GIS- and sensor-based technologies for individual plant agriculture

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Abstract

An increasing world population and thus a higher demand of agricultural products require optimization in agricultural processes. To become more efficient a better knowledge of the current plant status in the fields is necessary. To get detailed information about the plants the authors developed the autonomous platform “BoniRob” with a first application in plant breeding especially plant phenotyping. An integrated sensor system with several different sensors provides the authors with a high data volume. Developed algorithms analyse the data in terms of plant detection and plant parameter determination. Combining this calculated information with a geographic information system (GIS) affords a capable plant database and various further analyses. The clearly illustration of the plant data could easily lead to application maps with instructions for manuring depending on the plants height for example. The automated single plant detection and phenotyping therefore gives the opportunity for single plant treatment and thus is the step from site-specific to single plant agriculture.

Introduction

Due to global demands with respect to food, energy, environmental pollution, limited resources and climate changes, agricultural processes and corresponding technologies have to be optimized with respect to high yield and low input [1]. Thus Computer sciences combined with electronics and sensor technologies have become key technologies in agriculture. The introduction of these technologies, often named precision agriculture, offers for example options for site-specific treatments, thereby aiming at economical as well as environmental benefits.

In order to have a stronger reduction of environmental impact caused by agricultural processing itself, latest technologies enable the user to have a look at the single plant for low-density crops (e.g. maize) or at a cluster of plants for high-density crops (e.g. wheat) [2]. The authors have developed sensor and system technologies for individual plant crop scouting used for plant breeding research [3]. In order to apply these technologies under economical reasonable boundary conditions the development of autonomous vehicles is one of the most promising options. As compared to large machines small autonomous vehicles can reduce soil compaction. Furthermore due to the fact that phenotyping is mainly performed by experts manually judging samples of plants on a field and thus an expensive and time consuming operation there is a need for automated phenotyping platforms with high throughput [5]. For these reasons recently the authors have developed the autonomous crop scout BoniRob (see Fig. 1) for individual plant phenotyping [4].

Fig. 1: The autonomous field scout “BoniRob” in field trials

In this paper, GIS- and sensor-based technologies for individual plant agriculture using the autonomous field robot BoniRob are presented. Therefore, the determined plant parameters, based on measurements of the BoniRob, are imported into the open source Geographic Information System (GIS) OpenJUMP to have a database for every single plant in the field plot. Thus the interpretation of data by agricultural experts and farmers corresponding knowledge-based instructions can be improved. In this work GIS maps are generated for single plants with specified parameters, such as the plant GPS coordinates, plant height, spectral properties or number of leaves. Additionally imaging data could be included. Since the global plant position is saved within the individual plant dataset, it is possible to redetect the plant by using a RTK-DGPS system. This enables the user to perform the phenotyping at different growth stages in order to analyze the growth process of the single plants. This application has a very high potential for crop scout applications in agriculture.

Sensor technology of the autonomous field scout BoniRob for plant phenotyping

Phenotyping has become extremely important for seed breeding purposes but it is the bottleneck in breeding trials because of low automation [5]. To perform an automated phenotyping of maize plants the authors used different sensor technologies to determine plant parameters like plant height, number of leaves, stem thickness or spectral properties and the precise location of each single plant on the field. Table 1 shows a list of sensors and the plant parameters detected using different sensor data. Thereby the dark grey bordered parameters are directly given by navigation sensor data while the light grey bordered parameters are calculated out of data from sensors applied for morphological parameter detection. The additional marker points show which information is reused for further calculation.

Table 1: List of used sensors with plant parameters calculated out of their data

Light Curtain	3D Camera	Triangulationsensor	Spectral Im.	GPS	Rot. Encoder
●	●	●	●	●	relative Position
●				absolute Position (NMEA)	
Position (Stem + Start,Stop)	●	●	●		
		Stemthickness			
Plant distance					
Height	Height				
Width					
Area (Side)					
Quantity					
	Area (top)		Area (top)		
	Leaf area index		Leaf area index		
	Number of leaves				
	●		Humidity image		

During a measurement all sensor data are put into a mySQL database and are labelled with the actual time and position value. After the measurement algorithms developed by the authors using the software package MATLAB, analyse the data in order to calculate the desired plant parameters of the single plants.

Data analysis for plant parameter generation and positioning

The first application of BoniRob is to measure each single maize plant on a field several times in different growth stages also many other applications for BoniRob were thinkable e.g. single plant treatment with fertilizer. Beside the calculation of various plant parameters the challenge was to detect and redetect each plant to be able to observe the development of these parameters during the lifecycle of the plants. In order to assign calculated parameters to a specific plant its structure has to be recognized as a plant first and thereupon the position of the stem has to be detected. The algorithm for plant detection analyses the light curtains data. As shown in Figure 2 out of this data a side view shadow picture of the plants is build up. In a first step this displayed structures are reduced to a skeleton. After that the algorithm analyzes the branch structure of the skeleton. Thereby it checks the height of the structure and counts the number of branch and endpoints of the plant’s skeleton which is an indicator for the number of leaves.

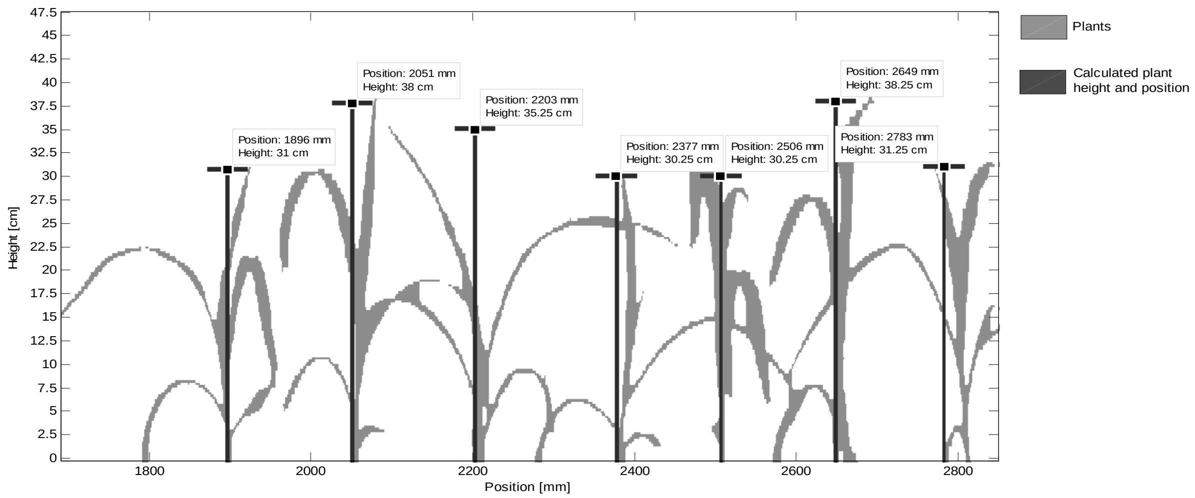

Fig. 2: Profile of measured maize-plants marked with calculated height and position

Since the overlap of the leaves of neighbouring plants can lead to incorrect results, several conditions were implemented to stop the run through one structure and let the algorithm start at the ground again to analyse the next structure. In this case, the position within the skeleton which led to the stop condition is considered to be an endpoint of the two neighbouring plant's skeletons.

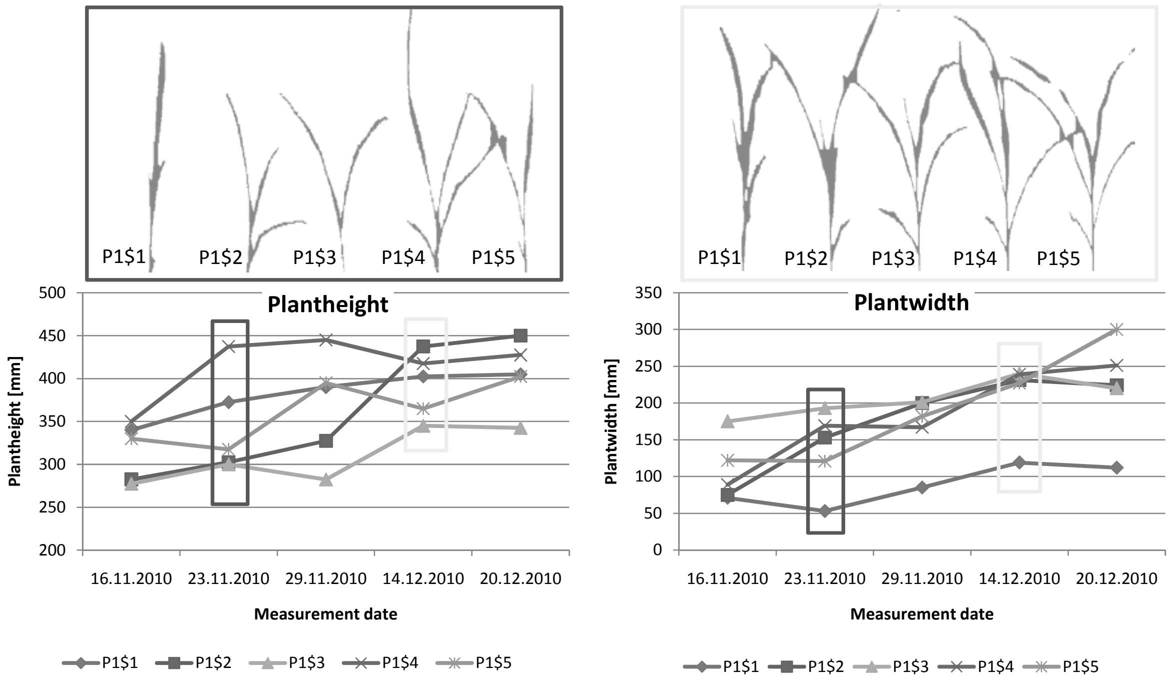

Fig. 3: Profile view of measured maize plants at different growth stages

If the determined skeleton meets some constraints like a predefined height, a minimum distance to the previous plant's position and at least one branch point, the analysed structure is recognized as a plant and the relative position, represented by the lowest point within the skeleton structure, (see Fig. 2) is combined with a precise GPS-position. All determined information for each plant is then stored in data structure with a unique ID. With the combination of GPS information and light curtain data, the authors were able to redetect plants measured five times within a time period of five weeks. Figure 3 shows a set of maize plants with their unique ID at two different growth stages. Underneath two diagrams display the development of the two parameters plant height and plant width during the period of five weeks. Additionally the upper displayed states are marked with frames in the diagrams. With this dataset, a base for the analysis of the growth process of single plants is given.

GIS-Technology as plant database and for application map creation

Transferring the obtained dataset into a geographic information system like OpenJUMP gives efficient overview over the plants as well as multiple tools for further analysis. Additionally, the GIS system could be used as capable plant database for the individual plants and their allocated parameters [6]. As displayed in figure 4 GIS maps could be created illustrating e.g. the relative plant height through circles with varying diameter to have directly an overview of the plants' growth process in the whole field plot. This information could for example be used in order to develop new strategies like the individual application of fertilizer. This application maps with a clearly presentation of the plants condition could fast lead to operating instructions for plant treatment and could make agriculture more efficient in terms of time and resource consumption. Figure 4 shows a GIS map from OpenJUMP with maize plants from three maize rows on a test field pictured as dots. The circles describe the relative plant height while the histogram in the right also displays an overview over the plant height.

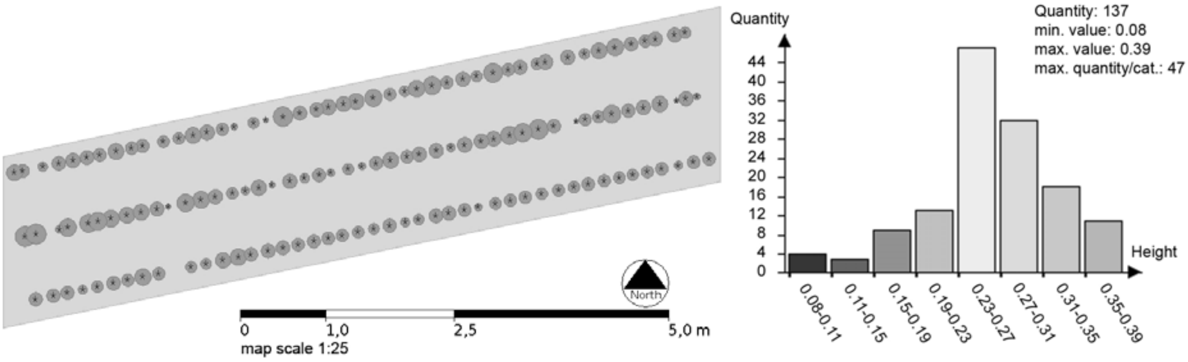

Fig. 4: left: GIS map with three maize rows; right: histogram of the plants height

Every plant in the map is thereby linked with the complete plant parameter set and image data to be able to have a fast detailed look at specific plants. With this option for single plant measurement and analysis one of the next steps could be the development of accessory equipment for single plant treatment.

Conclusion

An autonomous vehicle for agricultural purposes with modular and very complex system architecture was developed. With a first application in plant phenotyping of maize the authors were able to detect each single plant on test field plots labelling them with a unique id and a GPS position. Also the authors have the ability to determine different morphological parameters of each plant and re-detecting them on repetitive measurements in order to observe growth stages of plants and give conclusions about their behaviour. The combination of the flexible carrier platform with complex sensor systems, specific data reduction for plant parameter calculation and a GIS-tool like OpenJUMP as plant database and for evaluation of agricultural processes provides extremely high potential for individual plant treatment. Furthermore it gives possibilities for agricultural processes with less input and more output due to the fact that every single plant gets a special treatment corresponding to its needs.

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