Field robot „optoMAIZER“ : Development of a mechatronic system based on sensor fusion, a real time operating system and WLAN

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ABSTRACT

Based on the results of Eye-Maize (Field Robot Event 2004) a new concept based on a real time operating system has been developed. Information for row guidance, positioning for turning and counting plants is based on 21 sensors (8 different types) where the priority of algorithms is given to the low-cost camera CMUcam2. As bidirectional interfaces a display and a WLAN have been implemented. Moroever, powerelectronics for speed and steering control of 2 engines as well as power supply is integrated. WLAN is a powerful tool for developing and characterizing the field robot. The complexity of the mechatronic system has been overcome by the implementation of the real time system RTXtiny. The development of the project is combined with the diploma thesis of Ralph Klose and Martin Meier.

Fig. 1: Field robot *optoMAIZER*

KEYWORDS

Field robot, optoelectronic sensors, sensor fusion, CMOS camera, gyroscope, WLAN, compass, plant count, maize

1. CONCEPT

A new robot optoMAIZER based on the sensor fusion concept of the field robot Eye-Maize [Eye-Maize 2004] has been developed. The basic microcontroller-based system structure is shown in figure 2. According to the tasks of the Field Robot Event sensors for row guidance, turning and counting have been included, moreover redundant sensors for a safe operation are included. The low-cost CMOS camera system CMUCam2 is used for row guidance, the concept is described by the authors (see [CMUCam 2005]). Distance sensors of different ranges and speed support the row guidance and are used for counting the maize plants. A new gyroscope integrated sensor, a compass, mechanical sensors as well as hall sensors are used for the turning process at then of the row as well as for safety. A display serves as a user interface for activitating programs and changing parameters as well as visualizing the status of the system. A WLAN bridge has been integrated to control the system completely via an external PC. The wireless operation is extremely helpful during the development of the field robot, the PC is not used for the operation of the robot in the maize field. Two accumulator batteries are used, moreover a power electronics takes care for speed and steering control of the 2 engines.

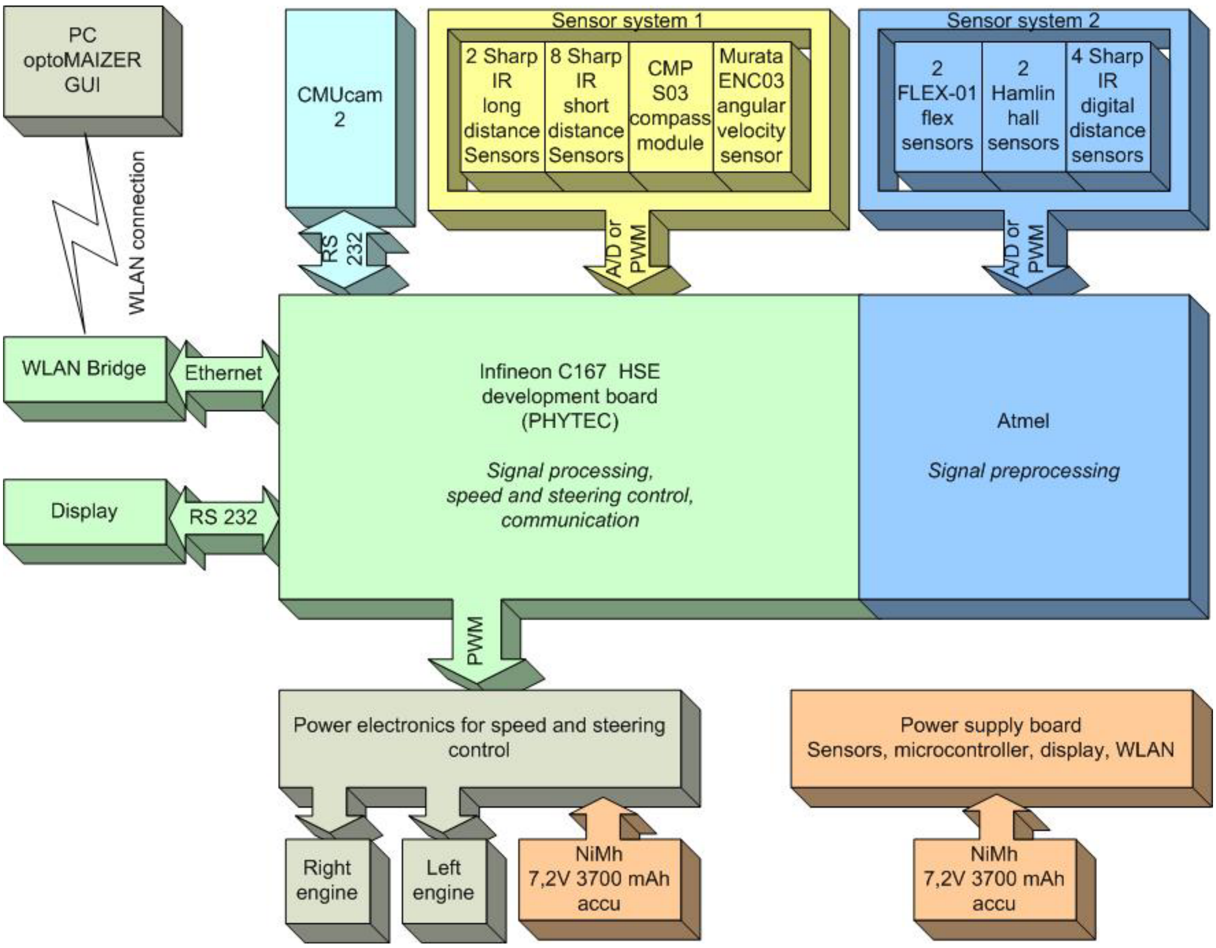


Fig. 2: Electrical block diagram of the concept of optoMAIZER

2. Mechanics

Base unit

The base of our robot consists of a track based model made by "Tamiya" and a self designed case to protect the hardware against rough conditions.

The base model has two electrical engines which are connected to the tracks via a gearbox (fig. 3). This combination makes it possible to control the two tracks individually and to make a turn without moving forward.

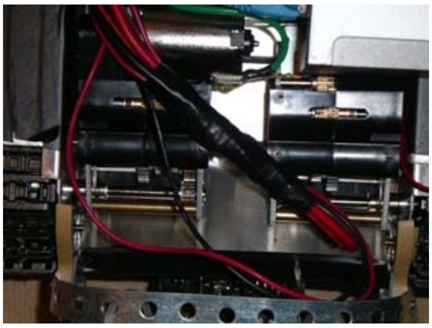


Fig. 3: Gearbox

The model also includes a power electronic module which is connected to the two engines. This power module can be linked to a microcontroller via PWM channels for steering and direction control.

For the case, we decided to use a combination of aluminium and plexiglas (fig. 4). The plexiglas gives the opportunity, for all interessted people or spectators, to have a look inside our robot.

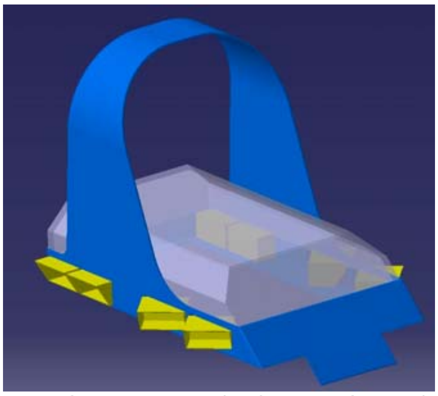


Fig. 4: Case design (software: CATIA)

3. Sensors

CMUcam2

Fig. 5: CMUcam2

The CMUcam2 (fig. 5) consists of a SX52 microcontroller interfaced with an OV6620 or OV7620 Omnivision CMOS camera on a chip that allows simple high level data to be extracted from the camera's streaming video. The CMUcam2 is connected to our controller board over a RS232 link (fig. 6). We have decided to use this type of camera because of the many useful features.

- Track user defined colour blobs at up to 50 Frames Per Second
- Find the centroid of any tracking data
- Gather mean colour and variance data
- Gather a 28 bin histogram of each colour channel
- Transfer a real-time binary bitmap of the tracked pixels in an image
- Arbitrary image windowing

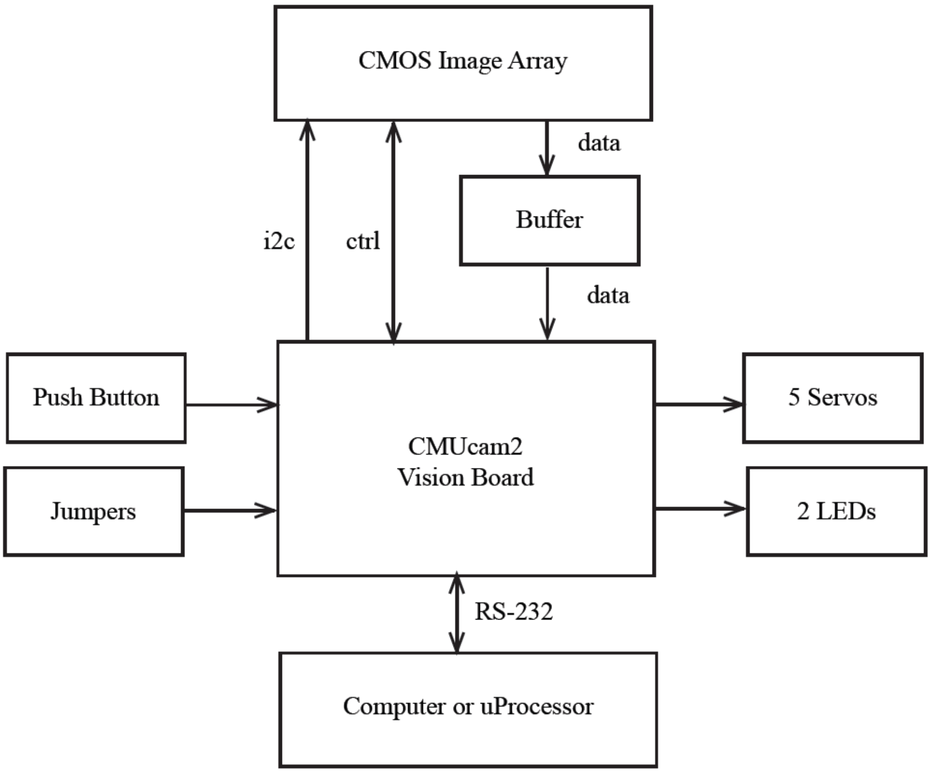


Fig. 6: Functional block diagram CMUcam2

The most important feature of the cam is the colour-tracking functionality (fig. 7). It can be used easily by sending a defined colour-track command over the serial link to the cam. With the use of this command the cam sends back a T-packet. This T-packet contains:

- centroid of the traced colour (X, Y)
- a frame around the pixels of this colour (Xmin, Ymin, Xmax, Ymax)
- number of the tracked pixels
- the occurrence of tracked pixels in the selected area

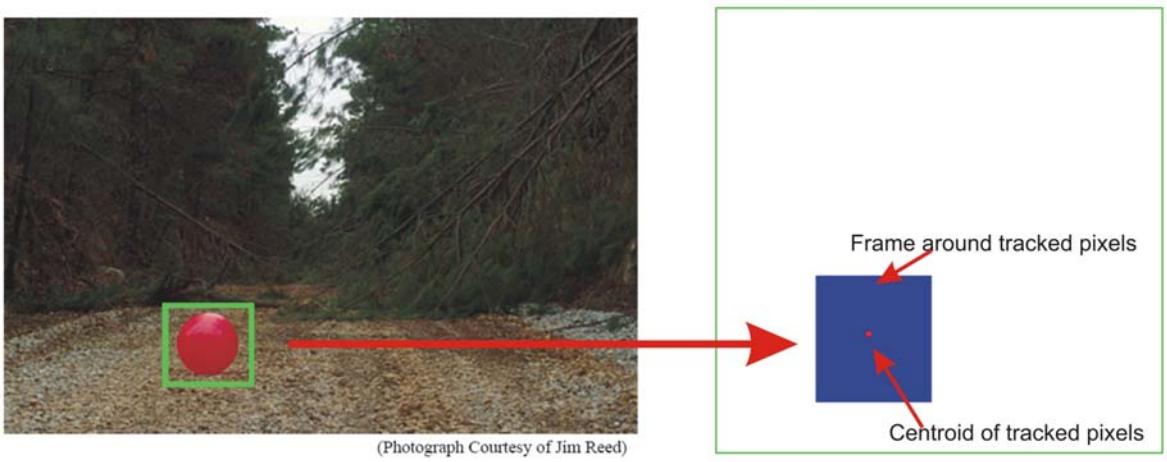


Fig. 7: Colour-tracking of the CMUcam2

The CMUcam2 offers two different colour spaces: RGB and YCrCb (fig. 8). It turned out, that the YCrCb colour space is more robust against illumination changes. The following pictures show what the robot sees when colour-tracking is set to green.

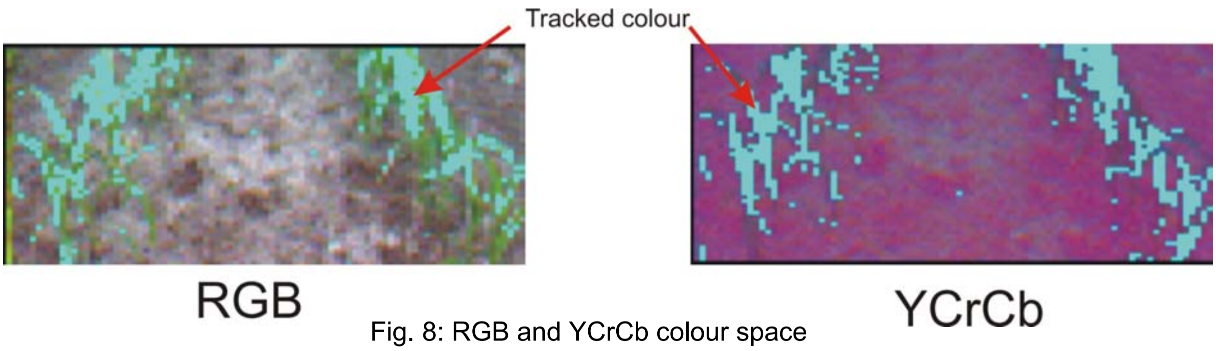


Fig. 8: RGB and YCrCb colour space

The camera offers the possibility to divide the picture into virtual windows (Fig. 9). The track-colour function can be used within each window separately. With this functionality it is possible to search for the colour centroid in different areas of the picture.

We have divided the picture vertical to examine the left and the right row of the field separately.

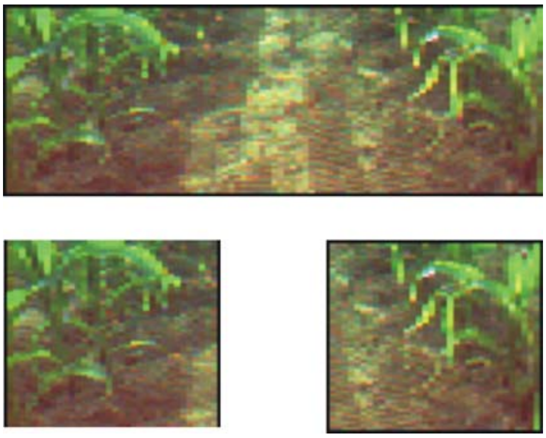


Fig. 9: Virtual windows

With this positon information of the centroid in the different windows a reliable steering decision can be made. We gave the CMUcam2 the highest priority in our multi sensor concept.

Distance sensors

Fig. 10: Sharp GPY0D02YK

For the detection of the maize plants we decided to use two different types of IR sensors. The first type is the Sharp GPY0D02YK long distance IR distance sensor (fig. 10). It can measure distances between 20 cm and 150 cm. Because of their possibility to look far ahead, we have mounted two of them on top of our robot. It is their job to look ahead into the row for the detection curves and to avoid collisions.

The second type is the Sharp GP2D12 short distance IR sensor. It can measure distances between 10 cm and 80 cm. We placed eight of these sensors around the aluminium case. With the information gathered from these sensors, we are able to calculate the position of the robot in the row.

These sensors generate a voltage representing the distance measured. All the distance sensors are connected to the A/D-converter channels of the microcontroller board. One negative aspect about using these kind of sensors is the slow internal conversion speed of about 50 ms. This aspect makes it very difficult to detect the plant while the robot is moving fast.

Fig. 11: Sharp GP2Y0D340K

Additionally, with the need to count the plants, we have integrated two Sharp GP2Y0D340K digital IR distance sensors (fig.11). They have a 1 bit digital output which toggles at a defined distance of 60 cm (distance can be changed).

To place these sensors as deep over the ground as possible, we have mounted a holder next to the tracks.

Gyroscope

Because of the need to make an exact turn at the end of each row, a sensor measuring the rotation angle of the robot had to be integrated. After a search on the internet we decided to use the Murata ENC-03 angular velocity sensor. The basic operation of the chip is as follows (Source: ENC-03 datasheet, see fig. 12):

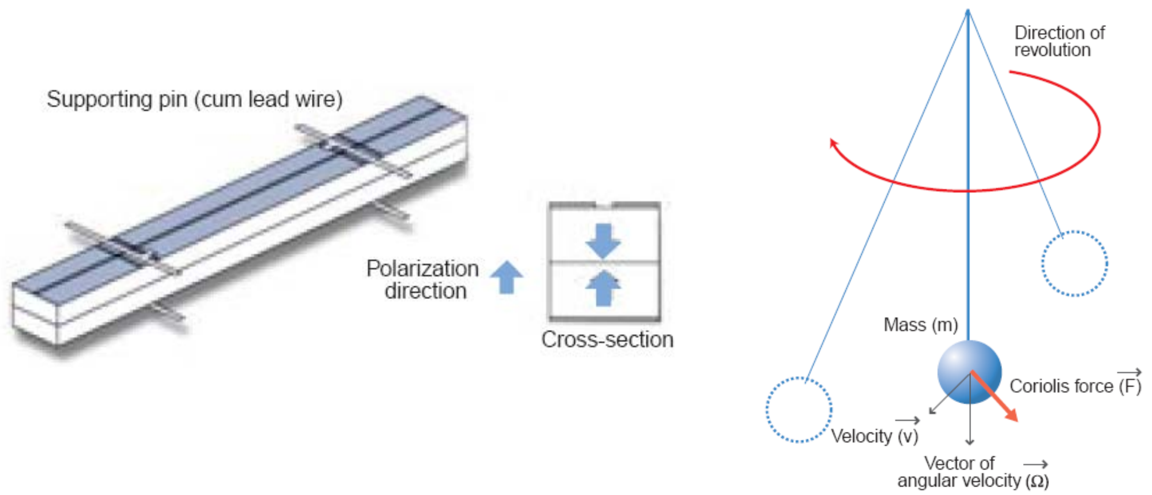


Fig.12: Basic structure and principle of the angular velocity sensor (Murate ENC-03)

"This gyroscope utilizes the coriolis force. Coriolis force operates in a direction perpendicular to the direction of the motion of the pendulum and is proportional to its velocity. The piezoelectric vibrating gyroscope has its tuning bar vibrator by use of piezoelectric ceramic – this corresponds with the pendulum's vibration – and if this vibrating system is

given a revolving angular velocity, Coriolis force is generated in a direction perpendicular to the original vibration.Since this gyroscope uses a piezoelectric ceramic, Coriolis force can be detected and transformed to electric signals by the basic principle of piezoelectric ceramic."

"The structure of a ceramic bimorph vibrator is shown. It is structurally characterized by a ceramic plate adhered to another, and these two plates are arranged so that their polarized direction are reversed. When voltage is applied to these electrodes, a curvature movement is effectively excited in which one of the plates expands while the other shrinks. In the case of the ceramic bimorph vibrator, voltage is applied to the right and left electrodes formed on the flat upper surface to drive the vibrator. Vibrations are detected by the right and left electrodes on the upper surface of the vibrator, in the same way as the vibrator is driven."

Fig. 13: ENC-03

The ENC-03 (fig. 13) generates a voltage representing the angular velocity in mV/°/s. This voltage is A/D-converted by the microcontroller and integrated to calculate the rotation angle of the robot.

To avoid the effect of temperature drift or to suppress the noise components in the sensor element, a circuit board with a high-pass- and a low-pass-filter had to be developed. The schematic is shown below.

Compass

Fig. 14: Compass module CMP S03

As an additional system to determine the direction of the robot, an electrical compass module was integrated. The compass module Devantech CMP S03 (fig. 14) is the most common module. It can be connected to a microcontroller in two different ways:

1. Use of a PWM channel
2. via I²C bus

The module has an resolution of 0,1° and a calibration functionality which allows the modules to extract other magnetic fields interfering the earth magnetic field.

Mechanical sensors

Fig. 15: Flex sensor

For security reasons we have integrated two flex sensors (fig. 15) at the front of the robot to avoid collisions with plants/walls. They consist of strain gauges which change their resistance for 10kΩ to 20 kΩ when pressed.

4. User Interface

WLAN converter

We decided to integrate a WLAN converter to give the possibility to change the settings of the robot or to transmit the cam pictures to a remote PC.

Fig. 16: D-Link DWL 810+

The D-Link 810+ WLAN converter (fig. 16) is connected to the Ethernet interface of the microcontroller board.

It has the following features:

Standards: IEEE 802.11b IEEE 802.3 Ethernet; Adapter Type: IEEE 802.3 Ethernet to IEEE 802.11b Wireless; Data Security: 64-bit and 128-bit WEP (Wired Equivalent Privacy) Encryption

Network Architecture: Supports Ad-Hoc Mode (Peer-to-Peer without Access Point) or Infrastructure Mode

Data Rate: 11 Mbps

Touchdisplay

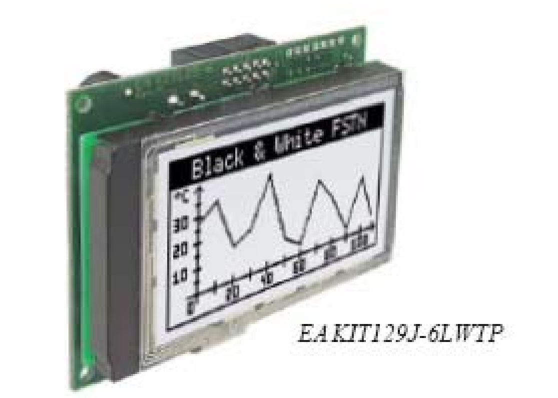


Fig. 17: Tochdisplay made by Electronic Assembly

Additionally we have integrated a touch display to give the user an easy way to control the functions of the robot.

5. Microcontroller system

Atmel controller board

For signal preprocessing we created another board, where the signals of flex-sensors, hall-sensors and plant-count-sensors were analyzed (see fig. 18). The flex-sensors are parts of two comparator-circuits. If the electrical resistance of the sensor is higher than an adjustable level (potentiometer) the comparator will give a “high”-signal, otherwise a “low”-signal. These signals are directly led to the C167-board. The digital signals of the hall-sensors and the plant-count-sensors were analyzed with an Atmel AT902313 microcontroller. As a result of the magnetic field of the electrical engines there are short unwanted peaks in the hall-signals. Because of the relatively huge length of the hall-impulses it is possible to filter them out.

The length of plant-count-impulses depends on the speed of optoMAIZER. In case an an impulse is more or less long than expected, it is probable that the reason for the impulse wasn´t the trunk of a maize-plant and thus it will be ignored. The analysis of the two hall-signals and the up to four plant-count-signals is realized on an atmel AT90S2313 microcontroller. If an impulse is realized as correct it is given to the C167-board.

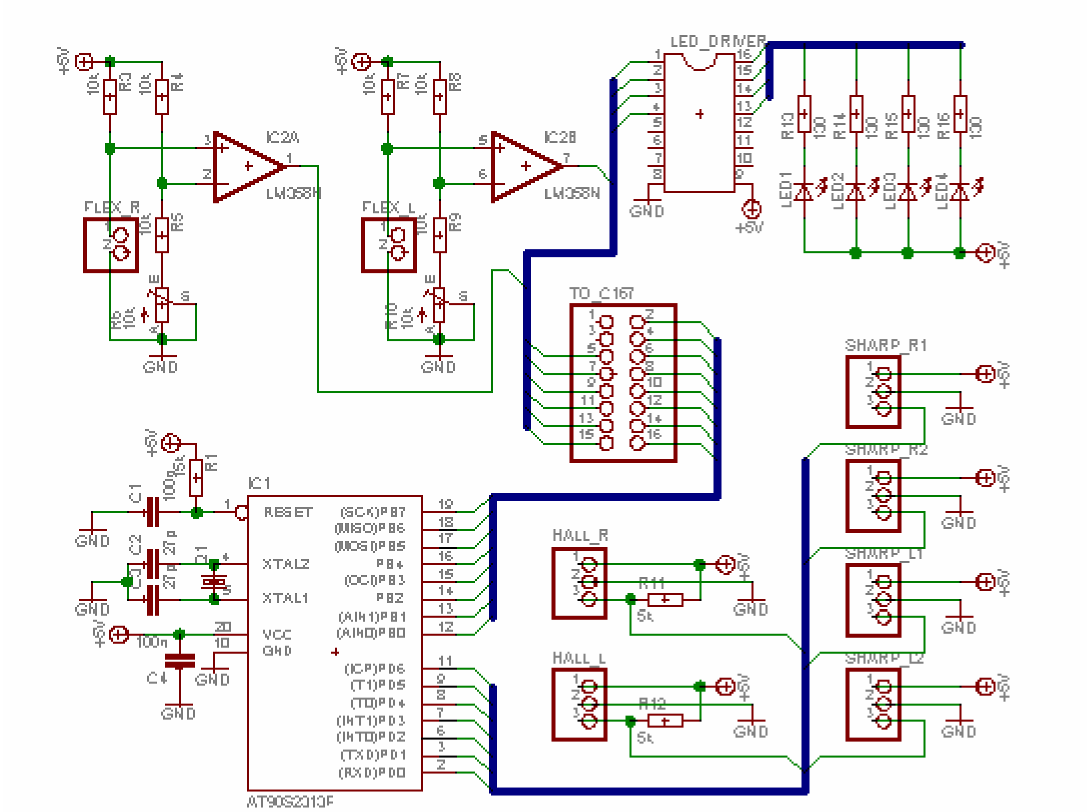


Fig. 18: Schematic of the Atmel board

Phytec development board with Infineon microcontroller

As the main controller board the Phytec development board “phyCore-167 HSE” (fig. 19), equipped with an Infineon C167CS, is used. It handles the information of the IR distance sensors, the cam, the display, the gyroscope and the compass. With these information it can make speed and steering decisions.

Another main task of the controller is to handle the communication with the optoMAIZER graphical user interface over the WLAN link.

The microcontroller's features include:
• High Performance 16-bit CPU with 4-Stage Pipeline
• 80 ns Instruction Cycle Time at 25 MHz CPU Clock,
• up to 40 MHz crystal speed
• 400 ns Multiplication (16 ´ 16 bit), 800 ns Division (32 / 16 bit)
• Enhanced Boolean Bit Manipulation Facilities
• Additional Instructions to Support HLL and Operating Systems
• 16-Priority-Level Interrupt System with 56 Sources, Sample-Rate down to 40 ns
• 3 KBytes On-Chip Internal RAM (IRAM)
• 8 KBytes On-Chip Extension RAM (XRAM)
• 256 KBytes On-Chip Program Flash (Endurance: 100 Program/Erase Cycles min.)
• 4 KBytes On-Chip DataFlash/EEPROM (Endurance: 100,000 Program/Erase Cycles min.)
• On-Chip Peripheral Modules
• 24-Channel 10-bit A/D Converter with Programmable Conversion Time down to 7.8 ms (used for the distance sensors)
• Two Multi-Functional General Purpose Timer Units with 5 Timers
• Two Serial Channels (Synchronous/Asynchronous and High-Speed-Synchronous) used for touchscreen and camera.

Fig. 19: Phytec controller board

6. SOFTWARE

Real time operating system

Because of the different task the controller has to handle, a real time OS was implemented (Fig 20). We used the RTXtiny real time OS. This OS is made by Keil especially for microcontrollers. It uses round-robin switching and cooperative multitasking. The OS supports the following kernel routines:

- **os_create_task**: Start a new task
- **os_delete_task**: Stop a task
- **os_running_task_id**: Return the ID of the task that is running
- **os_send_signal**: Send a signal from one task to another task
- **isr_send_signal**: Send a signal from an interrupt service routine to a task
- **os_clear_signal**: Clear a previously sent signal
- **os_wait (K_SIG...**: Wait for a signal
- **os_wait (K_TMO...**: Wait for a specified number of OS clock ticks
- **os_wait (K_IVL...**: Wait for a specified interval (since the last **K_IVL** call)

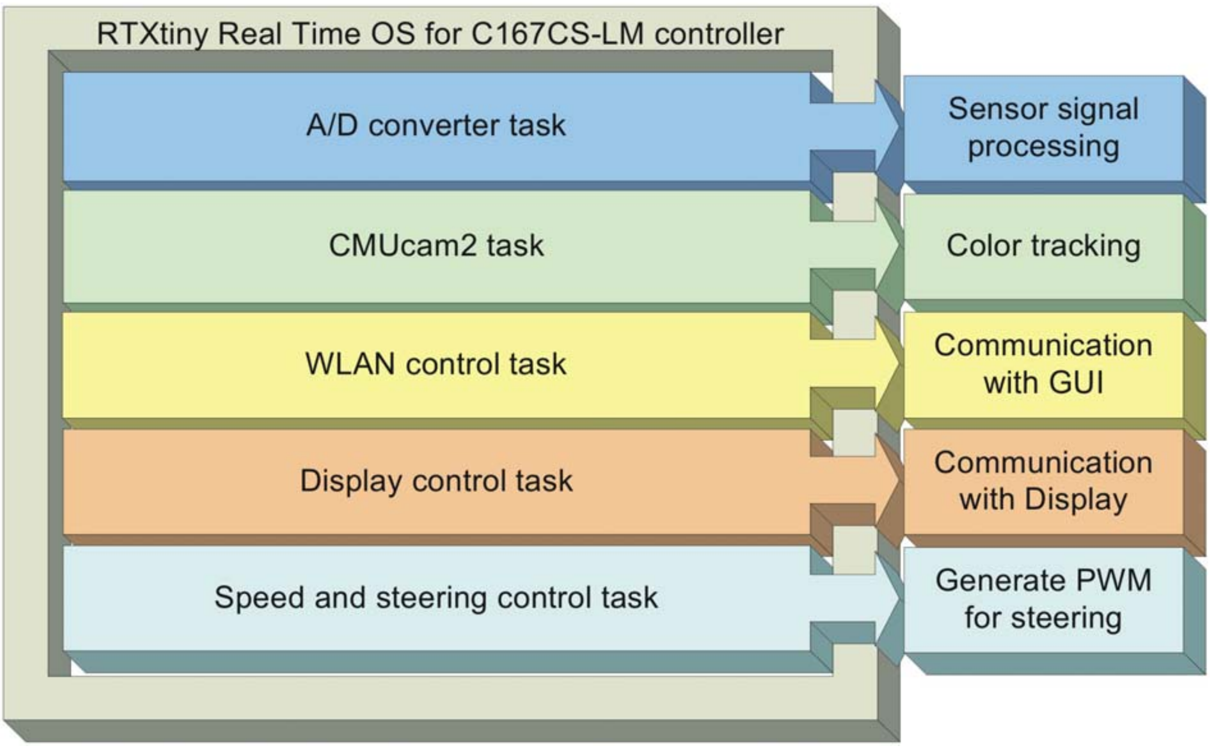
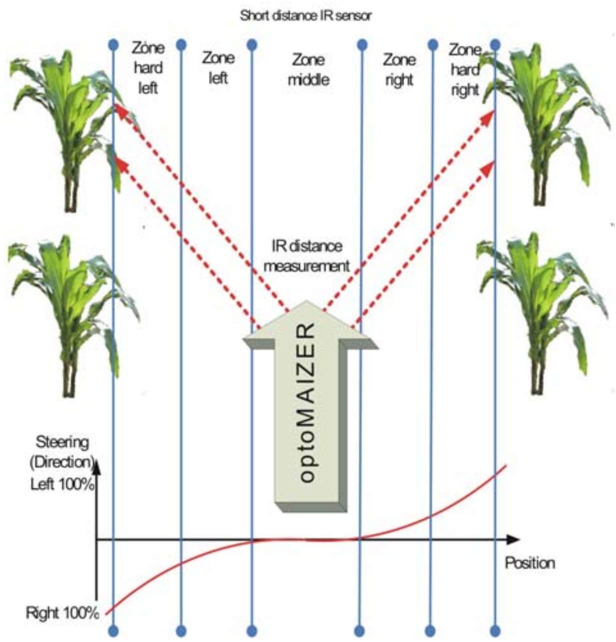


Fig. 20: Real time OS tasks

The A/D converter task includes the processing of the sensor signals, especially those of the IR distance sensors. It also includes the algorithms using the IR distance sensors. The CMUcam2 task handles the communication with the cam over the serial link as well as the calculation of the direction, using the CMUcam2 algorithms. The WLAN control task includes the whole TCP/IP software stack. In the Display control task only the communication with the touch display is handled. Another important role has the Speed and steering control task. Its main function is to generate the PWM calculated by the different algorithms.

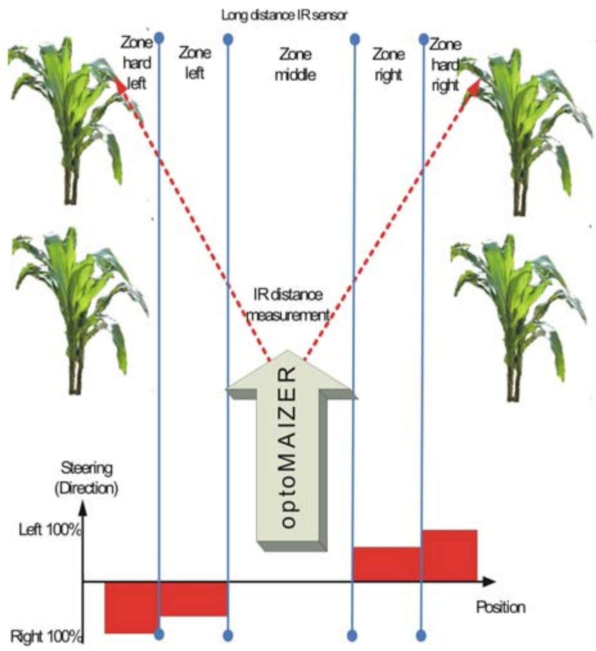
Usage of the short distance IR sensors



The short distance IR sensors are used to determine the exact position of the robot in the row. The position of the robot is divided into different zones in the row (see fig. 21).
These zones are used to calculate the speed and the direction the robot has to drive next.
We used two of the short distance IR sensors at each side of the robot to be sure that at least one of these sensors has measured the distance to a plant.
Additionally we have created an algorithm to detect reliable values.
With these algorithms it is still possible to determine the position of the robot if there are only plants available on one side of the row.

Fig.21: Usage of short distance IR sensors

Usage of the long distance IR sensors



The long distance IR sensors (fig. 22) were integrated for security reasons. Because of their ability to measure long distances, they have the important job to look forward into the maize row. That gives us the possibility to recognize changes in the field like curves or missing plants.

Another important aspect of using these sensors is to avoid collisions with plant.

In this algorithm, the row is also divided into zones which stand for a defined steering direction.

Fig. 22: Usage of long distance IR sensors

Priority of the algorithms

The priority of the algorithms is defined by safety reasons (flex sensors), the presence of plants (long distance IR sensors), first priority row guidance (CMUCam2) and second priority row guidance (short distance IR sensors):

1. flex sensors
2. long distance IR sensors
3. CMUcam2
4. short distance IR sensors

optoMAIZER GUI

The optoMAIZER GUI communicates over the WLAN link with the robot. In this graphical user interface parameters can be changed, algorithms - to be used by the robot - can be selected and the picture of CMUcam2 can be displayed. Another interesting feature is the ability to remote control the robot over the WLAN link.

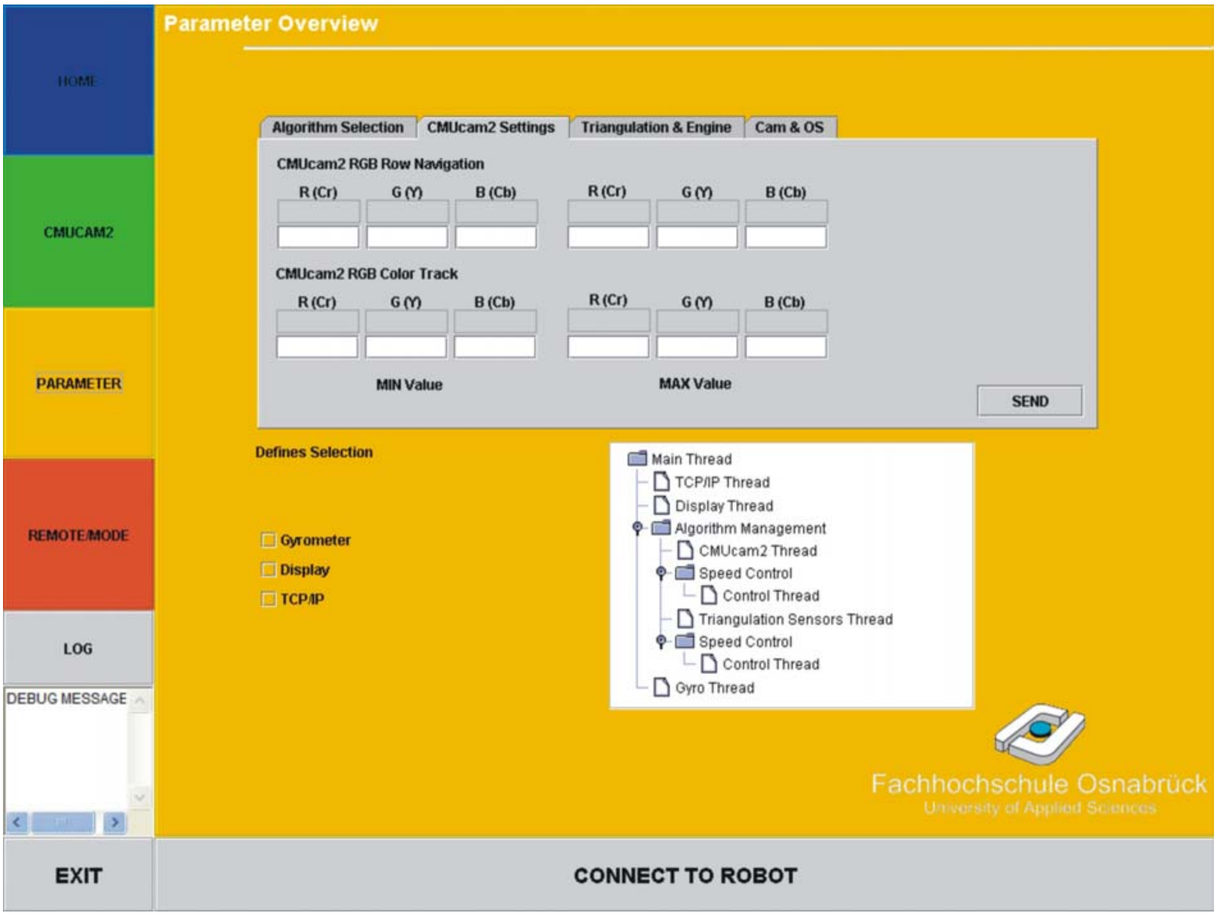


Fig. 23: Screenshot of a GUI window

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