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Autonomous robots in agricultural field trials

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Introduction

The technological improvements in electronics, communications and sensor technologies strongly push innovations in agriculture and are nowadays considered as key technologies in this field. Combining online information from measurements on the one hand with farmer experiences on the other hand offers new options for optimisations with respect to economical as well as ecological aspects. While sensors in precision farming technologies – such as the N-Sensor (YARA), MiniVeg (Fritzmeier) or AutoScan (Krone) – are taking average (statistical) values with respect to a small region of a field, new technologies have opened the view to future options, focusing more closely at the single plant (Åstrand et al. 2005, Griepentrog et al. 2003). In Figure 1 (left side) the basic concept of Precision Farming is shown, where site-specific information is used for various agricultural or economical applications. The technological access to the single plant (Figure 1, right side) offers a complete new window of opportunities, where agricultural field trial applications are the first steps. The automatic individual plant analysis is about to be developed.

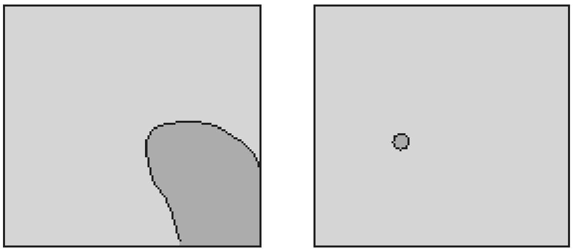

Fig. 1: Precision Farming (left) as compared to “Individual Plant Farming” (right).

An example for a classification of plants with respect to single plant weed control – as another application - is shown in Figure 2. It is obvious that the detection of crop and weed plants is a challenge to the related technologies, which have to be highly developed as well as robust.

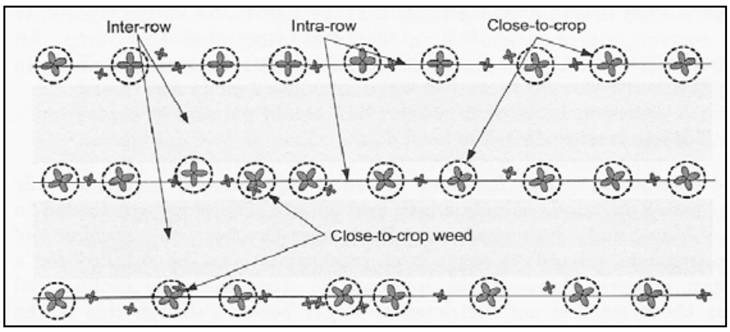

Fig. 2: Positioning of weed plants in row cultures (ÅSTRAND 2005).

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Material and methods

In particular, sensor developments, embedded system technologies, GPS and robotics are the basic technologies to be used for the goal of an autonomous robot for agricultural field trials. A successful integration strongly depends on a complex software development, where the robustness is a high challenge. Since selectivities vary, intelligent and real-time combination of different sensor signals is of high importance, compensating for lower selectivities of single sensors. This “sensor fusion” concept has already been applied for agricultural applications in 1999 (RUCKELSHAUSEN et al. 1999) and is nowadays a standard approach for complex measurement situations. Most new sensor technologies in agricultural engineering are based on optoelectronic systems. Examples are imaging technologies for crop/weed detection (OEBEL et al. 2006) or optoelectronic distance sensors for biomass measurements (THOESINK et al. 2004). Figure 3 shows, for example, the basic concept of two systems: A pulsed laser or LED light source measures the height of a plant as well as the corresponding soil level nearby. Such systems can also be applied from other angles, thereby acting as a stalk detector. The second sensor (fig. 3, right) shows the measurement of the profile of row cultures with a stack of light barriers (RUCKELSHAUSEN et al. 2004), where the absolute height of a plant as well as shape parameters can be measured. Moreover, the usage of binary data offers new options for real-time image processing. Due to variations in field and plant conditions the selectivities of single sensors show strong differences. To overcome this problem the above-mentioned concept of sensor fusion has continuously been applied to field measurements over the last years.

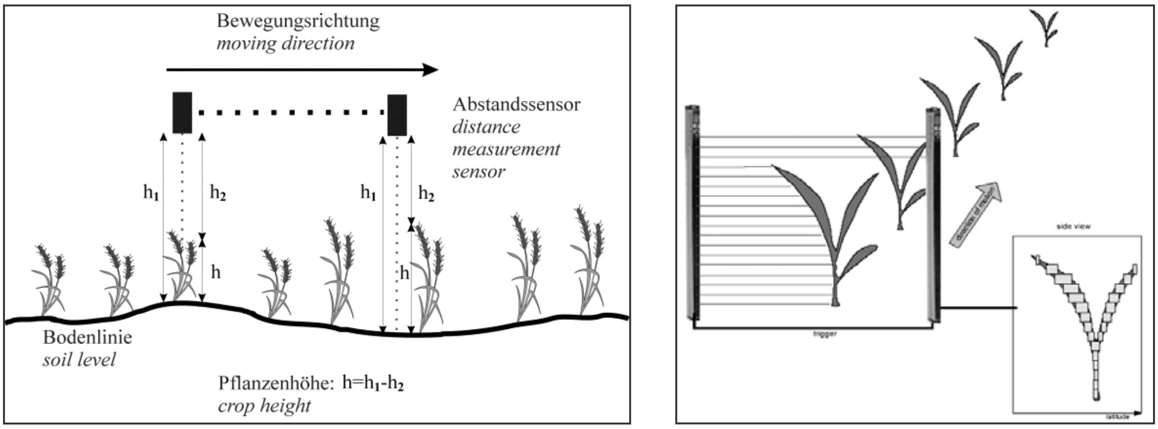

Fig. 3: Principles of optoelectronic sensors for plant detection: height measurement (left, THOESINK et al. 2004); plant profile sensor (right, RUCKELSHAUSEN et al. 2004).

Figure 4 shows the key components of the multi-sensor architecture. Each sensor (or sensor system such as a camera or a spectral imaging system) as well as the GPS technology has its own embedded microcontroller. Reduced data are communicated via CAN-bus and finally the sensor fusion algorithms are perfomed on a host microcontroller. Via a user interface the settings of the software and sensors can be modified. Moreover, for the development phase the complete measurement data can be stored and analysed. The modular system can be extended with additional sensors or components. This aspect is of high importance for the development of autonomous robots for field trials. With existing sensor and imaging technologies, morphological parameters of plants – and as a consequence the plant itself – can be determined if the field situation is not too complex (as for example with respect to the weed coverage). Thus, a broad range of information for different growth stages of plants (see for example MEIER 2001) might be analysed automatically by sensors as compared to the state-of-the-art analysis by hand. Typical data are the plant height, characteristic information about the leafs, stalk thickness or plant distances. Moreover, more complex sensors might be added, thereby giving additional information about plant diseases, soil properties, nitrogen or water contents. Such systems depend on complex technologies such as spectrometers, spectral imaging or fluorescence. The corresponding data are of importance for the plant characterization or further applications.

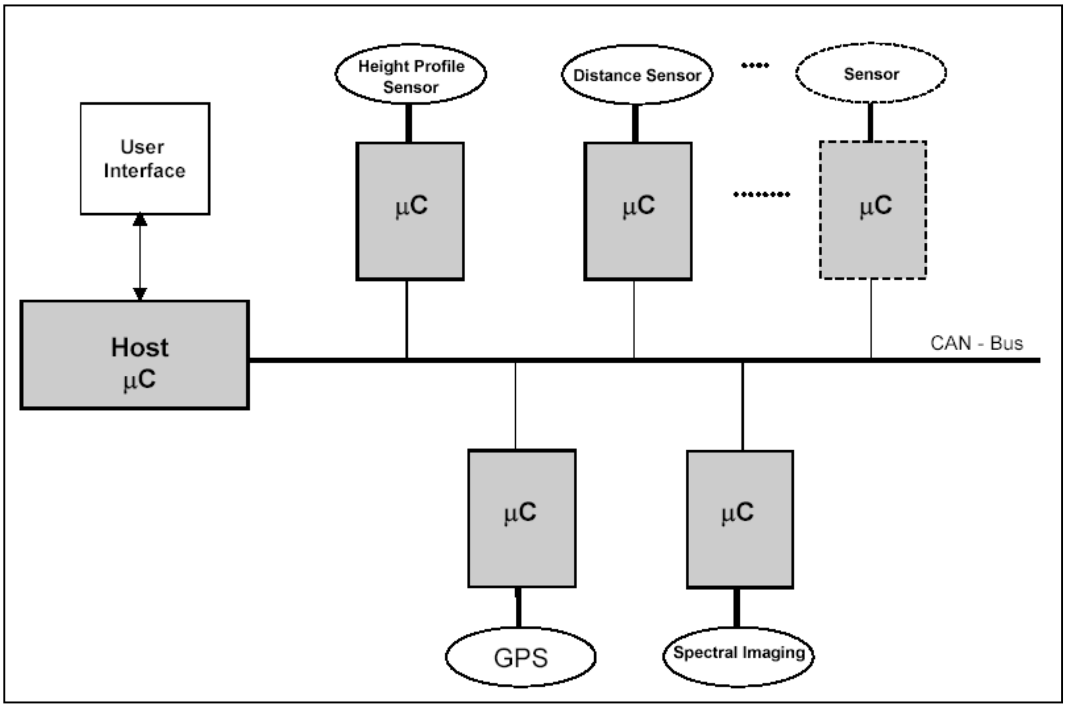

Fig. 4: Multi-sensor architecture based on the integration of different sensors, GPS and a user interface (FENDER et al. 2006).

The corresponding sensor technology can be applied to tractor-mounted systems or to vehicles with a user-defined design. For research applications in the field of weed control, several of such vehicles have already been realized or proposed (as for example ÅSTRAND et al. 2005, RUCKELSHAUSEN et al. 2006) The HortiBot (JØRGENSEN et al. 2006) is based on an existing vehicle platform and has been adopted for weed control applications. Figure 5 (left side) shows this robot in a presentation during the Field Robot Event 2007 in Wageningen (The Netherlands). The major technologies are the stereo-camera-based navigation and the chemical weed control based on image information. Due to ecology and sustainability new methods for mechanical weed control have gained importance in the last years. The combination of a sensor fusion concept and a cycloid how for intra-row weed control (RUCKELSHAUSEN et al. 1999) is show in Figure 5 (right side). In combination with existing technologies for inter-row weed control, this solution offers options for a complete mechanical weed control. However, until now there is no product available for this application, which is mainly caused by problems due to robustness for field conditions and costs.

Fig. 5: Left side: HortiBot (Aarhus University, Danish Technological Institute, Vitues Bering Denmark; photograph: A. Ruckelshausen, Field Robot Event 2007 in Wageningen/The Netherlands; JØRGENSEN et al. 2006). Right side: Mobile sensor unit with a sensor-based cycloid hoe (“Querhacke”) in greenhouse experiments (University of Applied Sciences Osnabrück, RUCKELSHAUSEN et al. 1999; supported by the Deutsche Bundesstifung Umwelt).

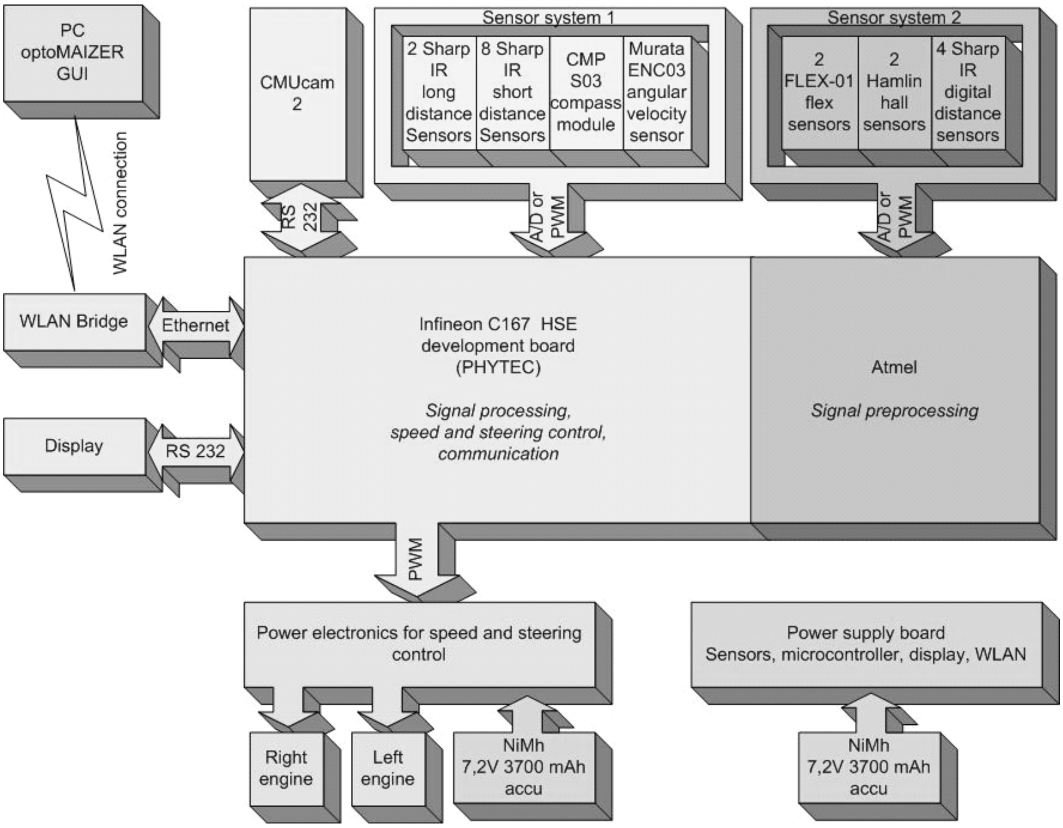

Fig. 6: Architecture of an autonomous field robot as designed for the Field Robot Event (KLOSE et al. 2007 and references therein).

In the field of user-defined vehicles the international Field Robot Event has resulted in a strong impact for robot development in agriculture (MUELLER et al. 2006). In the competition the robust navigation in maize rows is a major task. Moreover, there is a challenge for the autonomous turn in the headland or the detection of a golf ball with a corresponding weed control action. As an example, the system architecture of such a robot is shown in Figure 6. The sensor fusion concept has been applied, using typically about 20 sensors. The system technology is based on embedded microcontrollers. Via Wireless LAN and a user interface sensor data, parameters or software can be transferred in both directions. This aspect is of high importance during the development stage. The data can also be transferred via Internet, thus the robot can be run under remote control from an external PC. Moreover power supply and power electronics have to be integrated. A major part of the robot design is the development of the complex software, which includes hardware-related tasks, data transfer and algorithms. During the competition, the vehicles have to navigate completely autonomous. An example of such a robot is show in Figure 7.

Fig. 7: Autonomous field robot Maizerati (KLOSE et al. 2007), which has been designed for the Field Robot Event.

Results and outlook

The existing technologies with respect to sensors, embedded microcontrollers, GPS and autonomous vehicles are the basis for the future development of an autonomous field robot for agricultural field trials. As compared to the state of the art (time-consuming) characterization of plants based on sampling methods, this would be a fundamental step towards an automatic data generation for all plants.

The basic functions for plant detection described above can be realized with a sensor fusion concept in combination with precise positioning information. As for example in row cultures such as maize, the typical GPS-accuracy for individual plant detection has to be better than that for the plant distance. By using real-time kinematics (RTK) with a reference and one more rover receiver variations can be reduced to less than ± 2 cm. This allows a redetection of individual plants (FENDER et al. 2006). Figure 8 shows a section of a maize row as measured with a photo-diode array. The binary data of the array are analysed in real time with standard image processing algorithms. This information is combined with other sensor data – such as distance measurements or spectral imaging - and the relative position of the stalk of a single maize plant is determined. By using a RTK-DGPS system and a shaft encoder (for interpolation of the low-frequency GPS data), the absolute positions can be calculated. Figure 9 shows the results for 4 different runs, demonstrating that each single maize plant can be redetected. The vertical variations are due to different tracks of the non-autonomous mobile unit. The GIS-tool OpenJUMP has been used for the visualization of the data.

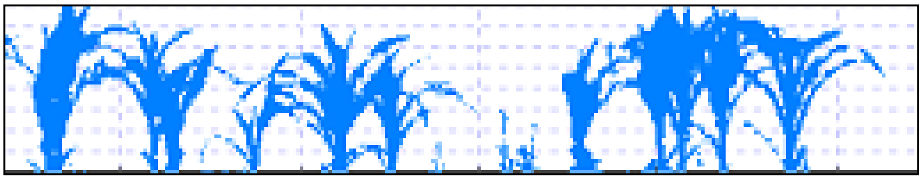

Fig. 8: Measurement result of a photo-diode array for plant profile detection (FENDER et al. 2006).

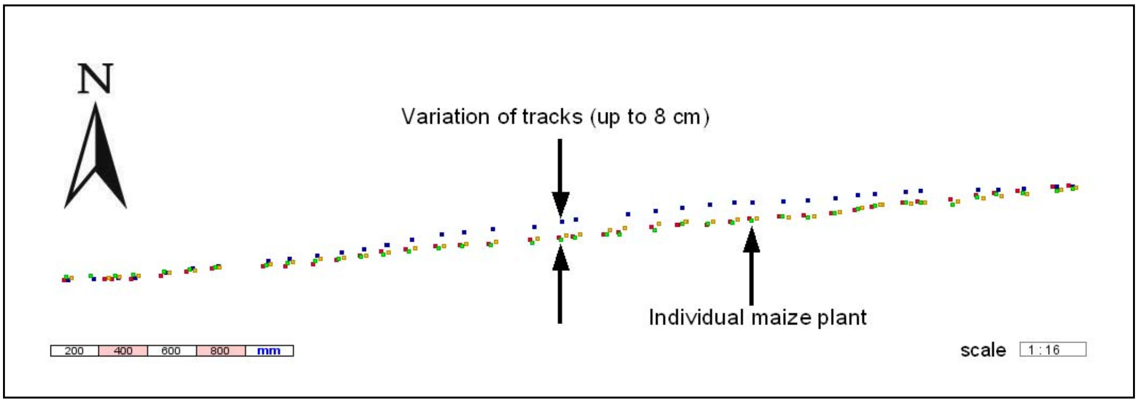

Fig. 9: GPS positions of single maize plants measured in 4 different runs (FENDER et al. 2006).

As a consequence this technology allows the characterization of parameters for an individual plant during the complete growth stages. Moreover, groups of plants might be analysed with respect to their position in the field or other boundary conditions (such as soil properties).

The real-time combination of sensor information and GPS is the first step towards robots for agricultural field trials. In the second step the technologies for autonomous field robots described above have to be integrated. Since the complex outdoor navigation as well as the characterization of plants strongly depends on robust sensors and algorithms, the characterization itself is the natural first application for an agricultural field robot. While the realization of commercially available autonomous field robots with actuators will still take some time, the concept of an autonomous field robot for field trials – as sketched in Figure 10 – might be realized within very few years.

The existence of a robust autonomous robot for field trial will offer a broad range of further applications. The already mentioned combinations with actuators – such as fertilization or weed control – are one perspective. Moreover, the existence of small robots has advantages with respect to safety and results in reduced soil compression as compared to present agricultural machines. In order to fulfil economical boundary conditions, robot swarms can be implemented. During the Field Robot Event 2007, a communication of robots (via WLAN) has been realized. The autonomous robot Amaizeing followed a human-defined red object, where the colour tracking of a smart camera was implemented. The data are transferred via WLAN to the robot Maizerati, which navigated according to the control of Amaizeing (see Figure 11). This demonstration of low-cost robots (total hardware prices are below 2000 € per robot) already illustrates future applications in agricultural engineering.

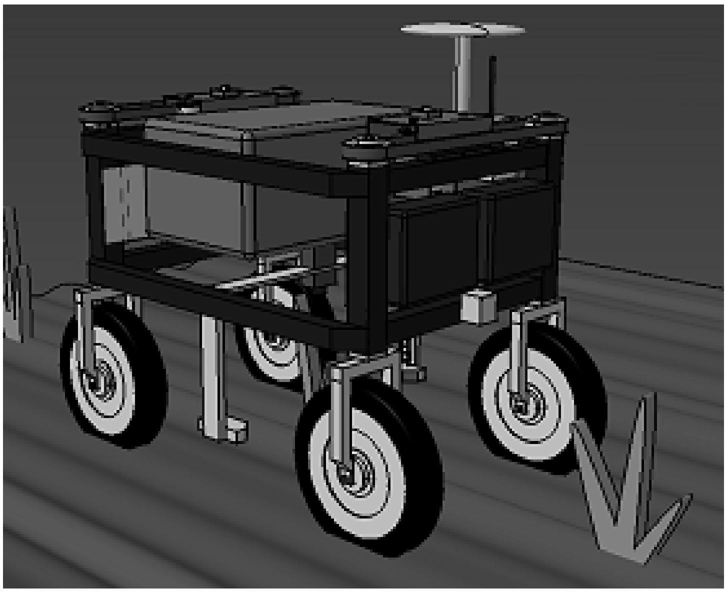

Fig. 10: Concept of an autonomous field robot for agricultural field trials.

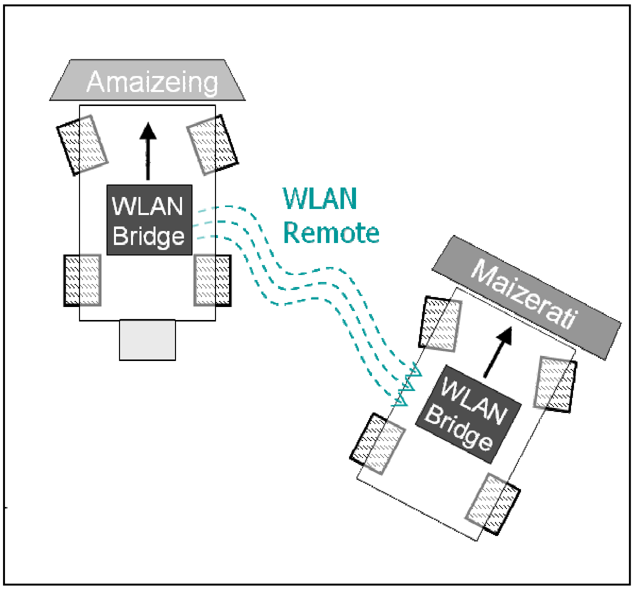

Fig. 11: Communication of autonomous robots (MEINKE et al. 2007).

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