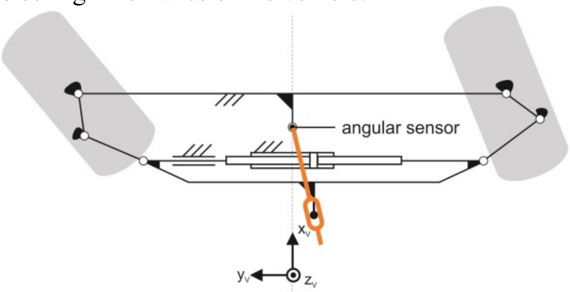

Figure 2: steering kinematics of the robot front wheels

The rear wheels are driven hydraulically via a separate hydraulic circuit.

The implement for mulching pasture leftovers is a flail mulcher. It is mounted between the front and rear axle of the vehicle and is consequently suitable for hilly terrain. The rotor drum equipped with Y-flails is driven hydraulically. The mulcher can be lifted by a single acting hydraulic cylinder while the mulching height can be limited mechanically and manually by a locking pin. Without applying this locking the mulcher is in a floating position.

For carrying out seeding on the detected spots without vegetation a seeder was developed within the i-LEED project, based on the experiences from previous projects caried out at the Institute for Agricultural Engineering and Animal Husbandry (ILT) at Bavarian State Research Center for Agriculture (LfL). It is based on the fertiliser spreader for plots (Fröhlich, 2007). Tests of longitudinal distribution by spreading seed mixtures instead of fertilizer were performed. The aim was to examine the behavior of the seed mixture (consisting of different grains with different sizes and masses) considering the decomposition of the mixture trough vibrations. A separation by vibrations and impacts was expected. However, a separation did not occur. Afterwards the seeder was redesigned, constructively modified and adopted for autonomous application. The shaft, on which 15 spreading units with cellular wheels are implemented, is electrically driven by a 24 V stepper motor.

Figure 3: pasture maintenance robot with mulcher and seeder

2.3 Robot hard- and software

The different hard- and software components were in the first instance developed independently by each partner. The two French partners Irstea and Effidence developed the hard- and software of the high level controller. The software of the low level controller, the agricultural engine control unit (ECU) and the supervisor PC was programmed by LfL. The equipment of the robot with additional hardware (see next sections) was also performed by LfL.

Afterwards the components were combined on the robot after defining the interfaces.

2.3.1 Architecture of robot control

The robot control consists of four main parts: the high level controller, the low level controller, the agricultural ECU and the original control of the machine, whose software was not changed nor modified. Figure 4 shows the architecture of the robot control with its components.

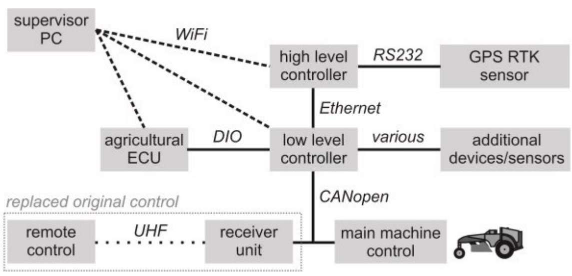

Figure 4: Architecture of the robot

The high and low level controller as well the agricultural ECU on the robot are connected to a stationary supervisor PC by a Wifi interface from which the farmer can have access at any time to control the robot manually or monitor it.

2.3.2 High level controller

The high level controller is a development of the two French project partners Irstea and Effidence. The main task is the autonomous guidance function of the robot. First a file with the trajectory of the path, which the robot should follow, is created by the i-LEED mission planning software on the supervisor PC and then sent to the high level controller, see the detail of the speed and steering control algorithms in (Cariou et al., 2009). After this, the automatic guidance can start and the robot can execute the mission.

2.3.3 Low level controller

The machine was originally radio remote controlled using ultra high frequency (UHF). On the machine is a receiver unit which converts signals into CANopen commands. The main machine control unit (MCU) communicates using CANopen. Within the framework of the i-LEED project the remote control system, consisting of remote control and receiver unit, was replaced by the low level controller. It consists of a myRIO hardware from National Instruments combined with an X-CAN Adapter from Stratom. This CAN interface is connected to the MCU. Thus it is possible to program the low level controller, which controls the machine by sending CANopen commands to the MCU. All actuators of the machine including the combustion engine can be controlled by the low level controller based on commands sent from the high level controller or the supervisor PC. Additional devices, e.g. the control of the motor for the seeder and sensors can be connected to the low level controller. The software running on the myRIO system is controlled by the supervisor PC (target-host). It is programmed within a LabVIEW environment. With the modular design the machine can either be controlled via the low level controller or by the original remote control.

2.3.4 Agricultural ECU

Another part of the robot hard- and software is the agricultural ECU, for which another myRIO hardware is also used. The task of the agricultural ECU is to communicate and acquire data from 2D laser scanner based on TCP/IP Ethernet connection in order to detect pasture maintenance spots. Consequently the 2D laser scanner is connected to this device via a TCP/IP Ethernet connection. The scanner delivers its raw data to the ECU, which acquires and analyses the data to provide relevant information for supporting decisions considering pasture maintenance.

The LabVIEW software calculates the current grass height in the scanning zone, which is divided into smaller sections with a width of 50 mm. In each section of the scanning zone the average value of the measured grass height is calculated. Moreover the percentage of sections, where the grass height is higher than a certain value, is continuously determined by the program which runs on the agricultural ECU. These two values define if there is a mulching spot at the current robot position or not. The farmer has the possibility to set the minimal grass height and the percentage value via the supervisor PC. Thus he can decide about the minimal dimensions of leftovers to be mulched by the robot.

According to the seeding spot localisation, the software detects the energy values from the laser scanner and calculates the average value of each section as well as the coefficient of variation. The software checks if the average value and the coefficient of variation are in certain ranges which characterises seeding spots. The limits of these ranges of the energy value and their coefficient of variation were analysed in preliminary studies, see (Seiferth et al., 2016). If a seeding spot is identified, the seeder is activated by the low level controller.

2.3 Development of the automatic guidance control system for the robot

The most important requirement of an automatic guidance is a precise steering control. On pasture a high understeering of the vehicle was expected, because most of the machine's weight is on the rear axle and the front wheels are quite small and have a quite smooth tyre tread. Thus, higher slippage at the front wheels was expected. To get a function for the real steering angle and the steering command values, steady-state circular tests on grassland were executed. Different circles with different steering command values were driven. Afterwards the steering radius of the circles recorded by the GPS position were measured. Finally the result was a mathematical model of the real steering angle dependency on the command value. This model was integrated into the low level controller.

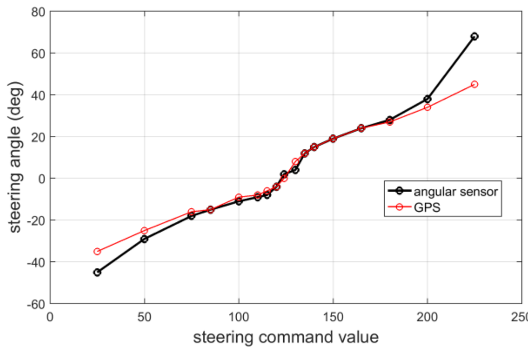

Figure 5: result of steady-state circular tests for different steering command values

Figure 5 shows the theoretical steering angle, which corresponds to the value measured by the angular sensor, and the values measured by the GPS sensor dependent on the steering command value. Differences between the two values were detected, especially for large or low steering command values or in other for large steering angles. This cirucmstance confirms the assumption of steering slippage at the front wheels.

2.4 Tests on pasture areas

The automatic guidance control of the pasture robot was tested on grazing areas. The lateral deviation on straight lines is less than 0.1 m, see figure 6. In curves it is maximal 0.3 m.

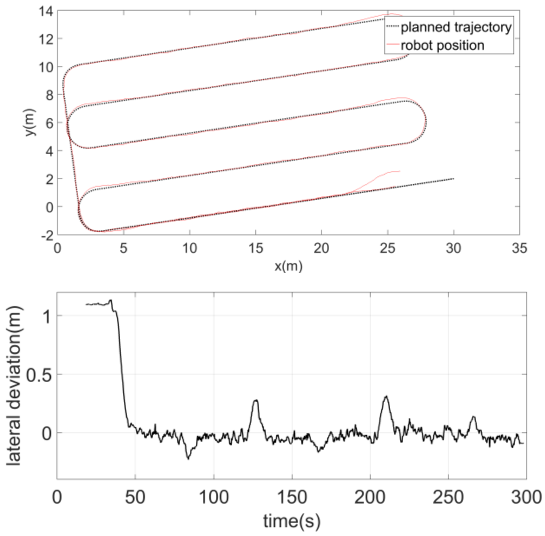

Figure 6: test on grazing area; reference and actual position (top), lateral deviation (bottom)

Moreover the pasture maintenance spot localisation (see 2.1) was recently tested under field conditions. In regard to the leftover detection first results are available. To analyse the localisation of leftovers, the robot followed a trajectory which fully covered an area of nearly 50 m x 8 m in 8 parallel tracks. In order to prepare the field conditions, simulating the area, the mulcher was activated. For the test randomly the mulcher was deactivated manually for a few centimeters by remote control while the positions and the mulcher status (on/off) were recorded. Consequently a reference for a second run with known leftover positions was obtained. Then the robot had to follow the same trajectory in a second run to localise the not mulched spots.

The diagram in figure 7 shows the results of this test. The filled points show the recorded GPS positions of the first trajectory following (approximate distance of 1 m). The black ones represent the positions where the mulcher was deactivated, simulating leftovers. The circles show the positions of the second run. The ones with the black line mark the positions where the robot localised leftovers. As demonstrated by these first results all leftovers could be localised by the robot. But there are also localised spots even though there was no leftover spot (in figure 7 one point). These misinterpretations have to be analysed and the algortihm has to be optimised to reduce the number of misinterpretations. Further tests and analysis of results are planned.

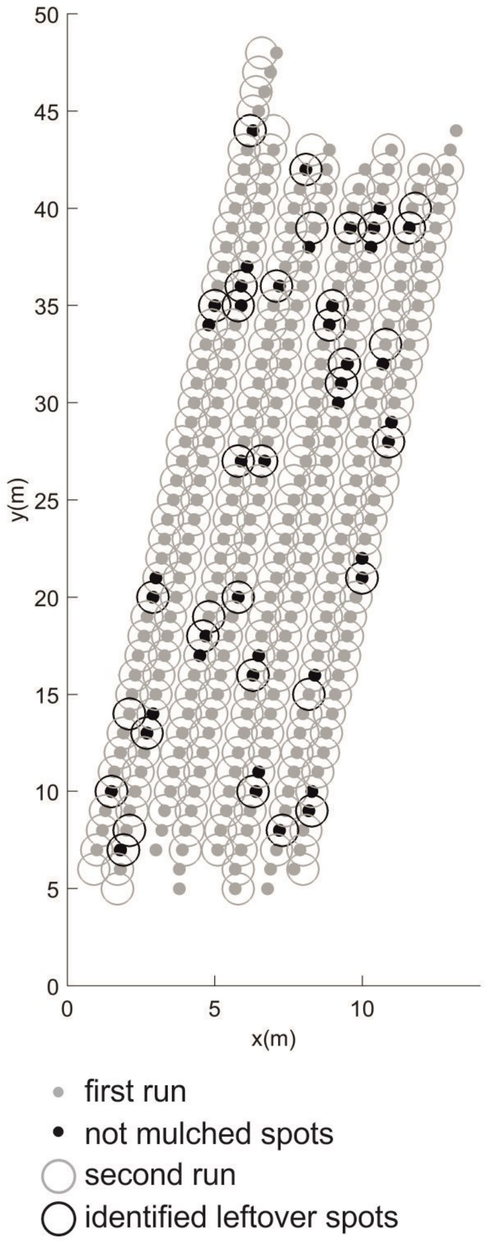

Figure 7: first results of field tests for analysis of the pasture leftover localization

4 CONCLUSION AND FURTHER WORK

The presented pasture robot is a prototype, developed for tests on pasture under real conditions. A commercially available remotely controlled mulcher was upgraded. The software of the orginal machine was not changed nor modified. Based on the preliminary results the pasture robot is able to accurately follow previously planned trajectories and to localise pasture maintenance spots. This enables selective pasture maintenance operations like mulching and seeding. Additionally, the farmer receives information about the status of his grazing areas and is supported by taking decisions considering management strategies.

Analysis of fuel consumption according to selective mulching and mulching the whole area are planned. Furthermore, the reliability of pasture maintenance spot localisation will be tested and evaluated in detail.

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