Microcontroller-based multi-sensor system for online crop/weed detection

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ABSTRACT

Automatic crop-weed distinction has become increasingly important in weed control applications. A new approach based on the combination of sensors with different properties and a microcontroller hierarchy has been developed and applied.

Plants may be described in terms of their geometrical, optical and mechanical properties; each of the sensors selected is aimed at least at one of these properties. Since selectivities vary, intelligent and real-time combination of sensor signals is crucial for distinguishing weed and crops, thereby compensating for the lower selectivities of single sensors. This is achieved by an architecture utilizing high-end 8- and 16-bit microcontrollers communicating via CAN bus. The high flexibility has been enhanced by adding programmable devices, facilitating online adaption to specific crop-weed patterns. Sensors and software are being activated as required. The system is designed for speeds up to 10 km/h with a resolution of 1 sample/mm.

The multi-sensor-system has been applied to maize cultures in a greenhouse and field experiments thereby activating mechanical hoes or position sprayers. The first prototypes have been tested as mobile standalone equipment and tractor-mounted versions. The first experiments resulted in crop-weed-selectivities of above 90 %.

INTRODUCTION

Ecological as well as economical demands aim at further reduction of herbicide applications for weed control. However, the local application of herbicides as well as mechanical weed control systems strongly depend on the availability of detection systems. The corresponding sensors have to be able to distinguish between crop and weed or even recognize the different weed plants. Moreover, the detection process has to be very fast for practical applications.

Up until now no sensors have been available satisfying the above mentioned requirements with respect to quality and real time ("on-line") detection ability .

The most promising concepts for detecting single plants use optoelectronic devices, e.g. image sensors or photo diodes.

The processing of image data obtained via a video camera has been improved during recent years (Gerhards et al. 1998). However, the problems with respect to algorithms for overlapping structures and the short processing time needed for on-line detection are not yet solved. Addressable xy-imagers in CMOS technology have recently become available and have been applied to crop-weed distinction by the authors (Linz et al., 1998, see table 1). The high flexibility of these digital CMOS-cameras as well as their low price might result in a strong impact of xy-imagers for on-line image analysis.

The second concept is based on the spectral properties of plants. Due to the typical reflection in the near-infrared range caused by chlorophyll, green plants can be distinguished from soil or wheat by relative measurements (Biller et al., 1997). Such systems are commercially available for non-selective plant detection. Despite the fact that there are differences in the reflection spectra from different weeds, the application of photo diodes with mounted filters for distinguishing "green" plants from "green" weed is limited caused by the mixed spectral signature of plants and soil.

The idea of combining different sensors in order to overcome the above described disadvantages has recently been proposed by the authors (Dzinaj et al., 1998). The realisation and application of this "multi-sensor-system" is described below.

MATERIALS AND METHODS

The multi-sensor-system has been designed for high precision agricultural applications to detect single plants within row cultures for crop/weed distinction and mechanical weed control. The sensor signals are available every millimeter up to a velocity of 10 km/h.

In order to detect single plants within row cultures , the characteristics of crop and different weed plants have to be considered. The spectral, geometric or mechanical properties could vary due to their growth stages or environmental parameters. Thus a "plant database" is generated which is crucial for the application. On the other hand, each sensor - as a part of a multi-sensor-system - detects different aspects of the plants or non-target surfaces. The basic idea of the concept is the correlation of different sensor signals with respect to the plant characteristics. As an example the measured correlation of two optical sensors is shown in figure 1.

The selectivity of the sensor signals with respect to the plant characteristics vary. A single sensor signal might lead to a misinterpretation whereas the combination of all sensor signals results in a higher selectivity for crop-weed-distinction.

The system architecture is shown in figure 2. Several sensors have been tested, including various configurations with photodiodes and filters, CMOS-cameras, triangulation and ultrasonic as well as pressure sensors (Dzinaj et al., 1998). In order to avoid high volume data streams, each sensor has its own "intelligence" , namely an 8-bit microcontroller. In our application the PIC-microcontroller from Arizona Microchip Technology was used . All sensors were connected to the CAN bus via a CAN-interface. The multi-sensor-system was controlled by a powerful 16-bit host microcontroller (C167 from Siemens). Data sampling on the sensors was simultaniously triggered by a frame which is sent every millimeter by the host controller. After a signal was detected by the CAN-interface a frame with reduced signal data was returned to the host. The host combined the reduced signal data and took control over a mechanical hoe, a position sprayer or any other actuator. The distance of the actuators relative to the sensors as well as the velocity have been taken into account in the system design.

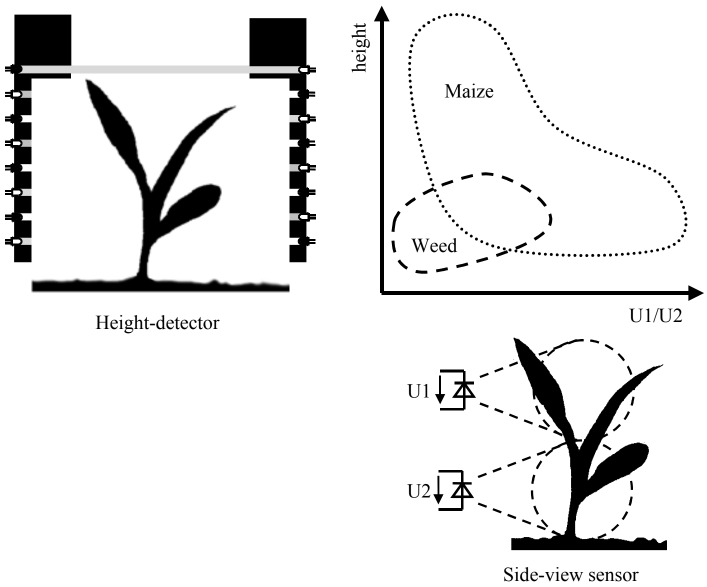

Fig.1: Measured correlation of two optical sensor signals. The information of a "Height-detector" (vertical axes) is compared to corresponding numbers obtained from "Side-view sensors" (horizontal axis).

The system is fully programmable thereby allowing a high flexibility with respect to different row cultures, growth stages or environmental influences. The application of microcontrollers has resulted in an embedded solution, no personal computer is needed for the application. The human interface is realised via a touch panel, where input and output parameters can be transfered.

The system setup consists of a learning phase, where the sensor data for a special row culture are collected without any filtering. The high-volume data are analysed ("off-line") with a PC and the corresponding correlations and thresholds are defined. These numbers are transfered to the microcontrollers and the system is applicable. Depending on properties of the field and the impact of environmental influences sensors as well as software programs can be activated or de-activated as required.

As far as possible standard sensor and electronic components have been used, thereby taking into account cost considerations as an important issue during all stages of development.

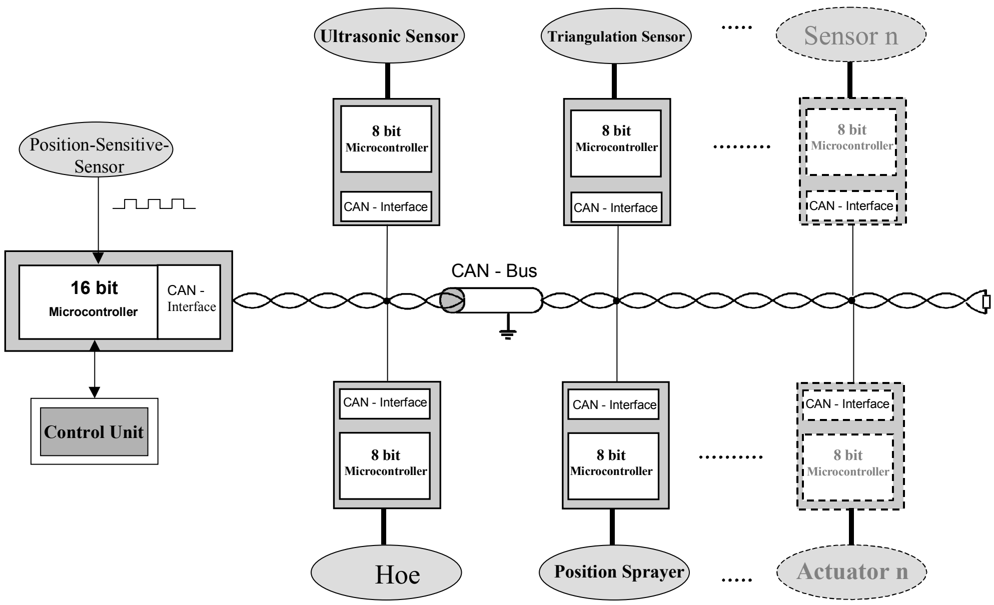

Fig.2 : Architecture of the multi-sensor-system for on-line crop/weed detection.

DISCUSSION

The method has been applied to maize cultures as test plants for row cultures. This selection has been influenced by selective geometric parameters of maize plants during the period of mechanical weed control.

Two different pieces of equipment have been constructed for use in practice (see table 1). One multi-sensor-system was mounted on a vehicle and served as a test module (Sensor Modul: "SEMO") for the implementation of new sensors or features (e.g. user interface, position sprayer, slip correction, etc.) or test runs. The position of the vehicle was determined by a position-sensitive sensor. Moreover a slip correction method has been developed by using the information from the multi-sensor-system. A second multi-sensor-system (Low Cost Modul: "LCM" ; see fig. 3) has been designed with fewer sensors and optimised with respect to lower susceptibility to malfunction. The influence of vibrations and dust or water has been investigated and taken into account. Moreover, additional functionality - including sensors - insure the reliability of the electronic signals. The LCM can be easily changed from a standalone mode for test runs (similar to SEMO) to an aggregate coupled on a wagon for agricultural tractor applications.

The multi-sensor-systems and the corresponding equipment has been tested in different stages: static and dynamic laboratory measurement setups , greenhouse and maize field. Experience with respect to sensor selectivities and disturbances have been obtained.

To our knowledge, it has been demonstrated for the first time that a single crop (in our case: maize) can be distinguished from a weed plant with an online multi-sensor system thereby controlling a mechancial actuator or a position sprayer. A prototype version of the equipment is available for determining agricultural parameters and reliability investigations.

Table 1 : Equipment for multi-sensor-systems

	SEMO (mobile sensor module)	LCM (low cost module)
Application	Data collection Test runs User Interface Slip correction	Test runs Aggregate for tractor-mounted hoe
Applied Sensors	"Height-detector" "Side-view sensors" "Soil-plant sensor" CMOS-camera Pressure sensors Triangulation sensors Ultrasonic sensors	"Height-profile-detector" "Side-view sensors" "Soil-plant sensor" CMOS-camera
Actors	Hoe Position sprayer Acoustic or optical signals	Hoe

There is still some optimisation to be done in order to create semi-automatic adaptions of the system for different growth stages or soil structures. The corresponding task is dominated by analyzing measurement data and changing the software of the microcontroller devices. The whole system can be easily extended by connecting another sensor to the CAN-bus (see fig. 2) and modifying the corresponding host controller software. The development of a multi-sensor-system has moved strongly from hardware optimisation to software activities.

The first field experiments in a greenhouse and a test maize field have been analyzed. Preliminary results show that typically 2-5 % of the maize plants were detected as weed, while 1-8 % of weed were detected as maize. Depending on the strategy of the actuator (position sprayer, mechanical hoe) this would result in a loss of maize plants up to 5 % or an incomplete weed control of 8 %. This number strongly depends on the soil structure and the number and shape of the weed plants.

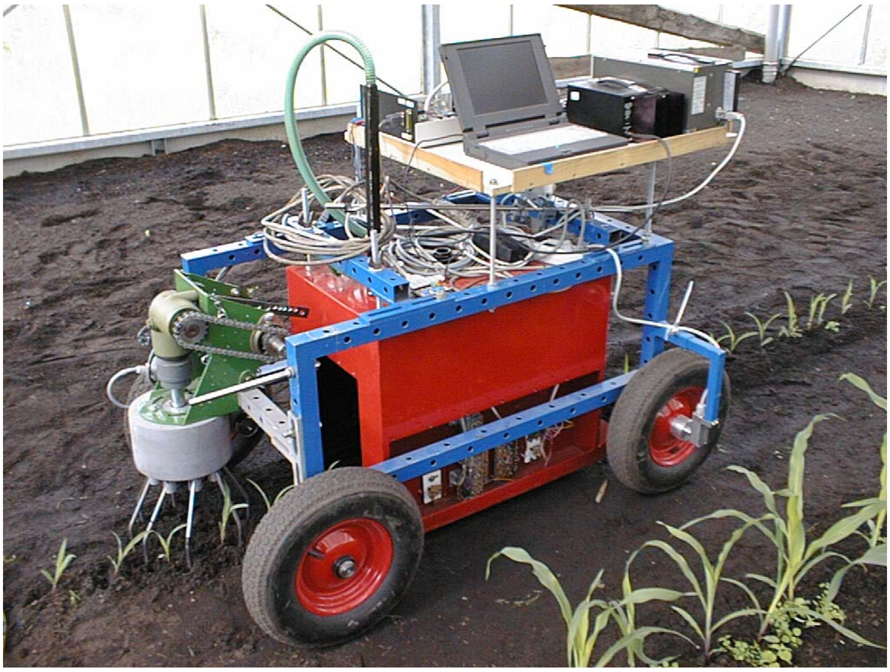

Fig.3: Low-Cost-Modul (LCM) with a mechanical actuator

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