Multi-sensor simulation method for outdoor plant phenotyping based on autonomous field robots

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Abstract: Based on an existing field robot for outdoor plant phenotyping a simulation environment has been built up for multi-sensor simulation. The development environment Microsoft Robotics Studio, typically used for 3D robot navigation purposes, has been adapted to this application by creating services representing sensors such as 3D-Time-of-Flight cameras, light curtains, color cameras, GPS or incremental encoders. As the real robot the virtual sensor data are stored in a data base and can be analyzed with sensor fusion algorithms. First comparisons of real and simulated data show good overall agreement, in particular an artificial plant and its corresponding virtual counterpart have been compared. There is a high potential of the new method for plant phenotyping purposes as well as for other field robot applications.

Keywords*:* Simulation and modeling, sensors, plant phenotyping, field robots, field trials

1. INTRODUCTION

Food production, energy consumption, limited food production, energy consumption, limited resources and climate change are challenges for present and future sustainable agricultural processing. This strongly effects plant breeding, where high yields for food and energy production processes should go along with low input applications due to environmental damages. While genotyping technologies have reached a high level, the evaluation of the plants within field trials is still a problem. Until now typically a few samples are evaluated by experts, which is very time consuming, generates high costs and may cause uncertainties for the optimization of the breeding or other agricultural processes. On the other hand technical innovations in sensor and system technologies offer the option for automatic plant characterization. This topic – typically called “phenotyping” – has come increasingly into focus for research purposes (Montes et al. 2011). The authors are working in this research field and have applied sensor systems on newly developed phenotyping platforms for field trials (Busemeyer et al. 2010). In particular the influence of several environmental parameters and field parameter are a challenge for outdoor sensor application and data interpretation. Thus the usage of different sensors with varying selectivities is a promising approach to increase the robustness of outdoor sensing (Ruckelshausen et al. 1999) followed by sensor data fusion algorithms (Mitchell 2007).

Having a look at highly automated field trials, the plant phenotyping process is a possible candidate for first autonomous field robot applications. Such a crop scout has been developed by the authors – called BoniRob (Ruckelshausen et al. 2009) - and is equipped with several sensor and imaging systems for measuring morphological and spectral plant parameters in row cultures, such as maize (see figure 1). Due to the high complexity of the system as well as of the plant phenotyping process the idea came up to simulate the multi-sensor data acquisition process. Such a 3D dynamic simulation has a very high potential with respect to optimizing the sensor arrangements and performance of the multi-sensor system. Examples of sensors are positioning sensors (encoders, gyroscopes, acceleration sensors, GPS), color cameras, spectral sensors, spectral imaging or 3D imaging devices, such as 3D Time-of-Flight cameras, laser scanners or stereo imaging. Having a look at simulation tools already used for robot navigation, these tools are promising candidates for the realization of this idea due to the high level of already implemented sensors including 3D-Imaging (Vajita et al. 2005, Siciliano & Khatib 2008).

FIGURE 1: Autonomous field robot BoniRob

As a consequence the experiences with the real sensors and real robot are used to develop a 3D multi-sensor simulation tool for plant phenotyping based on simulation development software typically used for robot navigation purposes.

2. MATERIALS AND METHODS

Service-oriented architectures (SOA) offer a high flexibility with respect to the application, which can be composed in wide varieties and with a high flexibility. The architecture of Microsoft Robotics Studio (Tsai et al. 2008) satisfies the boundary conditions for the plant phenotyping application with BoniRob (Tsukor 2011) at a high level and has thus been used for further implementations. The software has been used to implement the robot, a maize field and the sensor systems. As an alernative tool ROS (Robotic Operating Systems. ROS 2012) can be applied for the same application.

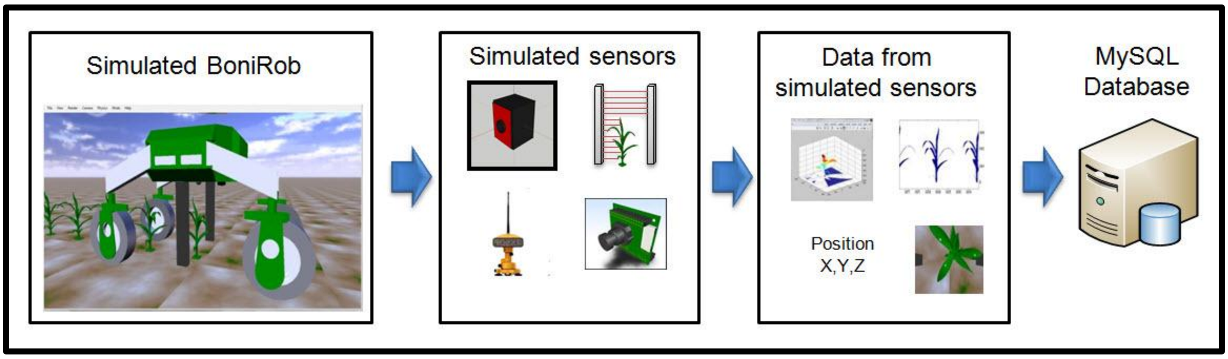

FIGURE 2: Basic structure of the simulation elements

For BoniRob a four wheel model has been implemented, which takes into account the physical parameters and the dynamic options for driving and positioning. The generation of the following sensors includes geometric and (as the major part) technical aspects: GPS,

positioning encoder, color camera, light curtain and 3D-ToF-camera. The data formats and frequencies of the real systems have been emulated, moreover, the data is stored in the data base such as the real data together with time and position stamps for further analysis.
Figure 2 shows the basic structure of the simulation elements: The robot on the field, the emulation of the real sensors, the virtual “measurements” of the sensors during the movement on the artificial field and the storage of the measurement results in a database. The data from the MySQL database are used for offline sensor data fusion and calibrations in order to determine plant parameters such as height, number of leaves or biomass. The data of the virtual field trial with the virtual BoniRob can be stored in the same way like in the real field situation. An overview of the developed software architecture (Tsukor 2011) is shown in figure 3, in particular additional components (such as a user interface) are integrated.

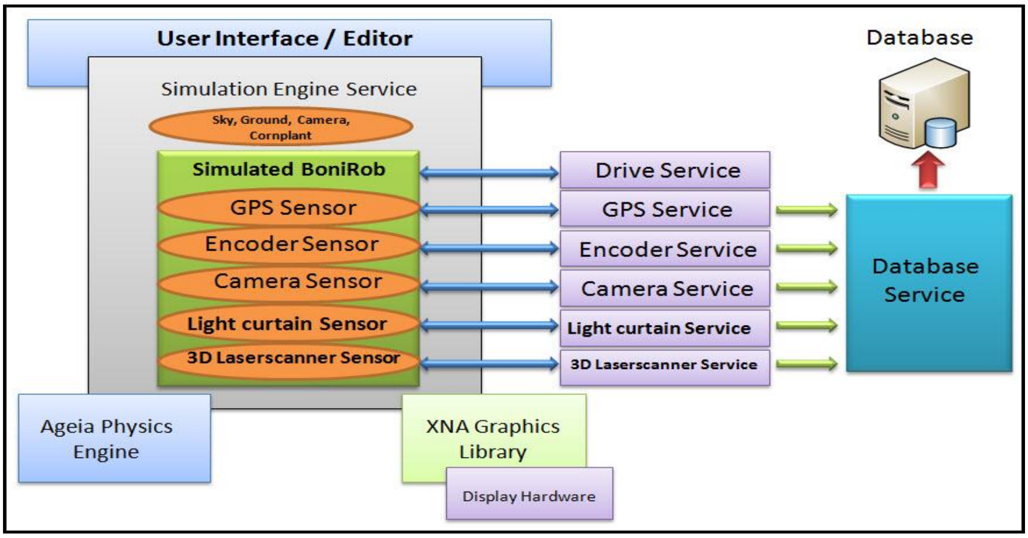

FIGURE 3: Software architecture of the simulated multi-sensor data acquisition

Figure 4 shows the concept of the real and virtual light curtains, which have a high potential for robust imaging in row cultures under field conditions (Busemeyer et al. 2010). The service of the light curtain has been integrated together with the services of other sensor like a color camera. Further options like color filters can be integrated. The usage of 3D Time-of-Flight cameras (Klose et al. 2009) offer a high potential for online 3D image acquisition and have also been integrated in the simulation tool. Positioning is performed via incremental encoders and GPS information. Figure 5 shows an example of the visual environment of the simulation tool.

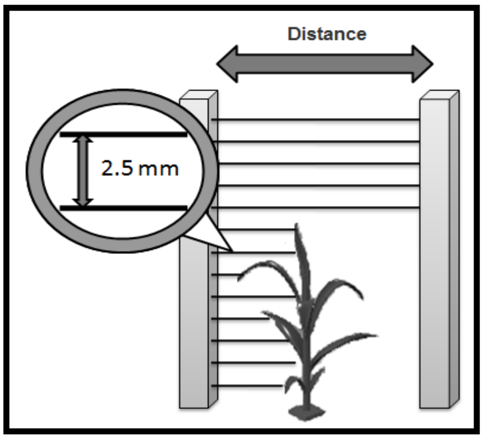

FIGURE 4: Concept of light curtain imaging

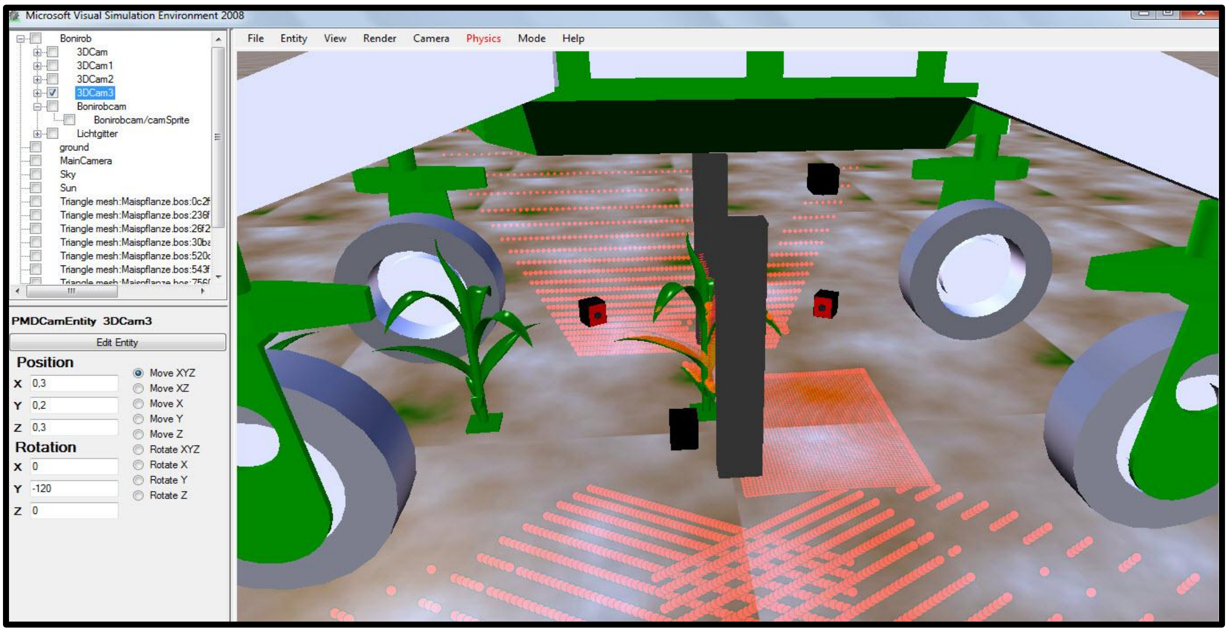

FIGURE 5: Visual environment for BoniRob multi-sensor simulation

3. RESULTS

The model has been realized by developing the models for the field robot BoniRob, the field and the maize plants and the following sensors: GPS, incremental encoder, camera, 3D Time-of-Flight camera and a light curtain. Dynamic simulations have been carried out to verify the physical and sensor parameters and check the data, the rates and the plausibility of the results. The new method thus allows the data analysis of real data (from BoniRob measurements on the field) as well as simulated data from the developed software environment based on Microsoft Robotics Studio. Both sets of data can be analyzed with the same data analysis software using the data from the MySQL data base.

Thus the algorithms can be tested prior to field trials, thereby looking for an optimized sensor arrangement. This can include the number or type of sensors, the geometric positions, data rates, redundancies or the influence of environmental parameters such as sunlight or ground roughness. Moreover, the combined simulation or robot navigation and phenotyping is of high interest for a broad range of crop scout applications. Figure 6 shows a result of a virtual measurement in a maize row, the light curtain data are shown as an example

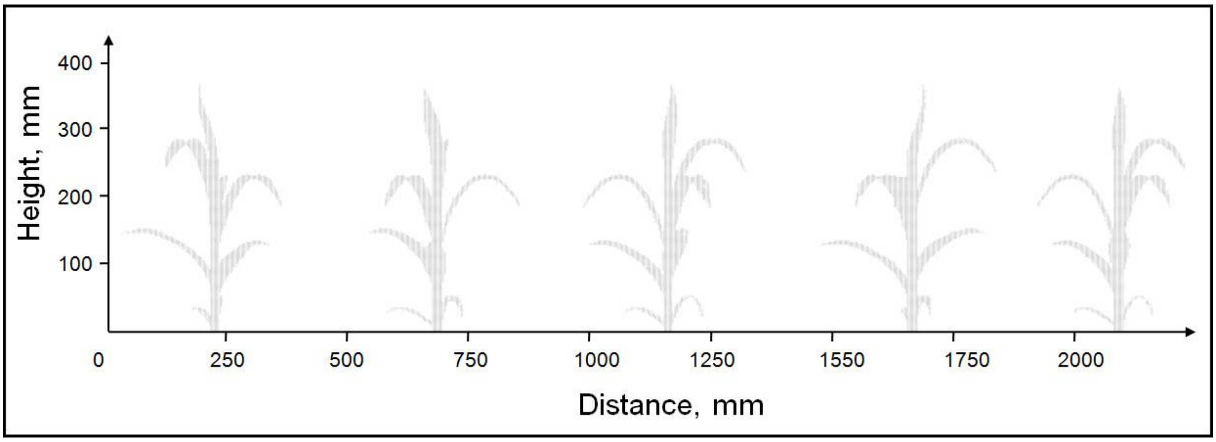

FIGURE 6: Results of virtual light curtain measurements

FIGURE 7: Measurement of the artificial plant with virtual (left) and real (right) BoniRob

For calibration purposes a CAD model of a real maize plant has been generated. This virtual maize plant is implemented in the Robotics Studio software and has been used to create an artificial (hardware) maize plant with a rapid prototyping machine. As a consequence – next to standard geometric objects – nearly identical virtual and artificial maize plants are available for calibration and tests. First comparisons of measurements with BoniRob (see figure 7) and the new model show good agreement and demonstrate the power and options of the method for virtual experiments (see figure 8).

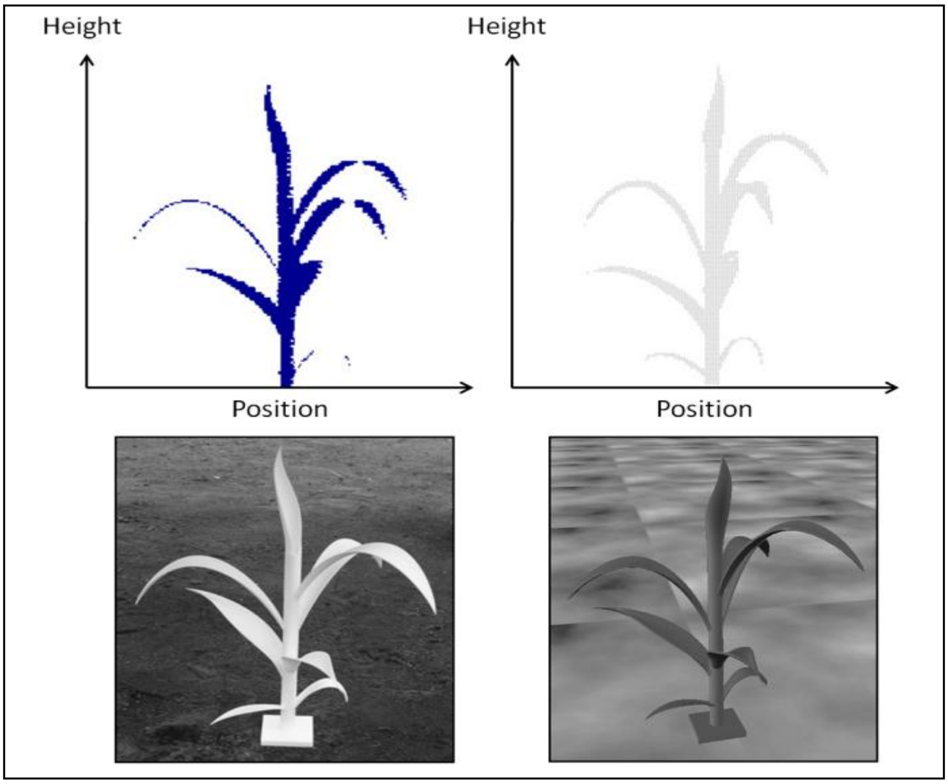

FIGURE 8: Measurement results of an artificial maize plant (left) and a virtual maize plant (right)

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