Amaizeing

Modular sensor platform for autonomous agricultural applications

Steffen Meinke, Andreas Ganseforth, Dennis Hagen, Thomas Eichler, Markus Kreienbaum, Matthias Gebben, Tobias Niermann, Jens Egbers, Stefan Haller, Arne Siebe, Dimitri Willms

University of Applied Sciences Osnabrück, Faculty of Engineering and Computer Science/ Interdisciplinary Research Center Intelligent Sensor Systems (ISYS), Albrechtstr. 30, 49076 Osnabrück/Germany, Phone +49541 969 2090, Email: a.ruckelshausen@fhos.de

Abstract

The autonomous vehicle Amaizeing has been developed to participate at the Field Robot Event 2007 (Müller et al. 2006). The requirements for the project team which consists of 12 students, was to make a concept and to realise a low-cost microcontroller based platform. The robot has to consist the rough field conditions and has to be able to fulfil the tasks of the event. The Team benefits of the previous developments of field robots at the University of Applied Sciences. The system architecture is based on a modularly, bus oriented sensor platform. The field robot has shown that low-cost robot systems are able to successfully fulfil tasks within a broad range of field conditions. Due to varying boundary conditions the complexity of such systems is rather high (VAN HENTEN et al. 2006, RATH and KAWOLLEK 2006).

Fig. 1: Field robot Amaizeing

Keywords: **Field Robot Event, autonomous robots, sensor fusion, modular sensor concept, maize**

1 Introduction

The 5th Field Robot Event takes place at Wageningen UR from 14th to 16th of June 2007. The University of Applied Sciences, Osnabrueck participated for the fourth time. Already becoming a tradition, a group of students designed a robot to compete the –partly new designed- tasks of the event. The team of 12 students of different departments implemented within a time of 3 months parallel to their studies 8 microcontrollers and 19 sensors in the Amaizeing, their autonomous vehicle is based on a monster truck model.

This are the tasks of this years field robot event.

- **Robust navigation in a maize field with curved rows**

In a time period of 3 minutes the robot has to drive off as much distance as possible, while navigating within curved rows of maize. At the end of the rows the robot has to turn to the neighbouring next row. The task should be absolved in most fast, accurate, tough and smooth way.

- **Advanced robust navigation in a maize field with straight rows**

In the second task the robot has to drive along a predefined pattern within straight maize rows. Arriving at the headland, the robot should drive to a predefined row (e.g. the fourth row on the left side). The predefined pattern is presented one hour before the competition and in the meantime there is no testing is allowed. To enhance the complexity, plants were missing in either one or both rows for a maximum length of 1 m. The headland width is limited to 1.5 m of length.

- **'Weed' – control in a maize field**

While driving straight maize rows, the robot has to detect randomly placed yellow golf balls during the third task, representing weed. When the robot detects this 'weed' it signalizes this by producing a flash-light or sound and performs a weed killing action.

- **Free style**

For the first time, the free style contest is no longer a separate contest but flow in the total results. The robots should perform a task that is on the one hand funny and has on the other hand agricultural relevance.

The money spent for the robot is also a criterion in the overall standings. The cheaper the system is the more points are assigned.

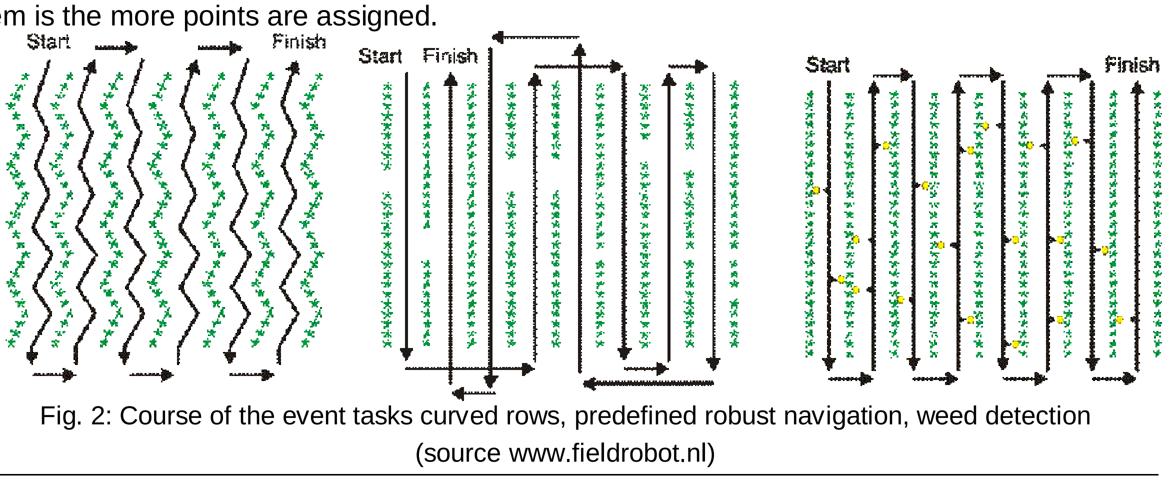

Fig. 2: Course of the event tasks curved rows, predefined robust navigation, weed detection (source www.fieldrobot.nl)

2 Concept

The concept of the new autonomous vehicle “Amaizeing“ is based on the developments of robots like “Eye-Maize” (Eye Maize 2004), “optoMAIZER” (optoMAIZER 2005) and “Maizerati” (Maizerati 2006) from the University of Applied Sciences Osnabrück which started at former Field Robot Events. The decision for the approved TXT-1 Tamiya model is based on the good experiences with the robot Maizerati.
To eliminate the distance measurement faults under unsteady field conditions a slipless distance measurement system was implemented. The approved sensor system from Maizerati was taken over with further development in the software. To increase the flexibility and scalability the CAN-Bus oriented system was extended by small microcontroller systems (SPC) around the robot which are responsible for preprocessing the sensor information. To realise the weed detection and to relieve the Phytec microcontroller, a separate microcontroller system was implemented and also connected with the whole system via CAN-Bus.
The high power consumption and the application area of the system raised the need of a reliable and powerful supply with separated energy sources for motors and electronics. Additionally it was important to attend EMC influence of the system to increase the reliability. The higher complexity of the system led us to build a new Graphical User Interface with a wireless LAN connection to the Phytec microcontroller. Figure 3 shows the whole system overview of the robot.

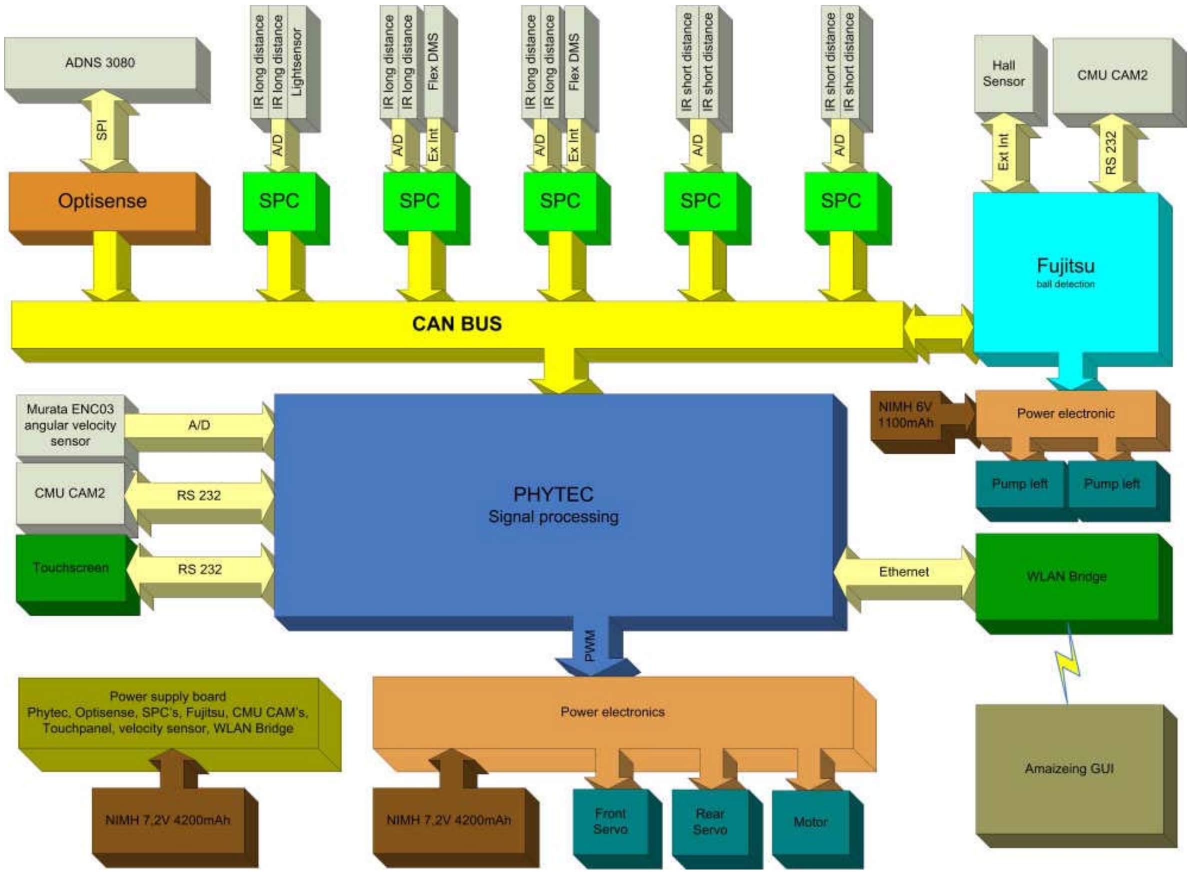

Fig. 3: System overview

3 Mechanics and Electronics

3.1 Mechanics

The base of our robot consists of a modified Tamiya TXT-1 RC-Monster truck model. This unit was also used by the previous model “Maizerati”. The model approved at the last Field Robot event in speed, agility and capacity.

Based on the CAD model, shown in figure 4, a new platform was designed. At this stage it was important to regard the intended structure of the control units and the concluding space consumption. Furthermore the mounts for the sensors, a weed killing module, a distance measurement module and especially two cameras had to be realized.

These requirements led us to use an approved combination of aluminium, high grade steel and Plexiglas. The Plexiglas provides the opportunity for interested people or spectators to have a look inside our robot. The high grade steel and the aluminium case design also give a high degree of security for the electronic components and handling. The construction of the Amaizeing platform and the Plexiglas were designed with the CAD software CATIA. In the original model the Tamiya TXT-1 RC-Monster truck contains suspensions. The platform of the Amaizeing robot had to bear such a weight, as the result of this the dismount of the suspension was necessary to keep good driving characteristics. So this design of aluminium and high grade steel was very important to protect the hardware against rough field conditions.

The base is equipped with two RS-540 electric engines which are connected to the wheels via a four-step gearbox. The all-wheel steering is driven by two servo motors. This combination allows controlling the front and rear axle individually.

The model also includes a no limit power electronic drive controller which is connected to the two engines energised with a seven cell battery stack. This power module can be linked to a microcontroller via PWM channels for speed control. The two servo motors for the steering are also controlled by a microcontroller via PWM and have their own power supply with a fixed voltage regulator.

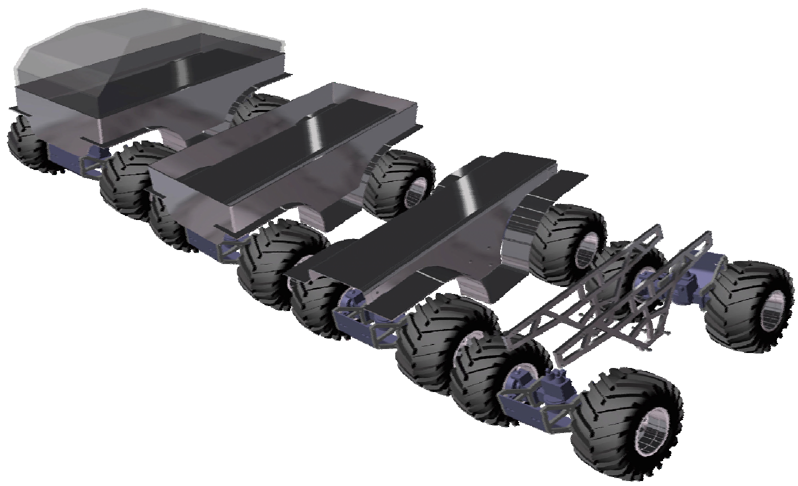

Fig. 4: CAD Model

3.2 Microcontrollers

As mentioned before the system contains a combination of different microcontrollers. One low-cost microcontroller is not capable to handle all needed functionalities. To remain with the existing algorithms for the Infineon C167CS and to keep a low cost system it was decentralised. The biggest advantage of using a combination of low cost microcontrollers is that they are able to work in parallel and only the important information's are exchanged over the CAN-Bus System with high transfer rates.

3.2.1 phyCore 167HSE

The Amaizeing contains the Phytec development board "phyCore-167 HSE" equipped with an Infineon C167CS microcontroller. This is responsible for the main signal processing in the System. Furthermore it processes the information from the CMUcamII, the Touch Display and it also does the A/D conversion for the gyroscope. The microcontroller collects most of the preprocessed sensor information on the CAN-Bus. Based on all these data, an algorithm computes a decision regarding course and speed variation. Another important task for the microcontroller is to handle the communication over a wireless LAN interface to the GUI. The additional circuit board contains the power-electronics for the flash-light, horn and the status LED's. Furthermore an optocoupler was implemented to realize the division between the different energy supply circuits.

3.2.2 Glyn evaluation board

The Glyn evaluation board has a Fujitsu MB90F345CA microcontroller. The main tasks are weed detection, preprocessing the hall sensor information and initiation of the weed killing action. The self developed additional circuit board contains power electronics for the weed killing action and LED's. Furthermore there is a CAN driver to realize the CAN connection and an EEPROM which saves all the parameters for the weed kill. Additionally there are external interrupts, I^2C bus connection and a third serial interface available for further developments.

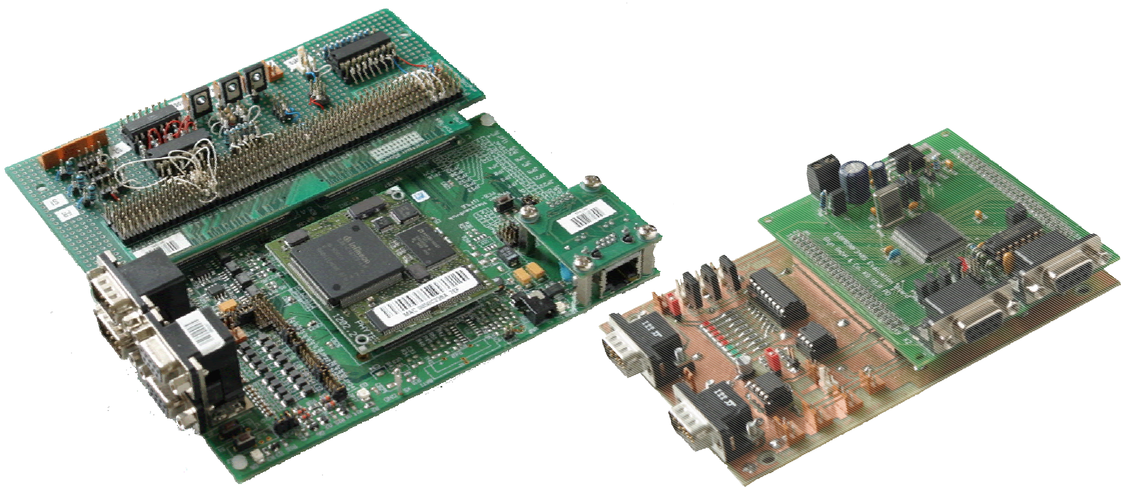

Fig. 5: Phytec and Fujitsu evaluation board with additional circuit board

3.2.3 SPC

With the demand of modularity, and due to the complex wiring of the former field robots, there was the idea of a decentralized sensor read-out and digitalisation. Therefore small modules had to be developed, which were able to connect the different types of sensor output signals. These modules shown in figure 6 are called SPC (Sensor to PIC to CAN). The overall idea was to use this module for all types of sensors. Therefore it had to provide analogue and digital inputs whereas I²C and SPI interfaces. Over this, all sensor data should be available on the CAN bus. So the node needed a CAN interface. As the market gave no cost-efficient module with all the desired interfaces, the decision to build own modules was born. With the help of DIP switches one can configure a module ID, which affects the sent out CAN message identifiers. By this, more than one module could be connected to a CAN network. Over this, the configuration via switches provided the possibility to use the identical software on all modules. The controller decision led to the PIC 18F258, giving the ability of easy In-Circuit programming at moderate cost with a large variety of interfaces. Different standardised connectors for the CAN bus and power supply were defined to provide mixing up. After layouting the circuit, a printed circuit board was etched within the laboratory. The soldering of all –mostly surface mounted- devices was performed manually. Afterwards the software-implementation started. The result was a 40 by 40 mm double layered module with 4 10-bit analogue inputs with a range from 0 V to 5 V, two external interrupts for fast edge detection of digital signals and an I²C interface. The cost of the parts of the module is about 15 €.

Fig. 6: Both Sides of SPC module

3.3 Sensors

Amaizeing uses different sensors in a sensor fusion system. As most of the sensors are already described in former publications, here is only a short overview over the implemented sensors.

3.3.1 Whisker

The whiskers, which are mounted on the front of the robot, protect it from colliding with maize plants. They consist of very thin strain gauges that are wrapped in isolating tape for mechanical stability. The strain gauges are wired in a full bridge circuit. The output of this bridge, a voltage difference goes to an operational amplifier that outputs a digital signal, which is processed from a SPC module with the help of an external interrupt.

3.3.2 Triangulation sensors

Triangulation sensors are used to measure the distance between the sensor and the maize row. Overall there are 10 triangulation sensors on the Amaizeing. Four long distance sensors with a scope from 200 mm to 1500 mm and six short distances with a scope from 100 mm to 800 mm are mounted. Two sensors look lateral to the driving direction and ensure that the robot drives in the middle of the rows. Four other sensors are in the bar at the front of the robot. The triangulation sensors have a large diffusion in their output values. Therefore, each of these sensors was calibrated with the help of a very accurate sensor. The result was a table to compensate the non-linearity. These tables are stored in the C167 controller, which uses them for linearising.

3.3.3 Gyroscope

A Murata ENC-03 solid state gyroscope was implemented. This micro-electro- mechanical system (MEMS) has a voltage output that corresponds to the turning rate. Integrating this output over time results in the turning angle. The measurement is based on the Coriolis Effect. Because of its high sampling frequency, the gyroscope is directly connected to the C167 controller and is used for measuring the turning angle on the headland turns.

For high precision measurements, the effect of temperature drift and the suppression of noise components can be achieved by a band-pass filter with a lower cut off frequency of about 0.3 kHz and an upper cut off frequency of about 1 kHz. The filter is implemented on the self developed sensor board.

3.3.4 optiSense

optiSense is a slope free optical track measurement system. It sends out CAN messages with the actual speed over ground and the milage. optiSense reaches an accuracy lower than 1%. The functional principle will be presented in further publishments.

3.3.5 CMUcam II

A CMUcam II is used for colour tracking to detect golf balls. This smart camera does not only give out raw pictures but has the ability to do preprocessing within the image. For example in colour tracking mode the camera only outputs the centroid of the colour within the picture and the diameter of the coloured space. All information is provided via a RS-232 connection, which is attached to the Fujitsu board. A second CMUcam II is used for the row navigation.

3.3.6 Light sensor

A light sensor measures the intensity of the sunlight. This information is used to realise an adaptive setting for the CMUcam II. While the light conditions vary, the registered colour of the golf balls, the soil and maize differs very. Especially on cloudy days, there is an ample need of this colour adaptation.

The whiskers, gyroscope, optiSense and light sensors work with self developed circuit boards. All of them were self designed, etched and populated within the laboratory. Figure 7 shows the used sensors and their additional circuits.

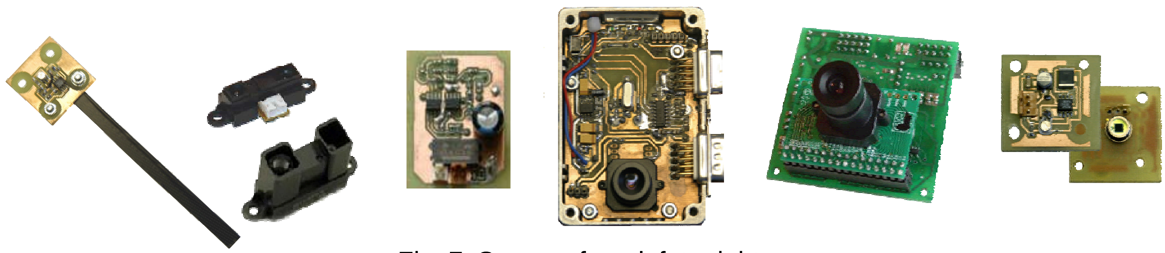

Fig. 7: Sensors from left to right
Whiskers, distance sensors, gyroscope, optiSense, CMUcamII, light sensor

3.4 Actuators

The Amaizeing is equipped with different actuators. To signal the detection of weed a horn and a flash light are used. Furthermore a weed killing action is performed with the device shown in figure 8. It contains two pumps and an own energy supply. The tank is able to contain one litre of fluid. To decrease the use of the fluid and to perform a precise weed kill the device is able to divide both sides. By this the connected microcontroller has to decide if the weed killing action should be performed on the left or on the right. If there is a demand for a weed kill the fluid is pumped from the tank threw a holding valve and injector.

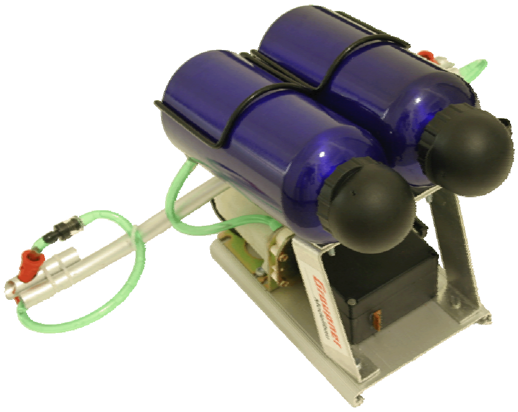

Fig. 8: weed killing device

3.5 Power supply

To realize a robust and reliable system there are high requirements to the power supply. The rough field conditions raise the need of stabile connectors. Also temperature can become a problem when the sun is shining. Another problem is that the signals can be influenced by EMC affects. To ensure this EMC stability two different voltage circuits with separate grounds are needed. The connection between both circuits is provided by an optocoupler. As a result of all these requirements two different power supply boards were built. The board in figure 9 is responsible for the supply of the electronic on top of the robot like the C167 microcontroller, the Glyn evaluation board, or the Wireless LAN Bridge. It consists of three fixed voltage regulators. It is very important to use high cross-section for the ground connections to decrease the EMC affects. A second board was implemented down in the chassis of the robot to realise the supply for the optiSense and the SPC modules. Furthermore there is a switching power supply for the servo motors. For safety reasons the power supply for the driving motor and the servo motors can be shut down by the C167.

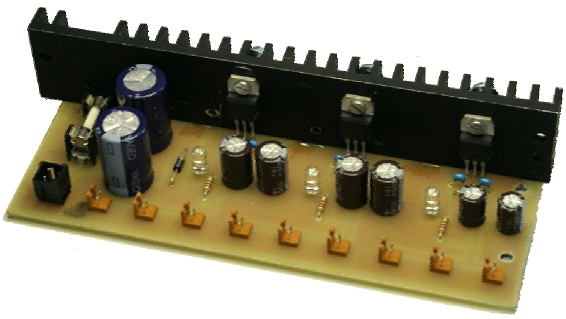

Fig .9: power supply board

3.6 External interfaces

3.6.1 Touch Display

To allow the user to interact very fast and easy with the robot a touch display was implemented (see figure 10). It gives the opportunity to start and stop the different tasks and displays the status of the robot and the result of the weed detection. Furthermore the user is able to control the status of the Wireless LAN connection to the robot swarm. Additionally the predefined path for the second task can be displayed before starting the robot. The touch display is very important for the test phase because of the need to abort and restart the actual task.

Fig. 10: touch display

3.6.2 WLAN-Bridge

The Amaizeing is equipped with a WLAN Bridge for the connection to an external PC. The use of a graphical user interface during the test phase is very important to find the optimal parameters or to get an overview about the actual sensor data. The requirements for the wireless LAN bridge were 5V voltage supply and the size has to be as small as possible. This led us to a WAP-0003 bridge from Level1. The wireless LAN bridge is wired to the ethernet connection of the Phytec microcontroller board.

4 Software

4.1 CAN Bus

The CAN-Bus is our main connection between the microcontrollers in the system. Data is transmitted by this asynchronous, serial, two wire bus system. It works with difference signals to make the transmission of data very robust. Additionally the data is saved by automatically added redundancy.
At the robot the bus carries most of the pre-processed sensor information. This bus system is very flexible and scalable. New microcontrollers which collect sensor information or control actuators can easily be added to the existing system only by software changes. The biggest advantage is that microcontrollers work independently in the system and collect the needed sensor information parallel. As a result of this the combination of a lot of low cost microcontroller systems affects a nearly real-time operation and a high working performance. Figure 14 shows the existing CAN-Bus identifier specification.

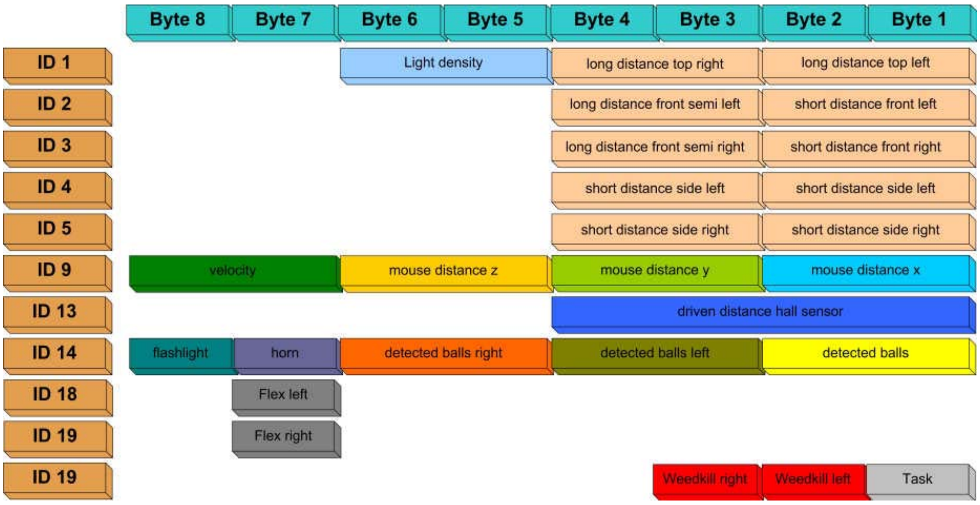

Fig. 11: CAN-Bus overview

4.2 External communication channels

To influence all the parameters and to get informed of the actual sensor data a wireless LAN communication can be established to the Phytec microcontroller with a graphical user interface shown in figure 12. By this way the user is able to affect up to 90 parameters to configure the robot. Additionally all the sensor data and other variables of the robots data is logged. As a result of this the user is able to interpret this data after a test drive to improve the system and adapt the algorithms or react on errors. Furthermore he is able to calibrate the course for predefined navigation for task number two. Another interesting feature is the ability to remote control the robot via WLAN link.

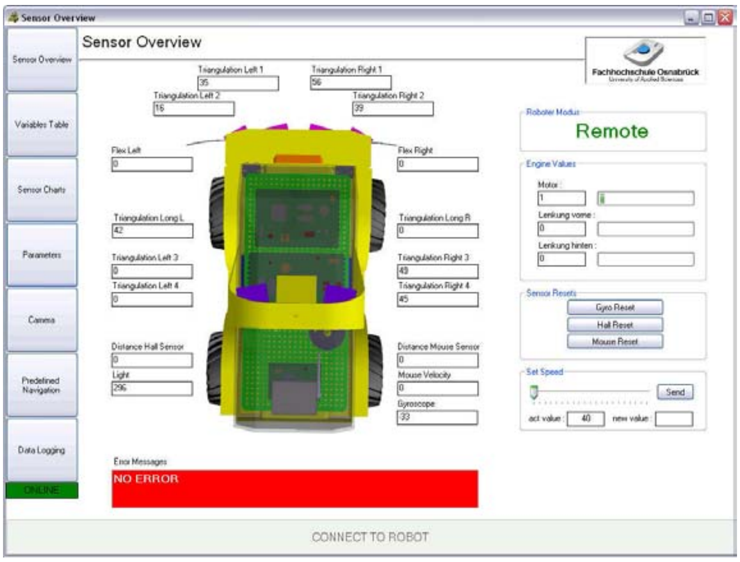

Fig. 12: graphical user interface
with sensor overview

4.3 Turning manoeuvres

Amaizeing has a turning radius of 75 cm, so it is impossible to reach the neighbouring row within one direct turn. To fulfil both requirements, a fast and smooth turn for the first task and a minimised headland width for the second task, two different turning manoeuvres were implemented shown in figure 13. The first is the Omega-plus turn. When the robot wants to turn to the right side, it firstly strikes out to the left side. Afterwards it does a 180° turn to the right. The strike out helps, that Amaizeing's position after the 180° turn is directly in front of the new row. Therefore the robot stands very early in a parallel position to the row and can change very early to the in-row navigation mode. The disadvantage of the Omega-plus turn is that it needs more space in the headland. With the Z-turn, a second turning manoeuvre is implemented. Turning right again, the robot at first does a 90° right turn. After this, the robot drives backwards lateral to the rows so that he reaches the row with the following 90° turn. Although there are two changes in driving direction, which require time for decreasing, stopping and inverse acceleration of the robot, the Z-turn has the advantage of using minimised headland width.

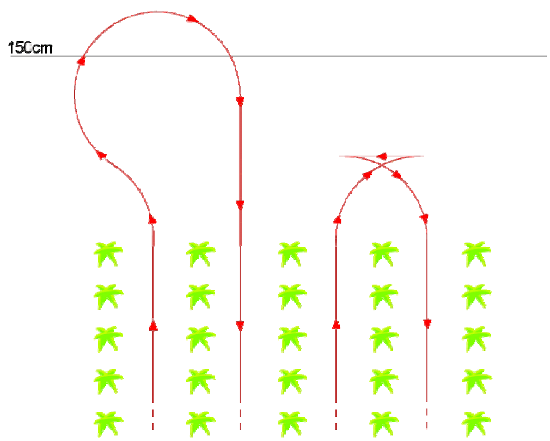

Fig. 13: implemented turning manoeuvres

5 Realisation of Tasks

5.1 Curved Rows

The basic point of the robot is to navigate between rows, whatever the rows are straight or curved. To realise this, the microcontroller has to interpret the data which is given from the sensors and has to estimate the orientation in the row. There are three different sensor-systems with an adjustable priority to give a steering decision. An adjustable priority is very helpful because of the varying surrounding environment. Unlike navigating in really high plants, navigating in plants with only 20cm height has to count on another sensor-system. These mentioned sensor-systems were with a descending order of the priority in small-sized plants the CMU-Cam, the two Sharp sensors for long distance on the top of the Amaizeing and the four Sharp sensors in the front. With the measured distance of the sensors, which target at the plants, it is possible to allocate the robot to one of five zones as it is shown in figure 14. The software algorithms try to control the robot in the centre of the row. Furthermore the robot has to turn at the end of a row in the next one, but where is the end? In contrast to a robot, for a human being it is easy to see the end of the row. There are two terms which must be complied to make a turn. First term which has to be complied to detect a turn is that the robot has to travel a given distance which is measured by the optical way measurement and the second term is that the infrared sensors at the front don't see plants for a couple of milliseconds. If both terms apply, the robot is turning with the z-turn in the neighbouring row.

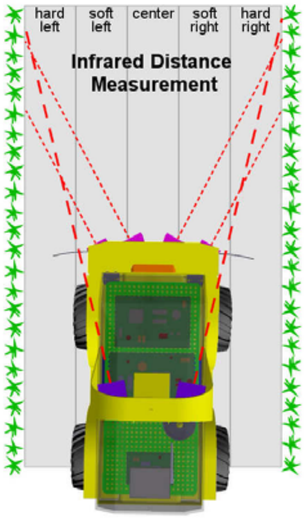

Fig. 14: usage of distance measurement

5.2 Predefined robust navigation

The navigation strategy is the same like the strategy in the first task. For the robust navigation it must be possible to navigate a small distance without any plants at both sides. This is given because of the foresighted sensors (CMU-Cam, sharp long distance sensors) and because of the slipless way measurement – the robot doesn't detect a turn in the middle of the row. Furthermore this task desires that the robot is navigating a predefined way. To allow this it must be possible to turn in each row, whatever it is the first one or the fourth one. Those will be enabled by the reliable distance measurement. To turn in the neighbouring row the Amaizeing uses the mentioned z-turn, because there is only a headland of about 1,50m. A turn in another row than in the next proceeds as follows. After a right/left turn of 90° the robot will go a predefined distance, and then the robot will drive again a 90° turn in the same direction so that he is in the requested row. You can implement the actual way the robot has to travel through in the programmed GUI shown in figure 15.

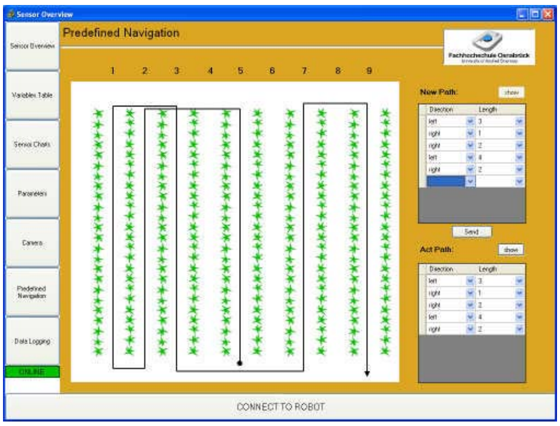

Fig. 15: GUI interface to configure predefined path

5.3 Weed detection

To realise the weed detection a CMUcamII is used. To do image processing the camera has a frame buffer and a small microcontroller. The resulting preprocessed information is then sent over a serial connection to the Fujitsu microcontroller who does the final golf ball detection. To get the needed information from the camera the used settings are very important to realise a reliable detection. Additionally the light conditions massively influence the parameters. Because of this a graphical user interface (see figure 16) was built to affect all these settings only a few minutes before the event starts. Furthermore the interface was very helpful to develop and debug the detection algorithm because the information from the camera can be logged and displayed. After configuring the parameters they are saved into a connected EEPROM on the additional circuit board to ensure that the parameters are still the same after restarting the whole system.

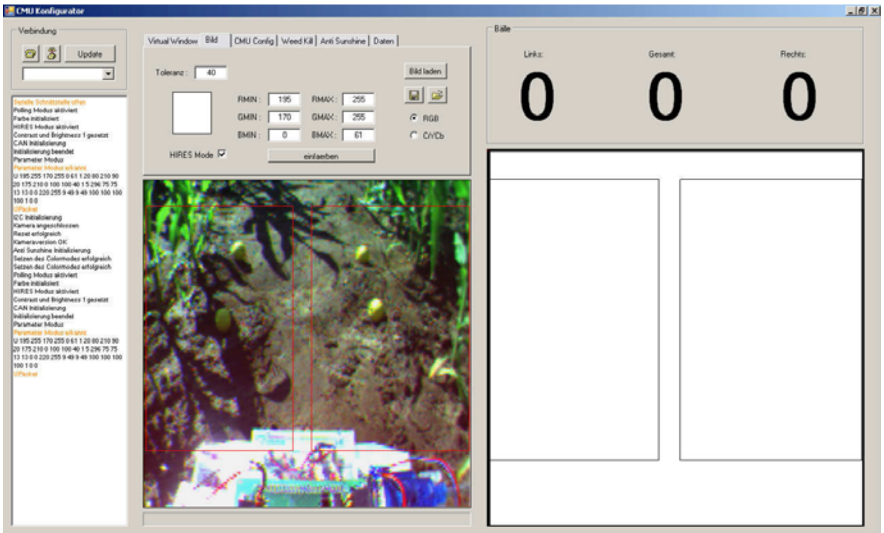

Fig. 16: GUI interface to configure weed kill

The Amaizeing detects the weed by controlling the differences of the colour tracking information in the predefined virtual windows. The algorithm has to differ between golf balls which are already detected before and which appeared in the field of view. This can only be realised by also attending the past sensor information. Furthermore the algorithm has to ensure that noise doesn’t cause a detection. Another problem was to redetect balls which are covered from plant for a short time. If there is a detection of a new golf ball the weed killing action is performed after a calculated distance for a short time. Additionally the information is send over the CAN-Bus to give the detection signal with the horn and flash-light. The detection information is also displayed on the touch display and the GUI which is connected via wireless LAN.

5.4 Freestyle (Swarming)

At the freestyle event the idea behind swarming was presented. Swarming is an increasing topic when it comes to the agricultural use of robots under field conditions. It is nearly impossible to build one robot that is able to do the whole work on the field. A lot of different sensors and tools are needed and the field size is too big to do all the work with one robot. To solve this problem a swarm which consists of many robots for the different tasks have to be build. The idea is to let robots work like the way bees work together in a hive or like other social insects for example ants. Social insects are known to coordinate their work to realise tasks that are beyond the capabilities of a single individual. To coordinate this so called robot swarm a communication (see fig. 17) between the robots is very significant. For example one robot on the field detects weed. This information is send to the robot swarm. Now the robot who is able to do the weed kill and who has the nearest position to the weed is able to drive to the exact position and performs the weed kill. By this way of communication a coordinated work in a swarm on the field is possible.

At the Freestyle event the idea behind the communication in a robot swarm was shown to the audience. The robot Amaizeing tries actively to establish a connection to other accessible robot systems. In this case the robot Maizerati. Afterwards colour tracking was performed at the robot Amaizeing. Colour tracking means that the robot follows a specific colour. The driving information from the robot Amaizeing was transferred to the Maizerati. By this way the robot Maizerati drives around only with the information from the other robot. At the second part of the Freestyle Event the Amaizeing also drives by the information of the colour tracking. The Maizerati was still connected and imitates the movements of the robot Amaizeing. As a result of this both vehicles nearly drive the same way synchronously.

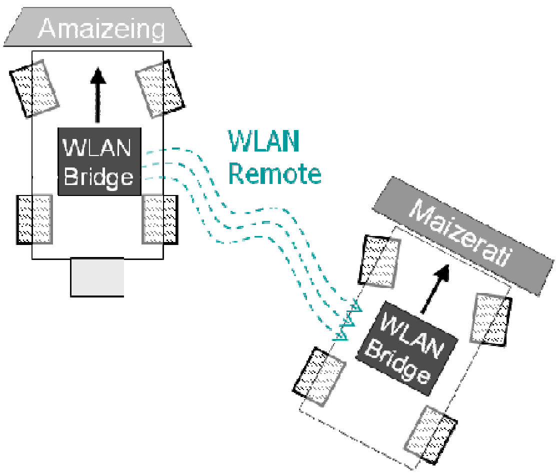

Fig. 17: example of communication in a swarm

6 Results and Conclusion

During the Field Robot Event, the robot performed very well. The development shows that low cost robot systems are able to participate at the field robot event. The robust construction consist the field conditions and no mentionable hardware problems occurred. Due to the high driving speed, some interactions were necessary to prevent the vehicle from destroying maize plants during the first task. The high driving speed was necessary, as the torque of the driving servo motor was not powerful enough so that the speed could have been even slower.
The second task, driving the predefined pattern, went excellent. The slope free track measurement and the robustness of the sensor fusion concept helped working so well.
The third task showed how tight the drive train really was. The weed killing actor enlarged the weight of the robot by approx. 1 kg. As the front axle lost grip on soil, the team enlarged the soil pressure on the front axle with the help of an accumulator. Summarizing, the robot weight increased for about 2.5 kg. To ensure, that the robot detects every golf ball, the driving speed was again decreased. The combination with the extra weight and a small acclivity in the field, led to the fact, that the motor was not powerful enough to drive the robot. It stopped and manual interaction was necessary to push-start it again. Nevertheless, the weed killing action did very well. The freestyle task showed the swarming principle. Also this performance worked very well. In the overall standings the Amaizeing reached an earned second place. In summary one can say, that the drive train was the bottleneck of the robot. But enlarging the power of the motor brings new problems in the drive train. The gearboxes from the modelmaking sector are not solid enough to pass higher power. So one has to enlarge the whole drive train. If the whole drive train has to be changed, there is no longer the advantage of using the platform of the model. A completely constructed solution would be necessary.
The electronic principle of using microcontrollers instead of PCs worked very well. The guarantee of fulfilling answering times of the controllers is a large advantage over PCs, which might delay the tasks for some seconds in extreme situations. Also the modularity and decentralism makes the complex system very flexible. Comparing this robot to the competitors, the computing power should have enough reserve to fulfil the tasks for the next years.
The next large evolution step could be to change to a professional platform using industrial motors and self designed gearboxes for high torque transmission.

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