Field plant characterization method based on a multi-wavelength line profiling system

Burawich Pamornnak[1], Christian Scholz[1], Dominik Nieberg[1], Matthias Igelbrink[1] and Arno Ruckelshausen[1]

Abstract: Phenotyping of plant characteristics is essential for plant breeding. Especially the growth stages of plants during field emergence, described by parameters such as plant height and plant counting, are of interest. But large-scale manual phenotyping is very inconvenient due to the workload, the harsh weather conditions, and time-consumption. Therefore, an automated system is needed. This research describes a field plant characterization method implemented in a plot divider machine for rapeseeds. The method consists of a plant height estimation and a plant counting system. Based on a multi-wavelength line profiling (MWLP) sensor system, the 2D and 3D point cloud information from visible wavelengths to near-infrared (NIR) are automatically mapped without any need for a matching method. The plant characterization processes consist of two main steps, 1) plant detection, and 2) height estimation. These processes use the 2D NIR and 3D point cloud as the main features. The proposed method was demonstrated with highly accurate results in several rapeseeds, illustrating the potential of this method to become a basic tool for crop characterization in plant sciences.

Keywords: phenotyping, 3D imaging, spectral imaging, plant detection, point clouds, field trails, agricultural machinery

1 Introduction

The plants' growth characteristic is one of the key features to determine the comparison with genetic and phenomic properties in plant breeding studies [Bu13] and to optimize the quality of seed [Ha20]. Two important parameters within this characteristic are plant count and height, specifically for small plants during field emergence. According to state of the art, these parameters are determined manually by the workers by using handheld tools like a ruler and laser distance meter. However, these parameters are subjective and time-consuming to determine and create a demand for objective, reliable, and highly automated measurements. Based on this demand, new technologies, such as drones and driving machines with serval sensors, are more and more used in seed breeding research during the last years [Ni20].

This work illustrates the use of sensors on driving machines (e.g., plot divider) to determine the plant count and height for small plants in the early stages of rapeseed. For this 3D laser scanners and RGB cameras are usually used to get the data to analyze the

[1] Hochschule Osnabrück: COALA, Sedanstr. 26, 49076 Osnabrück,
{b.pamornnak, c.scholz, d.nieberg, matthias.igelbrink, a.ruckelshausen}@hs-osnabrueck.de

results, which is a highly complex system [Bu13]. To solve this highly complex, reduce the number of sensors and the needed overlay calibration, the multi-wavelength laser line profile (MWLP) system was developed [St17]. This sensor combines selectable spectral characteristics and 3D information reflected from the high-intensity laser light sources (400 – 1000 nm) without any postprocessing for matching the data. With the 2D images and 3D point cloud information, this sensor was implemented on the field robot BoniRob and demonstrated with the 3D pattern calibration and automatic data acquisition system for rapeseed [Sc19].

Based on the MWLP sensor system's advantage, this work describes a method for plant counting with height estimation based on the MWLP sensor system installed on a plot divider machine [Ni20]. The method consists of two main steps. In the first step, the plant detection process uses the basic preprocessing and morphological methods with a 2D image to make a plant mask, which overlays the 3D point cloud image to identify the plants in the 3D point cloud. In the second step, plant height estimation uses the histogram analyzer to differentiate the distance between ground level and leave position. All plants in the whole plot area will be detected with their height characteristic from both illustrated steps.

This article is organized by addressing the MWLP sensor system installation and plant characterization method in Section 2. The implementation results will be demonstrated in Section 3, and the conclusion will be discussed in Section 4.

2 Material and methods

This section describes the machine implementation to be used on the field plots. The MWLP sensor system installation will be described first, followed by the plant characterization method, including plant detection and plant height estimation.

2.1 The MWLP sensor system installation

Figure 1 shows the MWLP sensor system installed on the mobile adjustable sensor holder platform on the plot divider machine, a Haldrup D-45 (Haldrup GmbH, Germany). Based on the light-controlled condition, the covered scanning area has been used to protect the image from external interference. Figure 2 shows the MWLP implementation workflow with a multi-spectral camera and three selectable light sources, red (650 nm), green (520 nm), and near-infrared (NIR, 850 nm), that cover the soil and leaves color characteristics. The calibration process uses the sensor level adjustment and a calibration template based on calibration software. The defined basic geometric dimension of the test object will be verified by the testing process. After the MWLP sensor calibration was verified, the MWLP sensor is ready to use in the field experiment.

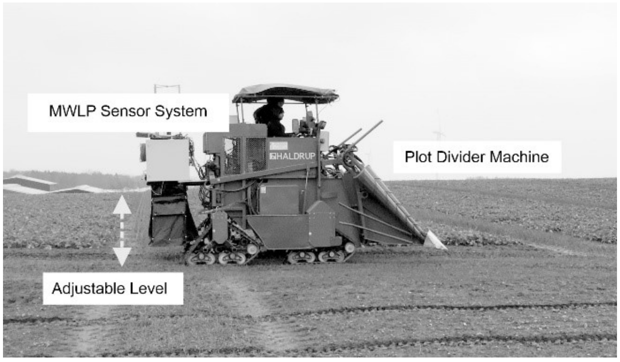


Fig. 1: The MWLP Implementation

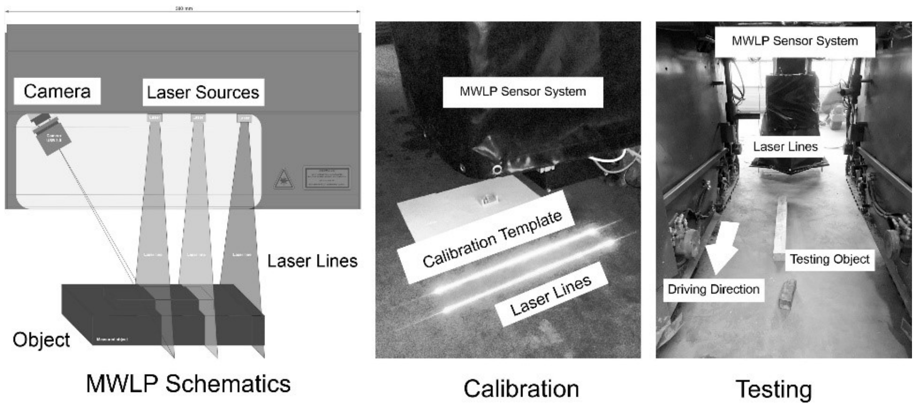
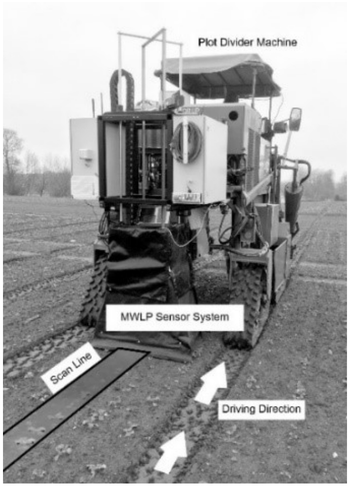


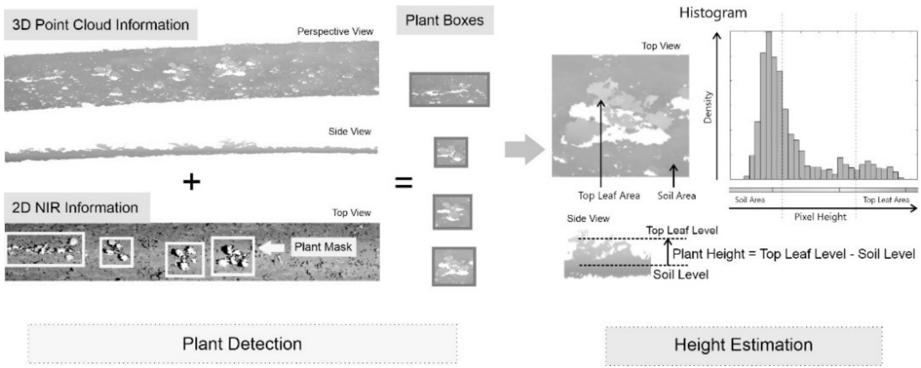
Fig. 2: The MWLP implementation workflow

2.2 Plant characterization method

Figure 3(a) shows the experimental setup with a plot divider machine and a calibrated MWLP sensor system. The sensor setup synchronized with the machine speed to correctly map the point cloud dimension in the acquisition process. This experiment was demonstrated in the rapeseed field in the NPZ-Innovation area (Hohenlieth-Hof, Holtsee, Germany). The entire field area was separated into subplots and selected the middle row of each plot to make a sample data called "Scan Line". This work used the MATLAB (MathWorks, USA) software to evaluate the plant characterization method. The system diagram consists of two steps, a plant detection and a height estimation, as shown in Figure 3(b).



(a)



(b)

Fig. 3: (a) The experimental setup showing the fully implemented system and (b) the two step plant characterization method with plant detection (left) and height estimation (right)

The first step is the plant detection method. This step takes the 3D point cloud information from three wavelengths, red, green, and NIR, into the array of XYZ positions for each wavelength without any matching process. The different grey level (from dark to light) represents the height level of soil and plants that varies by the soil surface curve due to the experimental field not being a flat area. By observation, the human can identify the plants and the soil from the 3D perspective view. Nevertheless, the machine vision system requires 3D color, and NIR information to locate the plant from the various soil levels. Due to the different reflection rates between the soil and the plant from red color and NIR wavelength, the normalized difference vegetation index (NDVI) technique or the NIR signal threshold have been used as a typical method in various work and these techniques can be used with the MWLP system. In this work, the threshold level of 2D NIR information from the top-view was optimized with image processing and morphological operations (such as median filtering, dilation, and erosion) to create a plant mask. After application of the plant masks to the 3D information, the plants on their soil area were evaluated into plant boxes.

The second step is the plant height estimation method. Based on the assumption that the low positions are soil and the high positions are plant leaves. From the histogram of each plant box, the mean value of 30 % from the lower level, called "soil level" and the mean value of 30 % from the upper level, called "top leaves level" are evaluated. The plant height can be assessed from the difference between these values.

3 Results and discussions

This section shows the plant characterization results of the first experimental setup for plant counting and plant height estimation compared with the human visualization based on the high-resolution raw data with plant heights between 2 and 16 cm. For the plant counting, 809 rapeseed plants have been used for testing. Figure 4(a) shows the plant counting correlation between the human inspector and the MWLP system. An R^2 value of 0.87 shows the potential to use the MWLP system to count the plants in the field. Figure 4(b) shows the correlation of plant height estimation between the human inspector and MWLP sensor system for 151 rapeseed plants. An R^2 value of 0.98 shows the high accuracy of the plant height estimation method. For the repeatability test, two each repetition have been executed, **Test #1** (T_1) for the first test run and **Test #2** (T_2) for the second test run. To evaluate the method precision, Figure 4(c) shows the correlation between T_1 and T_2 with an R^2 value of 0.98. These values show that the plant height estimation method as well as the corresponding technical repeatability are of high accuracy.

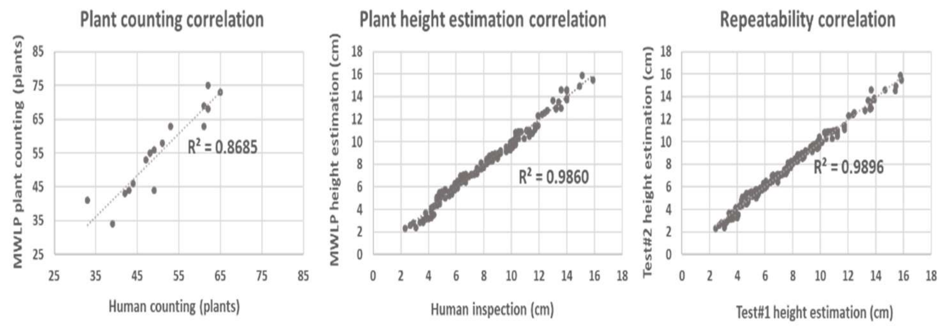


Fig. 4: Plant characterization method correlation results, (a) plant counting correlation, (b) plant heigh estimation, and (c) technical repeatability.

4 Conclusion

The first setup of a plant characterization method with the MWLP sensor system was implemented into an agricultural field plot divider machine. The sensor was installed with controlled lighting, adjustable levels and uses the software pattern calibration. The proposed method achieves plant detection and height estimation based on image processing technique. The technology has been applied in rapeseed field plots, with R^2 values of 0.87 for plant counting, 0.98 for plant height estimation, and 0.98 for the technical repeatability. The results illustrate the potential of the MWLP sensor system- implemented in a plot divider machine – for field-based phenotyping.

Acknowledgments

This work has been financed within the RapiD project and funded by the Federal Ministry of Food and Agriculture (BMEL), Germany and the Agency for Renewable Resources (FNR), Germany.

References

[Bu13] Busemeyer, L. et al.: BreedVision—A multi-sensor platform for non-destructive field-based phenotyping in plant breeding. Sensor Journal, 13(3), S. 2830-2847, 2013.

[St17] Strothmann, W. et al.: Plant classification with in-field-labeling for crop/weed discrimination using spectral features and 3d surface features from a multi-wavelength laser line profile system. Computers and Electronics in Agriculture, 134, S. 79-93, 2017.

[Sc19] Scholz, C. et al.: Multi-wavelength laser line profiling (MWLP) System zur feldbasierten Bestimmung von 3D Strukturen, spektralen Eigenschaften und Wachstumsparametern von Pflanzen. In Bornimer Agrartechnische Berichte, Heft 102, S. 127-135, 2019.

[Ha20] Li, H. et al.: High-throughput phenotyping accelerates the dissection of the dynamic genetic architecture of plant growth and yield improvement in rapeseed. Plant Biotechnology Journal, 18, S. 2345-2353, 2020.

[Ni20] Nieberg, D. et al.: Mobiles Hochdurchsatz-Phänotypisierungssystem für Feldversuche in Raps. In (Gandorfer, M., Meyer-Aurich, A., Bernhardt, H., Maidl, F. X., Fröhlich, G., Floto, H. (Hrsg.): GI Edition Proceedings Band 299 - Informatik in der Land-, Forst-, und Ernährungswirtschaft Proc. Referate der 40. GIL-Jahrestagung, Freising-Weihenstephan, S. 205-210, 2020.