SENSOR BASED SYSTEM TO DETERMINE THE HEIGHT OF TRITICALE IN FIELD TRIALS

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ABSTRACT

Due to the growth of population and changing surrounding conditions, plant breeders are in demand to deliver new effective cultivars of crops. Phenotyping of field trials plays a decisive role in this challenge, which is typically performed by experts rating randomly selected plants of each test plot. Sensors and system technologies can help to facilitate this work and provide the opportunity to judge more than just a few plants of a plot.

In this paper the authors will show, that with the use of a 3D Time of Flight (ToF) – Camera it is possible to measure the height of triticale in field trials under outdoor conditions. By using modulated light sources this kind of sensor calculates the distance to measured objects independently for each of its 64 x 50 pixels. The compact and robust camera can be easily integrated in existing agricultural machinery or phenotyping platforms and collects data while driving through the test plots. As part of the project "BreedVision", supported by the German Federal Ministry of Education and Research, the system was successfully developed and tested with approx. 800 triticale plots in four different growing stages. Two different methods were developed to prepare and evaluate the generated raw data for an automatic determination of the plant heights. These results were correlated to the manually taken measurements. While both methods show good results in early growing stages (R^2 between 0.78 and 0.85), the second method, "combined method", performs better in later growing stages and also in reproducibility.

Keywords: plant phenotyping, 3D Time of Flight – camera, field trials, sensors

INRODUCTION

The growth of world population, climate changes, use of crops as biomass energy, request of high resistance against plant diseases and low input conditions are new challenges for plant breeders developing new cultivars. Phenotyping is a key technology to evaluate plants in field trials. The benefit of analysing this information is the ability to develop strategies for new procedures and systematic hybridisation of different cultivars. For example, typical parameters of interest are height, progress of growth, yield, biomass and diseases. As an instrument for the systematic characterization of plants in different growth stages, standard measurement scales have been developed. The BBCH-scale (Meier 2001) is such a kind of decimal code for identifying the phenological development stage of cereals. For example: Code 11 means "first leaf unfolded", code 65 "full flowering: 50% of antohers mature". An excerpt of the BBCH-scale is shown in Fig. 1.

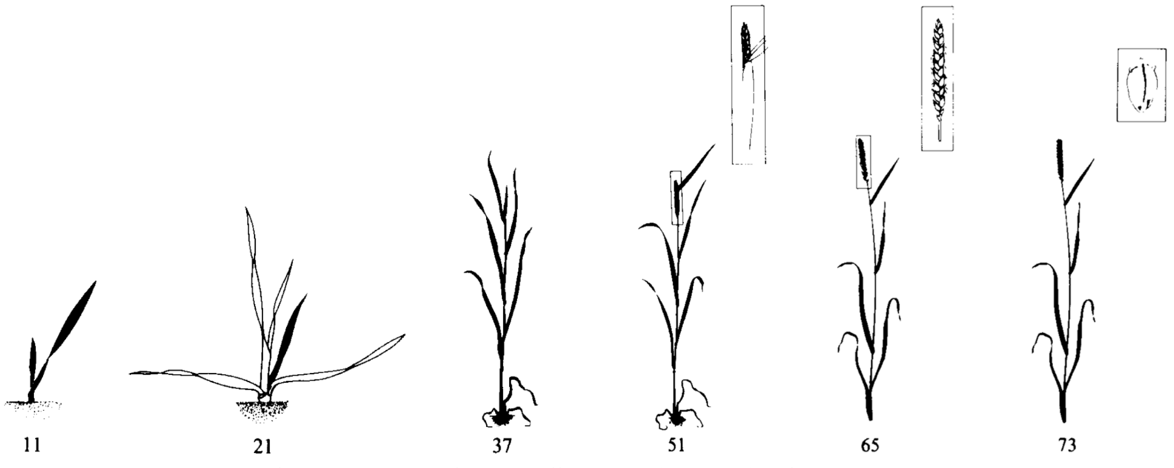

Fig. 1: Excerpt of the BBCH-scale (weed), (Meier 2001)

Until now, the analysis is typical executed manually by experts judging the field situation by characterizing random samples of a field plot. The result is a statistical overview of the plant's physical characteristics in the field. Since this analysis has to be done manually, it is very time consuming, generates high costs and has a varying reliability. Moreover, phenotyping is performed by different experts, this may cause additional

variations. Taking these effects and the fact that the data set represents a statistical overview of the field situation into account, it is often difficult to compare data sets or to develop new strategies.
As a consequence, the implementation of sensors, system technologies and algorithms for automatic phenotyping are of increasing importance to overcome the disadvantages of the manual methods described above. While static and greenhouse measurements – typically imaging applications – can be performed under well-defined conditions, online applications under 'real' field conditions on moving vehicles are still a challenge for corresponding technologies. Vibrations and uneven ground need solid built sensors and robust algorithms. In the following chapters, the authors present a system measuring height of Triticale field plots.

MATERIALS AND METHODS

Functional principle of 3D Time-of-Flight cameras

Fig. 2 (a) shows the measurement principle of a 3D Time-of-flight (ToF) camera as shown in Fig. 2 (b). It calculates the distance to objects by measuring the phase shift φ_0 of a reflected light signal to the phase of the light signal of their light source for every pixel of a built-in CMOS chip. Therefore the modulator of the light source is directly connected to each pixel. For illuminating a 3D scenery most of the ToF cameras using LEDs with a modulation of $f_{mod} = 20$ MHz. This frequency results in an unambiguousness measurement range of 7.5 meter calculated by the equation below.

$$d = \frac{c \cdot \varphi_0}{4\pi \cdot f_{\text{mod}}}$$

The advantage of Time-of-Flight cameras compared to technologies like stereo imaging, laser-line methods and laser scanners is their ability to generate real-time images of all three dimensions and an additional grey-scale image of the measured reflection without any additional extensive calculations.

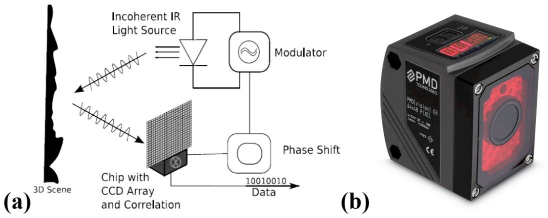

Fig. 2: (a) ToF phase-measurement principle (Kolb et al. 2008), (b) PMD 3D ToF Camera (PMDTec 2007)

Layout of the recording system

As part of a complex sensor system, an ifm M01594 3D-ToF Camera (identical to PMD O3D Vision) with a resolution of 64 x 50 pixels, a viewing angle of 40° x 30° and 20-25 frames per second was mounted in the viewing direction to the ground on a trailer. The trailer is pulled with a speed of 2 km/h from a high-clearance tractor, to avoid an irritation of the crops while driving through the plots. The recorded data is saved with a time- and positionmarker in a database. The technical layout of the system is shown in Fig. 3: A router with a linux based operation system has a clock that is synchronized over the Network Time Protocol (NTP) on an Industrial PC. A development board, which is connected with a rotary encoder, sends a UDP broadcast with the actual position to all connected devices. On the router, the 3D camera raw data is combined with timestamp and position and is transmitted to the Industrial PC that stores the data in a MySQL database. Most connections to the different devices are realized by using standard network components. A quite simpler structure is possible by using just a 3D-Camera and a PC (e.g. Notebook). Therefore an installation on existing tractors or other agricultural equipments can be easier but has disadvantages in expanding the system with other sensors and the analysis of the recorded data is through the missing rotary encoder more difficult.

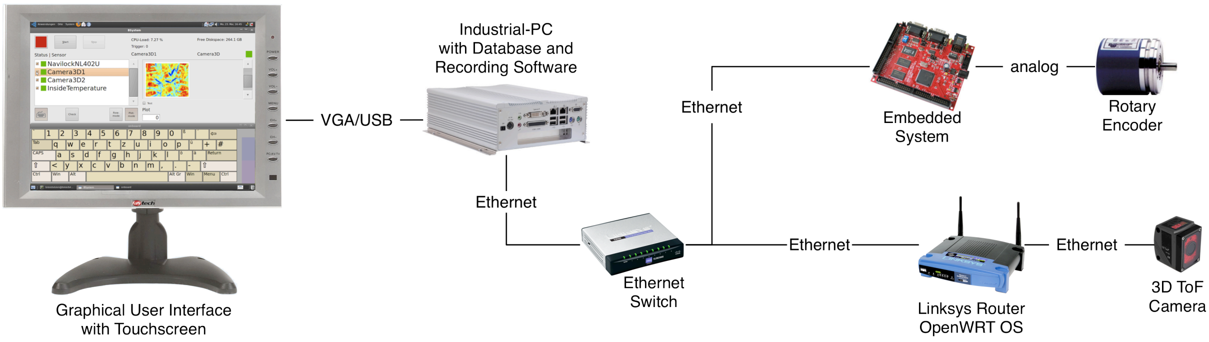

Fig. 3: Technical layout of the recording system

Field Plots

In 2010, a set of different Triticale species on 200 field plots was planted. Each field plot had a size of 1.25 x 4.5 meters and about 1.5 meters space to the next plot. Weed between the plots was removed for an easier determination of the beginning and end of a plot. At 4 different growth stages of Triticale (ear emergence, flowering, milk/dough ripeness and full ripeness) plant height of the 200 plots was measured manually and with the described sensor system, which was attached to the phenotyping platform BreedVision (Busemeyer et al. 2010). That results in a total amount of 800 field plot datasets in different growth stages, measured manually and digitally.

Data Recording Process

An important task is the mapping of measured data to a specific field plot. First step was starting and stopping a recording manually after each field plot and save the number with a time marker in the database in order to find the correlated 3D camera data. This correlation is very save but also very time consuming. In next step a manual start and stop is only needed at the beginning and end a row of with several plots. The range of every plot can be identified by algorithms using the 3D Camera data and is saved to the database.

Determining Plant Heights

In general, measuring the height of an object with a 3D-ToF Camera mounted as described above that is located on the ground needs a least two variables: the distance from the camera to the ground (*dg*) and the distance from the camera to an object (*dp*) as shown in Fig. 4. While working under constant conditions and mounting heights, there's only the need of measuring the distance to the ground once. If working under changing conditions like different grounds (soft ground vs. hard ground) or flexible and height adjustable mounting, there is a need for periodical measuring the distance between ground and camera.

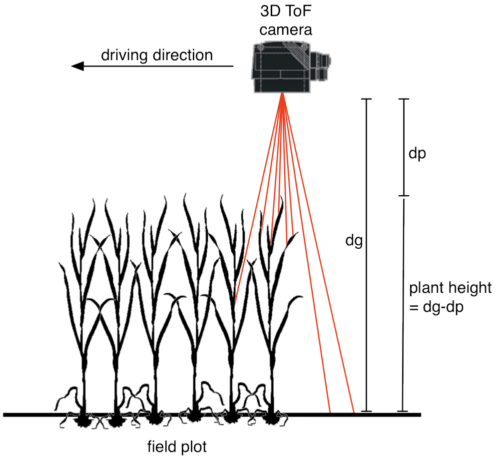

Fig. 4: Principle measurement setup: The distances *dg* and *dp* can be determined by a 3D ToF camera to calculate the plant height

Referring to Klose et al. (2011) a modified version of a statistical evaluation was developed. Fig. 5 (a) shows histograms of the distances recorded by the 3D Camera. It is easy to identify the field plot in the middle of the image. Fig. 5 (b) shows an overview of the minimum, maximum and most values of the histograms. By regarding the first and last histograms of one plot, the ground level can be defined by taking the distance with most values and, if they differ, calculating an average value (in this case shots 1-8 and 33-35). But this way isn't applicable for determining the distance between camera and crops. While the ground is more or less even, crops are jagged when looking from top view and there is only a small part of the plant that is relevant for taking the distance. Therefore, when looking at the right image, the difference between the most measured and the nearest measured values is significant higher within the shot then between two plots. Therefore an average value of the nearest measured values of the different shots is taken and subtracted from the ground level.

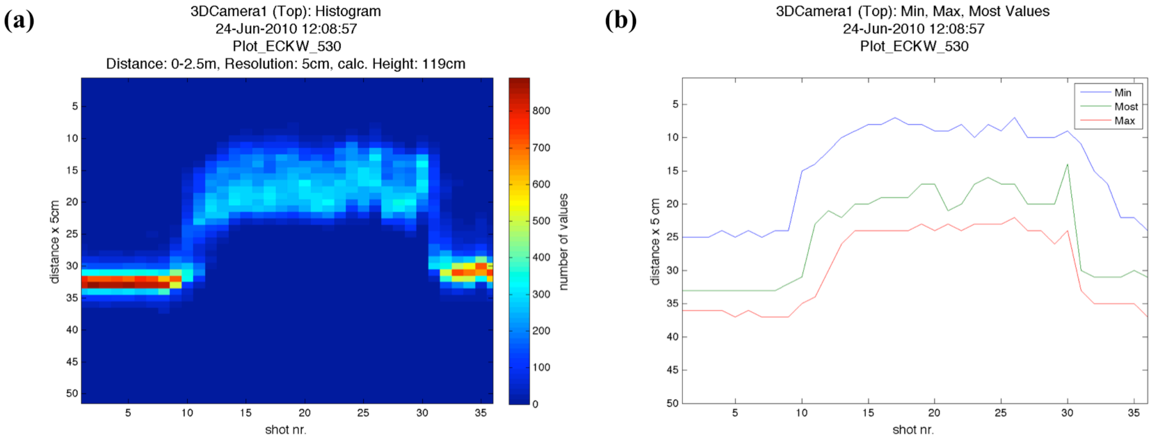

Fig. 5: (a) 3D-Camera histograms of a field plot. (b) Min, max and most values of this plot.

Because of the low driving speed (about 0,6m/s) and a frame rate between 20 and 25 frames per second, there is an overlap of successive pictures. Fig. 6 shows 3 successive shots of a 3D ToF camera in false colors. The bottom in the left picture is the middle part of the middle picture and the top part of the right picture. Therefore, many values reused for the calculation for several times.

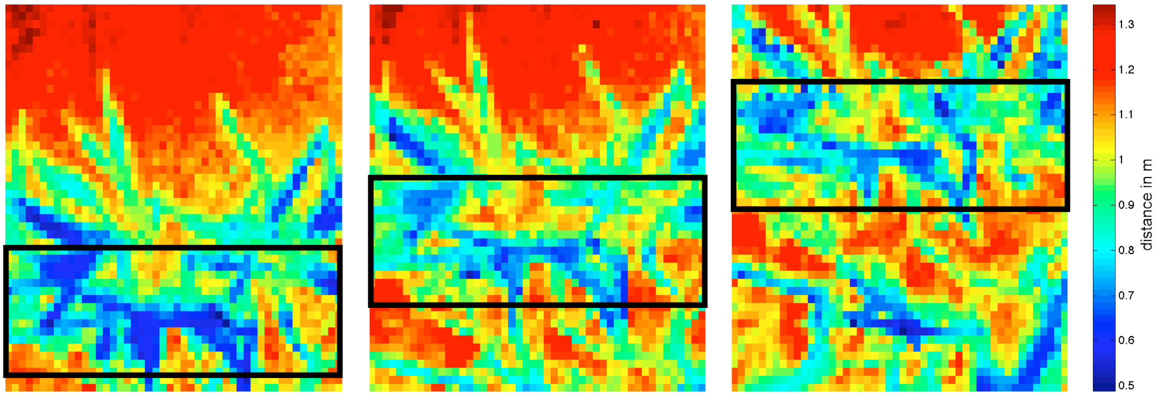

Fig. 6: 3 successive recordings of the 3D Camera

To avoid this, there are different possibilities to combine the different shots into one. One method is of course pattern recognition, but this is quite complex in comparison to the following:
The distance driven between two successive frames can be easy calculated with the value of the rotary encoder of two successive shots. But to combine the images at the right section, it is necessary to know the size of one pixel. By using the formula below, the width or height s of a pixel can be calculated depending by the measured distance d, the angle of aperture α and the number of pixels in x- or y-direction N:

$$s = 2 \cdot \frac{\tan(\frac{\alpha}{2})}{N} \cdot d$$

An example for a calculated 3D image for a complete plot is shown in Fig. 7. When composing the different frames to a single picture, as much as possible data was taken from the centre of a frame to minimize lens distortions. Beside data reduction the quality enhances, too. In opposite to the above described method, the distances from the first and last pixel rows are taken as average to define the ground level. This kind of calculation generates better results (as discussed later). To determine the height of crops, also the closest distances as average are taken from the pixel rows within one plot.

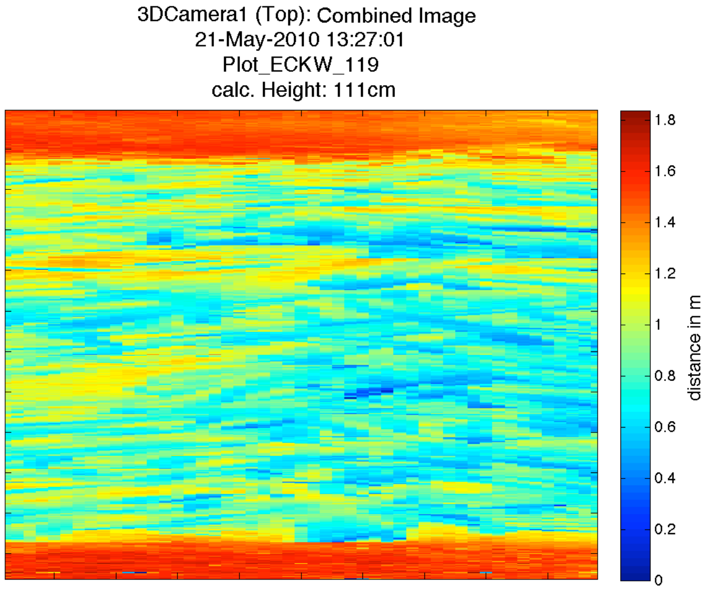

Fig. 7: Combined 3D image of a complete field plot

RESULTS

Discussion

The results of both above described methods were correlated to the manually measured data. Fig. 8 shows the results with the first described method, Fig. 9 the second with the combined 3D image.

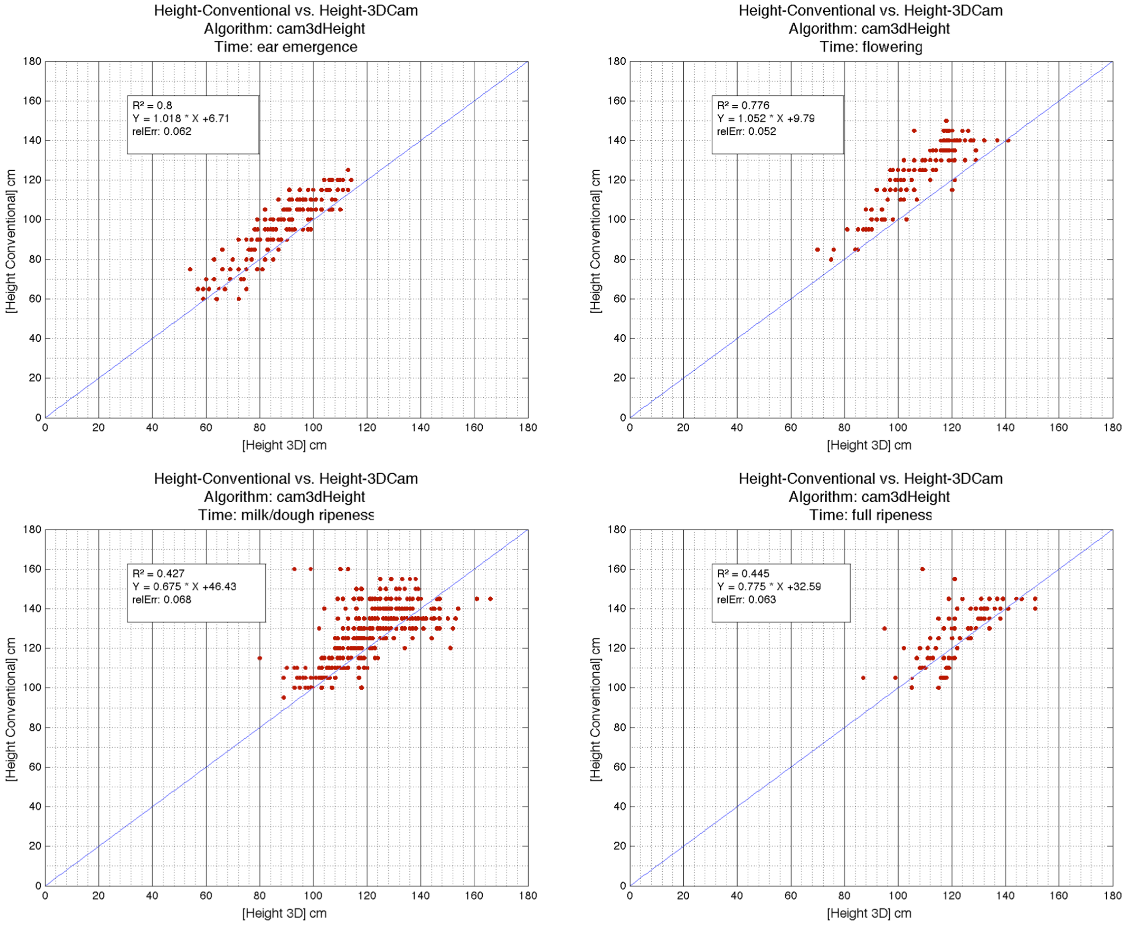

Fig. 8: Results of histogram based method (ear emergence, flowering, milk/dough and full ripeness)

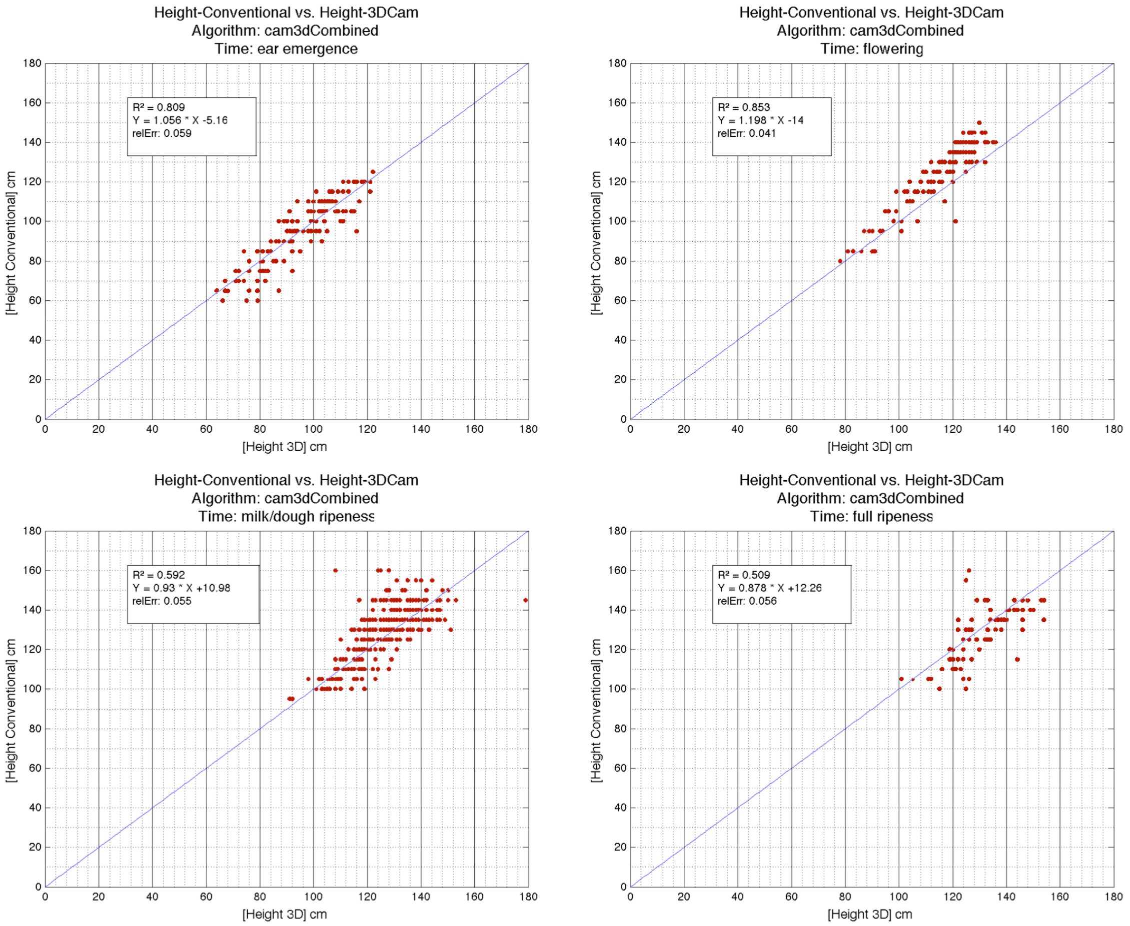

Fig. 9: Results of combined method (ear emergence, flowering, milk/dough and full ripeness)

In the first two stages, both methods generate good results. The second method performs slightly better. One reason is the different calculation of the ground level (as described above) another one the combining of the different shots to one. Noticeable is the declining correlation in later stages. This is partly caused by the type of measuring the plant height and the clearance height of the used tractor: The randomly selected plants get elongated, ‘hanging’ ears get raised. The plants also lose flexibility in later growing stages through increasing dryness and don’t go back to standing position. With the low error rate in early growing stages, both methods are good suitable for determining crops height.

Through the high overlap of the successive pictures, also a higher speed can be performed. However, costs for disk space are small: 800 plots produce circa one gigabyte.

Reproducibility

The third of the four measurements during the early milk and soft dough ripeness (the grain content is between milky and soft dry) was measured two times to check the reproducibility of both methods. Fig. 10 shows the results of this test.

As well, the combined method with a R^2 of 86,4% has a better reproducibility than the first method with R^2 of circa 70%. Because of the problems described above, beginning at this growing stage, the technical reproducibility in earlier stages should even be better.

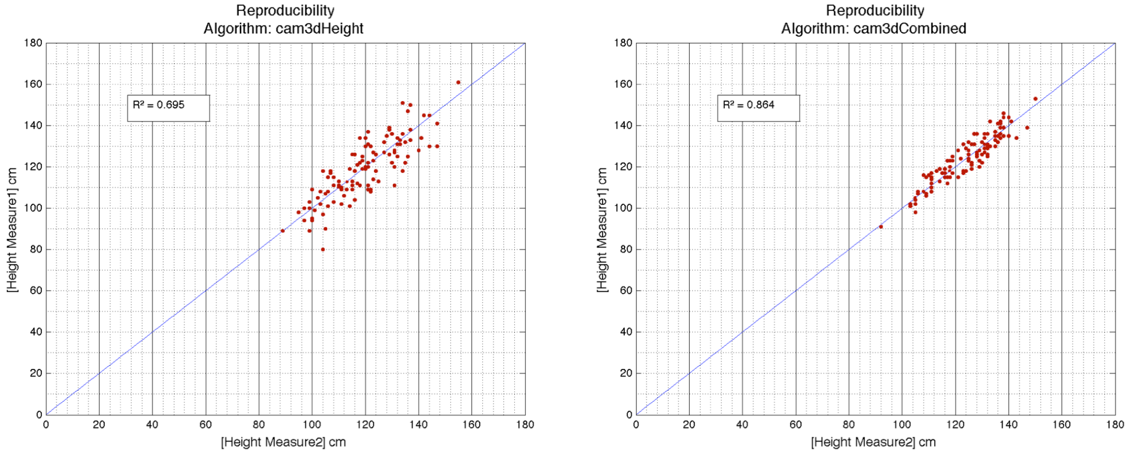

Fig. 10: Reproducibility

CONCLUSIONS

The analysis has shown that ToF cameras are usable for determining the height of Triticale in field plots under outdoor conditions. In first approach, both developed methods provide good overall results, especially in early growing stages of crops. Through further work on algorithms and accommodation on existing conditions even better results can be achieved. Due to the limited quality and reproducibility of the conventional measurement of humans, however, the better quality of the 3D-ToF-measurements and algorithms might not be expressed in terms of increased correlation coefficients. The system can be flexible integrated in existing agricultural processes and relieves plant breeders a part of their complex phenotyping process.

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