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PREFACE

In summer 2003, when the 1st Field Robot Event was "born" at Wageningen University, it has been an experiment to combine the "serious" and "playful" aspects of robotics to inspire the upcoming student generation. Specific objectives have been:

- Employing students creativity to promote the development of field robots
- Promoting off-curriculum skills like communication, teamwork, time management and fundraising
- Attracting public interest for Agricultural Engineering
- Creating a platform for students and experts to exchange knowledge on field robots

Driven by the positive results, the competition was upgraded to an annual international event. Furthermore, the 2nd Field Robot Event 2004 in Wageningen has been accompanied by a workshop, where the teams presented their constructs together with a scientific paper describing the hard- and software design. The submitted papers have been a valuable source of information for the Jury and the visitors and also have proven that the teams didn't just follow a trial and error approach but a well-structured design process. The respectable quality of the papers justified the collection and edition as *Proceedings of the 2nd Field Robot Event 2004*. The edition of the proceedings ensures that the achievements of the participants are now documented as a regular scientific publication and thus being accessible as basis for further research. Moreover, for most of the student team members it is the first scientific publication in their career - a well-deserved additional reward!

Wageningen, February 2005

Joachim Müller,
Chairman 2nd Field Robot Event 2004

INDEX

DEVELOPMENT OF "AGBO", A LASER SCANNER GUIDED AUTONOMOUS CROP SCOUTING ROBOT

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ABSTRACT

To effectively and timely collect production related information to support precision farming decision-making, an autonomous crop scouting robot was developed. The field robot features four independently driven and steered wheels and was equipped with a camera and GPS to georeference crop stress, as well as weeds and insect infestations in the field. A SICK laser scanner was used to guide the robot between the rows of corn autonomously and all sensors and wheel controllers were interfaced using a Controller Area Network (CAN) bus. The robot was programmed to turn at the headlands and enter the adjacent row using a magnetic compass. This paper reports on the physical design and control system development of the robot, as well as its performance under field conditions.

KEYWORDS. Crop scouting, precision agriculture, robotics, autonomous guidance, laser range finder

INTRODUCTION

Site-specific crop management works by virtue of the availability of instantaneous crop state information. Remote sensing has been used widely to collect overall information about the crop status as well as soil conditions (Diker, 2002). While aerial photography can efficiently gather information from a large area, its resolution limits obtaining detailed information. Gomide et al. (2003) used a radio-controlled robotic helicopter to cover a smaller area to improve the resolution, but it required a professional. To obtain detailed local crop state information, a system is needed that travels between crop rows and returns the data in an autonomous fashion. The robot as reported in this research was developed for this very purpose. In the future, it may also serve as a platform for small-scale field operations such as mechanical or high-concentration chemical weed control, insect control and to collect soil data for environmental monitoring purposes.

Although autonomous guidance in agriculture is well represented in the literature, few manuscripts report on autonomous crop scouting. In addition, most applications target automation of traditional farming operations such as tillage, planting, spraying etc. (Reid et al., 2000, Torii, 2000, Keicher and Seufert, 2000). A weed control robot was developed by

Baerveldt and Astrand (1998), and Bak and Jakobsen (2004) proposed a small field robot capable of traveling between crop rows to register the locations of crops and weeds using a camera and GPS receiver. If the robot is to be used solely for scouting, it can be as small as planet rovers (Biesiadecki et al., 2000, Kuroda, 2003).

Objectives

The importance of collecting real-time local crop state information is well recognized, however most crop scouting is currently performed by humans equipped with a GPS backpack and a good eye for abnormalities. The objective of this research was to develop a crop-scouting robot, which travels autonomously between crop rows and collects real time crop information without human intervention. The emphasis in the design was on flexibility and extensibility for easy inclusion of new sensors and actuators. To this end, a four wheel steering robot was developed that uses a Controller Area Network and local control nodes for all sensors and actuators. A SICK laser scanner was used to simplify the guidance control algorithm as compared to camera-based guidance systems.

DESIGN OF "AGBO", A CROP SCOUTING ROBOT

Hardware design

As shown in Figure 1, the developed robot has four independently driven and steered wheels installed on a flexible suspension linkage ("bogie suspension") to ensure all wheels contacting the ground at all times.

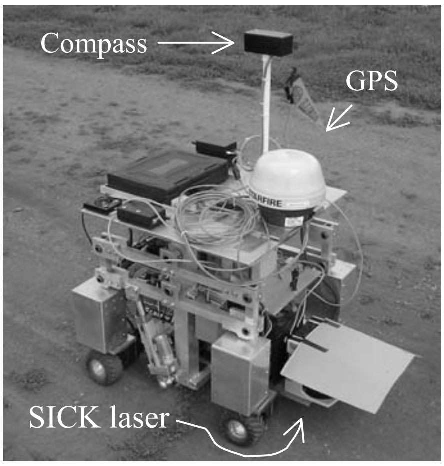


Figure 1. Crop scouting robot "AgBo"

The physical dimensions of the robot are 0.5×0.5×0.5m, which makes the robot suitable for traveling between crop rows in typical Midwest farms, where corn and soybeans are planted at 76 cm (30 inches) distance. When fully loaded, the robot weighs about 70 kg. For autonomous guidance, the robot was equipped with a SICK laser scanner that produces distances to objects in a 180-degree field of view (LM291, SICK® AG, Duesseldorf, Germany). Additionally, a magnetic compass (Vector 2X, Precision Navigation Inc., Santa Rosa, CA) was used to sense the direction when turning the robot at the headlands. All sensors and motor controllers were interfaced using a CAN bus. For collecting crop information, a camcorder was used to monitor the crop combined with a STARFIRE™ GPS system for georeferencing. The SICK laser scanner was placed as low as possible to avoid measurement errors caused by corn leaves, especially under high wind conditions. The top of the sensor was covered with a wide flat cover to avoid laser signal degradation by direct sunlight.

The flexible suspension linkage (bogie suspension) was designed to ensure reliable wheel-ground contact under varying field conditions. Figure 2 shows the suspension layout.

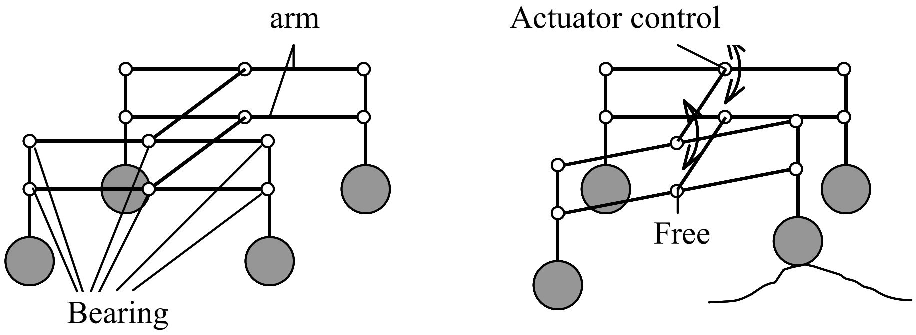


Figure 2. Flexible suspension linkage system

Both sides of the robot have the parallel beam linkage system as shown in Figure 2, for independent motion of the wheels. On one side of the robot, a linear actuator was connected to the frame, which implements inclination control using a tilt sensor. The inclination control offers the flexibility to adjust the SICK laser pitch angle, to perform optimally in varying crop stages. To obtain optimal robot maneuverability, four 50W DC brushless gear motors were used to drive the wheels and four 20W DC gear motors were used to steer the wheels.

The independent steering yields four basic maneuvering functions 1) two-wheel steering, which was used during between-row guidance, 2) four-wheel steering, 3) crab steering and 4) zero radius (spin) turn, the latter two being used during the headland turning. Figure 3 shows the steering principle. The Ackermann steering principle was applied to both 2 wheel and 4 wheel steering to ensure smooth motion. In the case of crab steering, all wheels were set to the same direction and during the spin turn, the steering angles were fixed to 45 degrees. The speed of each wheel depends on the turning radius and was calculated according to the geometry models for the different steering functions (see Figures 3a, 3b and 3c).

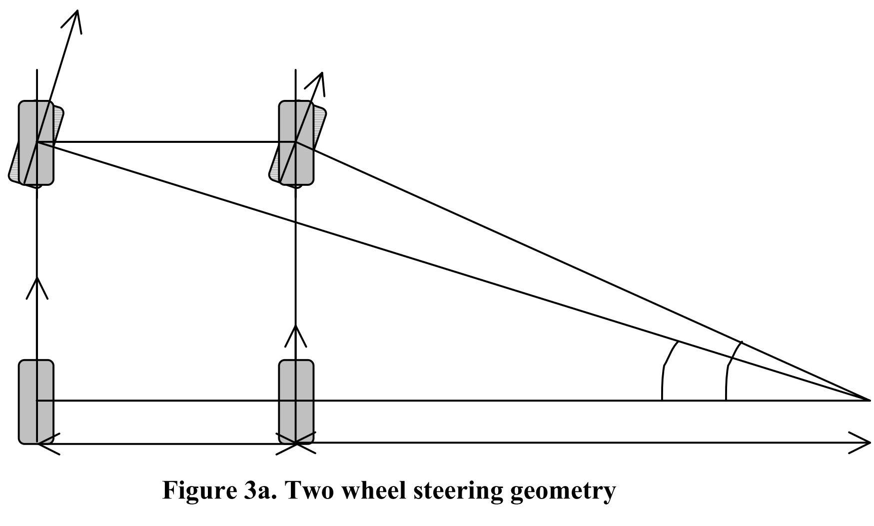


Figure 3a. Two wheel steering geometry

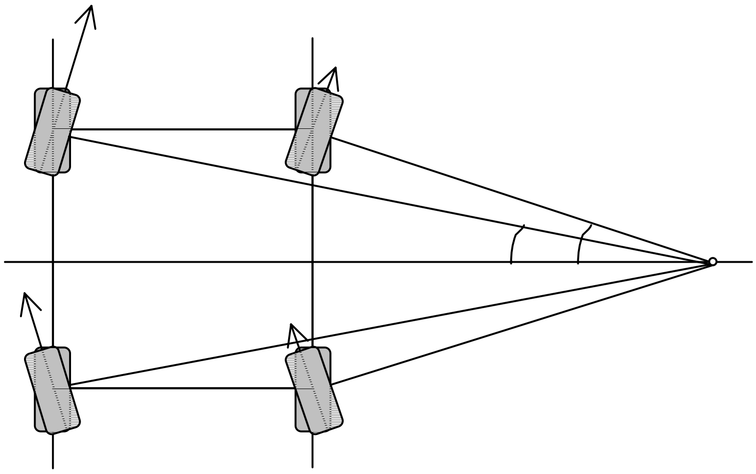
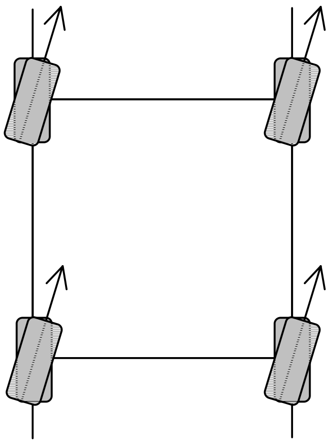
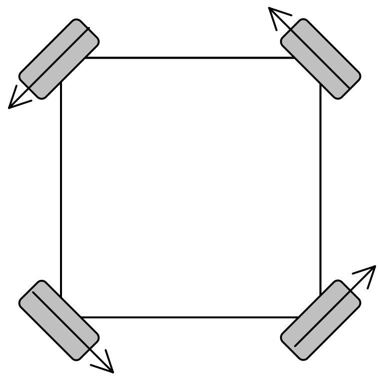


Figure 3b. Four wheel steering geometry



Crab steering geometry



Spin turn steering geometry

Figure 3c. Crab and spin turn steering geometry

Electrical design

The electrical sensing and control systems were used to collect both crop information as well as transmitting control signals to manoeuvre the robot. All the equipment control units (ECUs), including four wheel control units, inclination control unit, a remote radio control (R/C) unit, magnetic compass, SICK laser scanner and a portable computer for data processing were connected using a CAN bus to obtain efficient communication (Figure 4).

The CAN bus architecture allows for the addition of different sensors and actuators without significant changes to the robot design. The portable computer, used for autonomous guidance mode and radio control mode used same CAN ID and the two modes were selected using a mechanical switch.

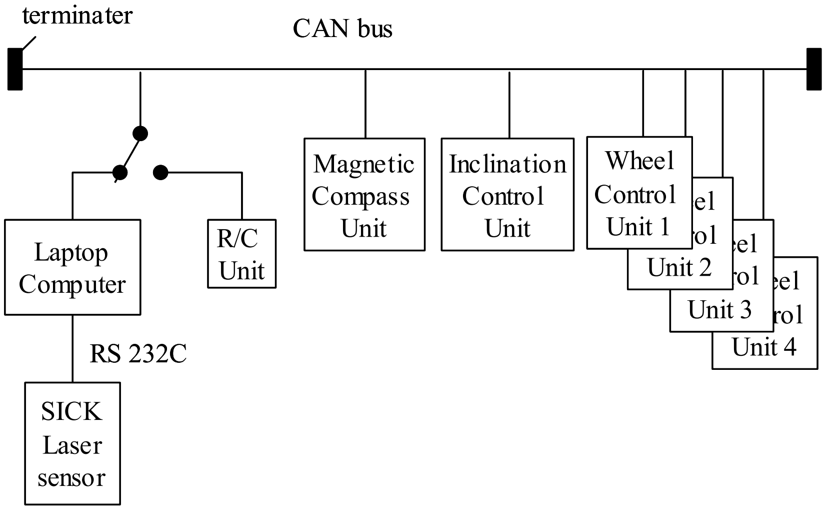


Figure 4. Schematic of electrical robot design

Each of the ECUs consisted of a 16-bit microcontroller (ATOM PRO24-M, Basic Micro, Farmington Hills, MI) and a CAN interface, connected to the microcontroller using a Serial Peripheral Interface (SPI) bus. The ATOM PRO 24-M has 2kB RAM, 32kB flash program memory and a 16MHz clock. Figure 5 shows the electrical schematic of a wheel control unit.

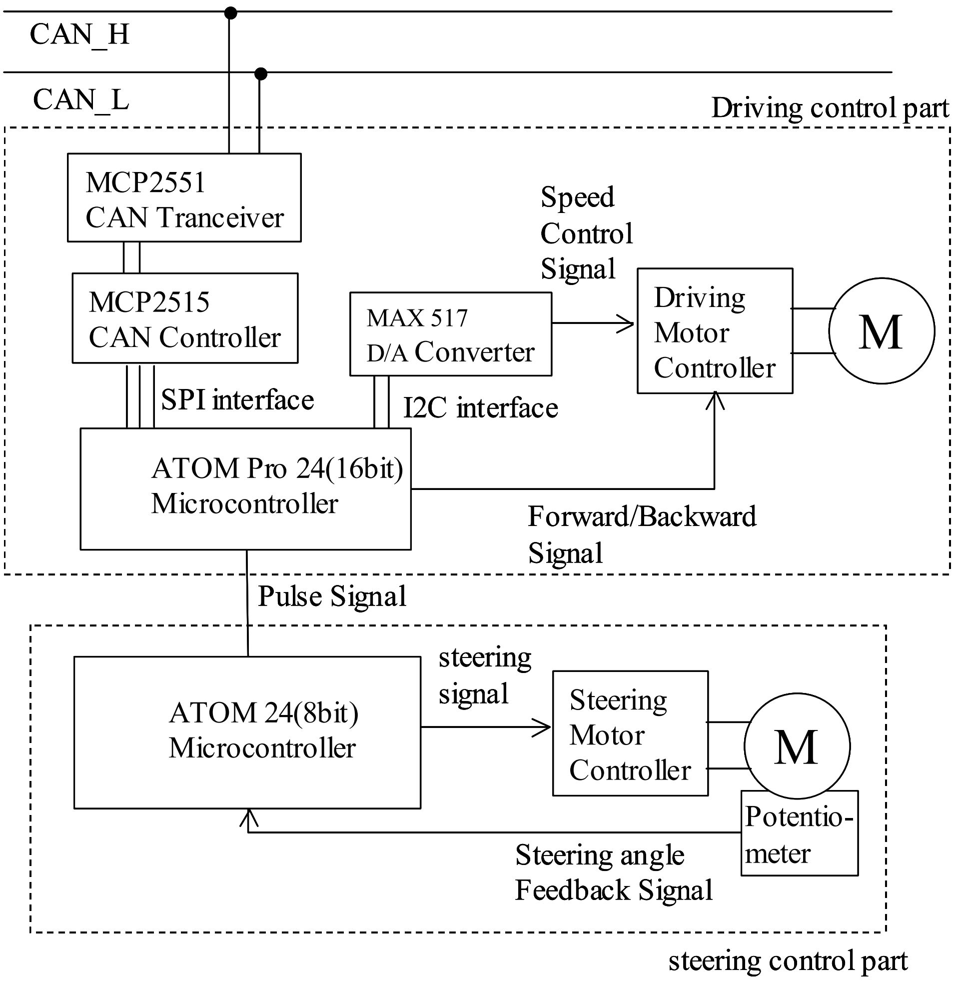


Figure 5 Electrical schematic of a single wheel control unit

DATA PROCESSING AND CONTROL

Data processing

The SICK laser scanner provides distance data every 0.5 degrees from 0 to 180 degrees. Table 1 shows the specifications of this sensor. The SICK sensor outputs data via RS232C in 38.4kb on request of a portable computer.

Table 1. Specification of SICK laser scanner

Type	Scanning angle	Resolution/Accuracy	Range (10% reflectivity)	Data Interface	Transfer rate	Power consumption	Weight
LMS291	180 °	10mm/±35mm	30m	RS232 RS422	9.6/19.2/38.4/500 kb	20W	4.5kg

A simplified model of corn stalks was to regard them as perfectly cylindrical shapes, placed in rows at constant distances as shown in Figure 6. The laser scanner measures the shortest distance in 0.5-degree increments. To control the robot, information is needed regarding the left and right side nearest row. Data filtering was performed using the following steps:

1. Collect distances and associated angles from SICK laser scanner.
2. Convert cylindrical coordinates to Cartesian coordinates within 2 m radius.
3. Discard lateral coordinates outside 15<|x|<80 (this window was chosen arbitrarily)
4. Discard longitudinal coordinates larger than threshold D. This value is adaptive; D is 150cm during between-row guidance and 80cm during headland turns.

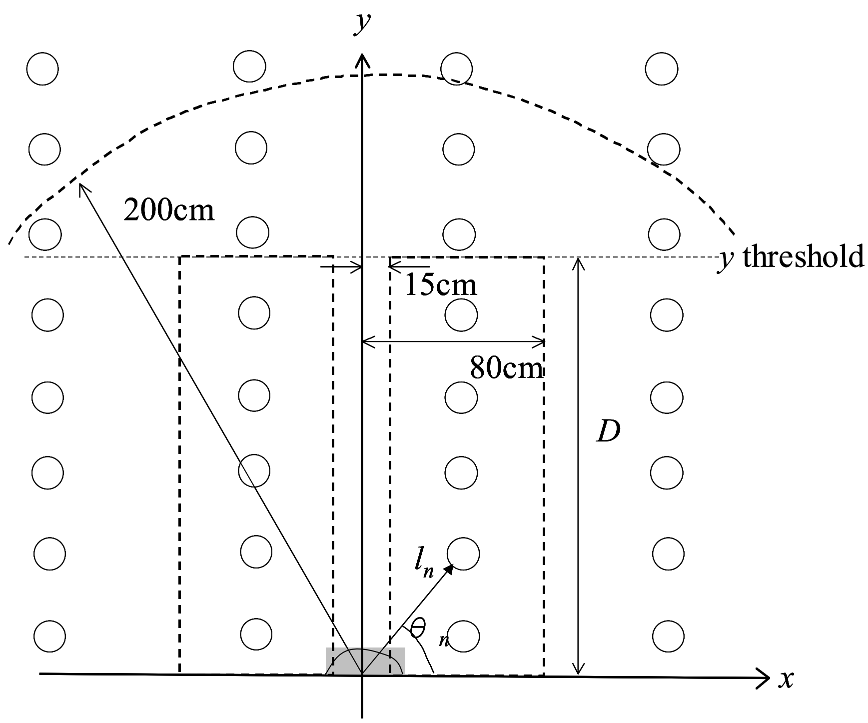


Figure 6. Simplified model of corn stalks in the field

Between row guidance

The between-row guidance control was based on the difference between the current heading and an aiming point, which was calculated using the filtered data from the SICK laser scanner. The aiming point was simply the mean value of the Cartesian coordinates of the corn stalks.

Headland turning control

The turning at the headland was performed using a series of steps as follows:

1. Detect the end of row by observing loss of data from SICK scanner.
2. Continue moving forward using current heading for 10 seconds (chosen based on maximum travel speed).
3. Perform zero radius turn through 180º using electronic compass.
4. Fine tune robot orientation with latest row using SICK laser sensor. Proper alignment was obtained when the actual heading is equal to the aiming point.
5. Move transversely (using crab steering) and stop when the robot is in line with the adjacent row using SICK laser sensor. As in step 4, proper alignment was obtained when the actual heading is equal to the aiming point.
6. Enter adjacent row.

Figure 7 shows the headland turning method of the robot.

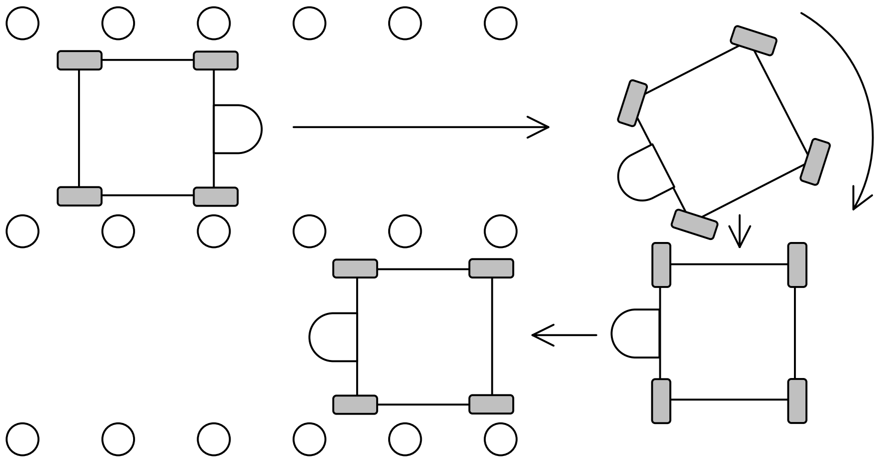


Figure 7. Turning sequence at the headland

RESULTS AND DISCUSSION

During the initial experiments, the corn was 4 weeks of age and about 40cm tall and the robot traveling speed was set to 0.14m/s. Figure 8 shows a sample of measured corn stalk locations after filtering, including the aiming point, being the middle point of the imaginery line conncting the mean of the left and right data points respectively. Aiming point is independent of the actual heading of the robot.

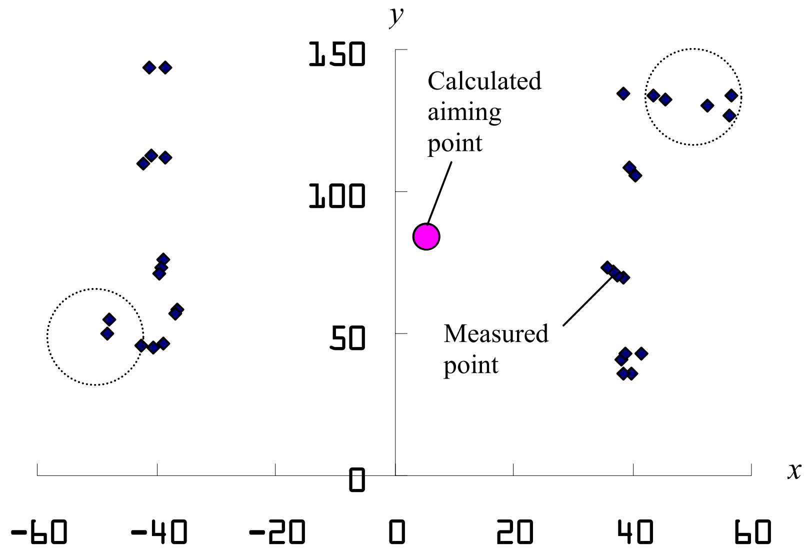


Figure 8. Measured point during autonomous traveling

Under high wind conditions, corn stalks can be masked by leaves as shown in Figure 9. The aiming point again, was obtained from the mean of the data points which puts it virtually in line with the robot, where in fact the robot should steer to the left. Under these high wind conditions, an offset was given. In the future, an electronic wind vane could be used to better estimate the value of this offset.

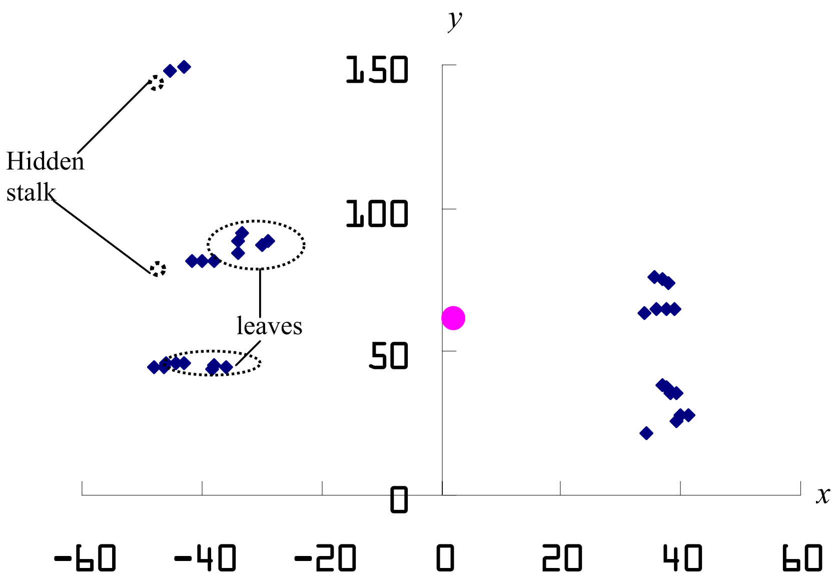


Figure 9. Measured point during autonomous traveling in strong lateral winds

Conclusions

An autonomous crop-scouting robot was developed which successfully negotiated cornrows and automatically turned at the headlands. The robot was tested in cornrows of 4 weeks age and traveled autonomously through rows repeatedly through a distance of more than 30 meters without damaging any corn stalks.

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Sub-canopy Navigation Techniques for a Small Agrobot

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Abstract. A computer vision-based row detection system was developed and tested using Labview software. Images where captured by a colour camera and then sent to a PC via wireless communication. Row detection is done by using perspective information to calculate the intersect of two crop rows The first set of crop row images showed that lightning conditions and crop height are challenging factors that also can complicate algorithm development. Hardware should be well taken care of to make the software not to complicated. Therefore, turning the camera to look at the sides of the crop row could be worthwhile to investigate.

Keywords. Navigation, row detection, colour vision.

The international Field Robot Event organised by the Agricultural Engineering and Physics faculty at Wageningen University, provides an excellent opportunity to test an autonomous field robot in real-life/competition environment. The robots are judged on different aspects of row detection and row following in a maize field.
A group of four Agrotechnology students, after four weeks work, have developed a small four-wheeled robot to participate this field robot competition. The vehicle will serve as an experimental robot for research in row detection, using small low-cost sensors.
This paper reports our work on colour vision based row detection algorithm. The challenges in using visual sensors lie in the variation in outdoor lighting conditions (Tang et al., 2000). After the first step of image acquisition follows the image segmentation, which is to divide an image into regions of, plants (weeds or crop) and background (soil, rocks and residue). The result is a binary image on which you can do your calculations for crop row detection.

Objectives

The general objective of this project is to develop a low-cost vision based navigation system for a small field vehicle that is capable of following crop rows. The specific objectives of this study were to:

- Investigate vision based crop row detection.
- Develop a row detection system for the small robot.
- Test the design, by participating in the Field Robot Event.

Materials and Methods

Hardware Design

Row detection can in general be done by using two types of cameras having different spectral sensitivities. One type is a monochrome camera with near-infrared filter (Åstrand and Baerveldt, 2002) that can capture

reflection intensity in near infrared region (Vrindts, 2000); another one is a colour camera (Woebbecke et al., 1994; Price et al., 2000) that is sensitive in visible colour spectra.
Until now stereo vision systems have not yet been used for row detectection. In autonomous helicopters they have proven to be very challengeble for the software developers (Roberts et al., 2002).
For acquiring the images, we used a single 1/3 CMOS colour image sensor (COMedia Ltd, Hong Kong). The video signal is then transmitted to the receiver (GigaLink, Querfurt, Germany) at the headland. The receiver is connected to a framegrabber (National Instruments, Austin, Texas), which is housed in a PC. The camera is mounted on the front side of the robot. Its distance and angle to ground level can be adjusted manually to test a different setup.
When the vehicle rides over rough terrain, the camera will also move. Camera mounting place and the wheelbase of the robot affect the magnitude of the movement. This motion can result in images that do not have enough crop row information. A pan and tilt head with additional software or examine every image before segmenting could be a solution.

Software Development

In comparable projects, modelling and simulation have shown to be of great help for testing hardware/software compatibility and scene generation/analysis (Johnson and DeBitetto, 1997). Due to time pressure and lack of experience with modelling, simulation and skills in C++, we choose Labview (National Instruments, Austin, Texas) for programming for its known power for rapid prototyping and its user-friendliness. To investigate vision algorithms, Imaq Vision Builder (National Instruments, Austin, Texas) is used, because it requires no programming. When the vision algorithm is ready, a Labview file is created for implementation.

Image Segmentation

For segmenting a colour image there are two well established methods, namely the modified hue and 2g-r-b (excessive green) contrast index, where r, g, and b are normalized Red, Green, and Blue (Woebbecke et al., 1994; Tang et al., 2000). Also genetic algorithms can be used to enhance image segmentation (Tang et al., 2000). In our vision system, the colour index Hue is selected for segmenting because that is a pre-programmed Imaq routine. The result is a grey scale image, on which a fixed threshold is applied
To enhance the image after segmenting, small blobs (weeds and noise) have to be removed. This is done by using an open/close operator.

Row Detection

The Hough transform is a well known, often used and robust method for finding mathematically describable shapes (Åstrand and Baerveldt, 2002; Marchant and Brivot, 1995; Meuleman, 2001). Programming the Hough transform could be more complicated. Because the camera is placed close to surface, resulting in totally other view, some easier to program methods could be applied.
When the robot is placed in the middle of two maize rows at least two rows are covered by the camera. These two rows start at the borders of the image and intersect at the middle of the image, as shown due to perspective geometry (fig. 1). The idea is to let the robot navigate through the crop rows by keeping the intersection point in the middle of the image. During field tests we also took a few snap shots with the camera at right angles to the crop row

to test if it is possible to navigate by measuring to distance between the vehicle and the row.
The image from a maize crop with 50 cm height served as example, as shown fig. 1. The intersection is detected by a vertical line-scanner. For every column, the mean pixel value is counted. The scanner starts on the left side and compares the mean pixel value of the scanned column, with the default value 200. If the scanned value is less, this value overwrites the default value and its x component is saved in a variable. The x value of the middle of the image is a constant, which is than compared with the x value of the minimum mean pixel value. The steering signal is thus based on the deviation of the two x values.

Figure 1- Sample image and resulting binairy image of 50cm height maize.

Figure 2- Sample image and resulting binairy image of 15cm height maize.

Results and Discussion

Due to lack of time, we could not show the vision based row detection at the Field Robot Event. In the workshop, the robot was put on a frame to see if the combined vision and steering software would work. The results looked very promising, but we had not enough time to let it work outside properly.

During first field-tests, we realised that outdoor lightning really is a challenge. Crop height outdoors was about 15 cm, while the canopy is still open fig. 2. This affects the complexity of the image segmentation, because of far more varying lighting conditions. But by manually adjusting the threshold and operators, row detection was possible. Modified hue, genetic algorithms, dynamic threshold and dynamic operators would result in better binary images under different sunlight conditions. Then it would be possible to navigate through crop rows instead of calculating the intersection of two rows for one particular image. Camera motion also is an obstacle in navigating through low crop rows. Either a pan and tilt head which keeps the horizon in the middle of the image, or ignore images that have not enough information when segmenting the image or calculating the intersect, could be a solution.

Due to problems with crop height and lightning conditions, a few images where taken with the camera 90 degrees twisted, to measure how far the vehicle is from the crop row, then it would also be easier to determine where the crop row ends. Also due to the lack of time, it is not tested.

Scene generation and modelling software could speed up the improvements on the vehicle, therefore this software has to be involved in future Agrobot projects.

With stereo-vision a whole new range of information would become accessible, such as: vehicle speed, stem thickness and precise navigational signal. For now the one camera configuration still remains challenging enough for automatically navigating a robot through crop rows.

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APPROACH TO DESIGN OF PHYSICAL MODEL OF THE FIELD ROBOT "ALPHA"

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Summary

ALPHA is a small-scale experimental platform for basic research on the selected sensors and control algorithms for precision agriculture in application as a robot with autonomous navigation. ALPHA was built with the purpose to join the Field Robot Event 2004. It is capable to navigate between straight and meandering maize rows under dray and wet conditions. Our participation in that event shall be resulted in the inspiring of further development of own concepts.

Keywords: agricultural robot, navigation system, navigation sensors, autonomous operation

1. Introduction

The new agriculture needs the use of Information Technology (IT) to achieve better product quality, better maintenance of machinery, cost reduction and optimal resource management. IT today encompasses communications, electronics, computers and control systems, while the core of IT lies in operating systems, programming languages and tools as well as Artificial Intelligence methods to deliver knowledge bases and intelligent programs [1]. In the new machinery (designed according to the mechatronic methodology) mass and energy flows must be accompanied by information flow. For this reason, machinery should be able to 'intelligently' process much information taken in real time by high precision sensors and from data bases. Nothing pushes IT beyond its limits like application of Precision Agriculture. A fundamental role in Precision Agriculture will be played by field autonomous robots [2, 3, 4, 5]. The application of robots is also expected in Organic Framing. The question is when this technology will mature and be massively produced to be cost effective for agricultural applications.

The main research task for mobile robots is development of navigation (guidance) methods in an agricultural environment. Nowadays the crop rows are exploited for automatic navigation of a mobile robot without the need to construct artificial landmarks. The most important problem of initial stage of agrirobot dealing is the designing of all-purpose autonomous traveling platform and selecting of electronic devices for detecting a guidance lines, and for identifying the surroundings objects [6, 7].

Looking to the future, agricultural robots (which are driven by electric motors) will by supplied from fuel cells that are actually intensively developed.

2. Materials and methods

2.1. Hardware structure

Alpha is a small-scale experimental platform for basic research on sensors and control algorithms for precision agriculture in application as a robot with autonomous navigation. Ultra sound range sensors, capacitance type whiskers, optical detectors sensitive to green color and measurement of front wheel turning angle, are used for navigation. An autonomous motion is performed by on-board Intel 8031 based microprocessor system. Robot is supplied from 12 V accumulator battery. The general view of field robot "Alpha" is shown in Fig.1.

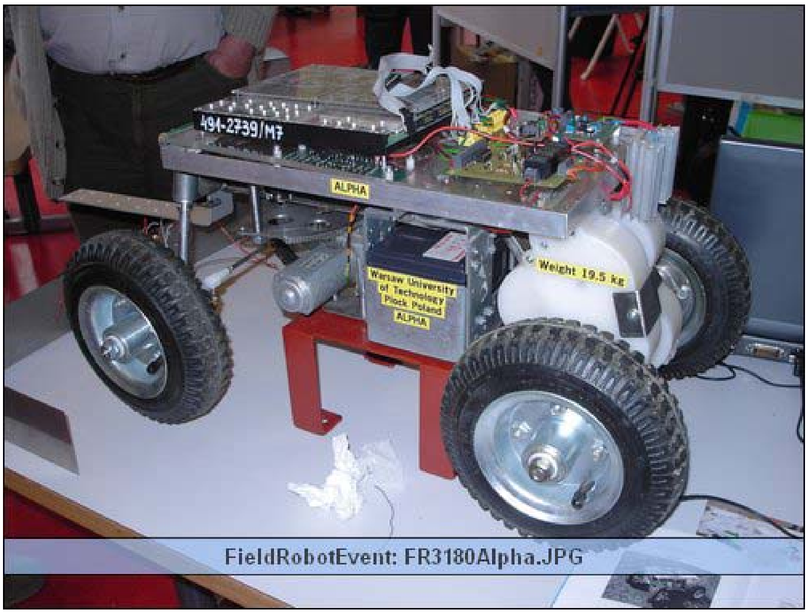

Fig. 1. The general view of field robot "Alpha"

The hardware structure showed in the Fig.1 and Fig.2 consists of chassis, 2 electric driving motor assemblies, electric turning motor with gear transmission and turning angle transducer, 3 PWM voltage regulators for each motor, sensors and microprocessor system with 8 analog inputs, 1 analog output and 24 digital inputs/outputs.

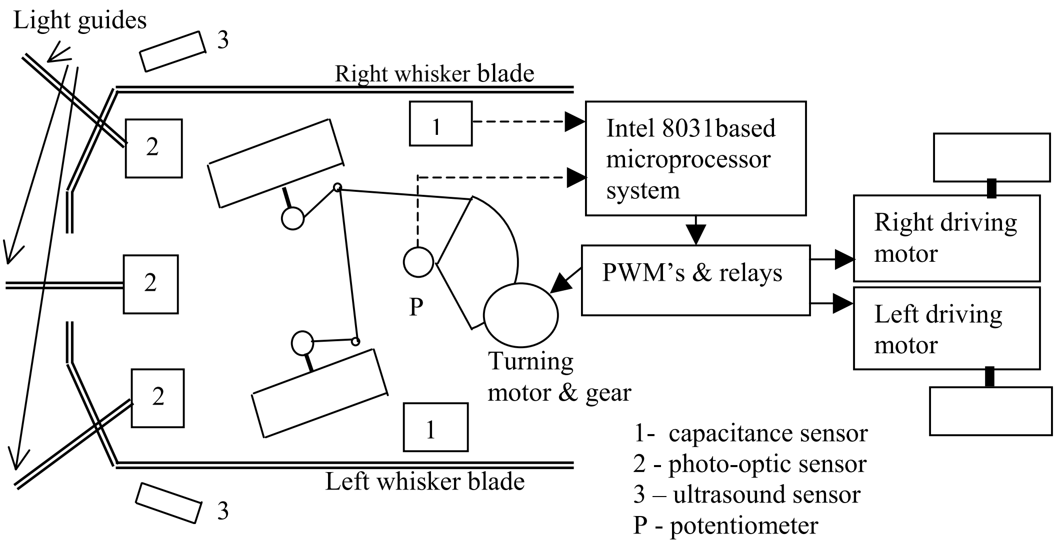

Fig. 2. Functional diagram of the hardware

The driving speed is controlled with help of 2 PWM regulators. The microprocessor system sets speed value via the parallel port. The set value is memorized in 8-bit latches and converted into analog signal by 8 bit DAC (Digital Analog Converter) converter for each PWM controller. The driving speed control system utilizing the turning radius value (voltage on the potentiometer slider) works as the mechanical differential mechanism. The third PWM controls turning velocity adequately to the driving speed and. Pre-set values of turning velocity are calculated by microprocessor system and sent to the PWM regulator throw an analog output.

2.2. Navigation sensors

As it was mentioned above, the robot is equipped with 3 kinds of sensors to navigate among the maize rows. The capacitance whiskers were designed and manufactured using very common known timer 555 and Phase Locked Loop detector LM567. A metal blade insulated from the robot chassis is the one electrode of the tuning capacitor. The second one is the ground with growing plants. When the metal electrode is very close to plants or touches them, 555 generator decreases its frequency and detector LM567 generates logical 1 on its output. These signals coming from both left and right whisker can be easily utilized by a micro-controller system for front wheel turning control.

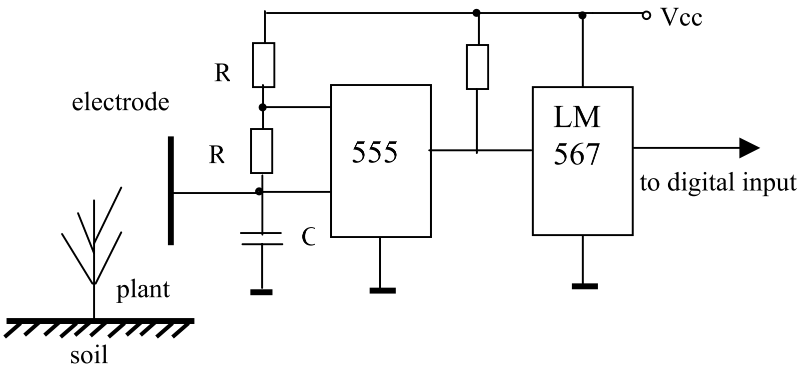

Fig. 3. Block diagram of capacitance detector

Photo-optical sensors were designed basing on the photo detector TSLG257, which is equipped with green filter (524 nm). The optical system consists of 3 sensors (left, reference and right), 3 logarithm amplifiers and 3 fiber optic light guides. The optical sensors are connected to the 8 channel ADC (Analog to Digital Converter) of the microprocessor system. These sensors can differ soil (brown or gray color) from the plants (green color) on both sides of the robot in reference to the illumination (full sun – cloudy) what allows the third sensor in the middle. The flexible light guides easily allow to adjust proper view angles.

2.3. Programming method

Parameters of the microprocessor system, mainly clock frequency 11,0592Mhz and terminated program memory, forced application of the assembly language to program robot functional procedures. The control algorithm must collect all input values (sensors and transducers) and calculate the control values basing on experimentally determined relations e.g. difference of driving motor speed versus the turning angle (differential mechanism). Additional tasks of the control algorithm are to check a status of the keyboard and indicate a key, as well to display several parameters on the 7-segment display, e.g. value of turning angle or control status (automatic or manual).

The exemplary procedure, showed below, simultaneously reads 8 digital inputs of PortA on the parallel 8255 I/O circuit (where the sensors are connected) and returns suitable signal for 7-segment display.

```
;8255 Ports
;PA.0 -left US sensor, PA.1 - right US sensor
;27H   control status-27H.7 AUTO/MAN, 27H.0 US left,27H.1 US right bit addressable
;internal RAM memory location which saves control status of sensors and mode of
;operation
;procedure reads port A of the 8255 and returns suitable signs for display
SENS_BUF      EQU    2FH    ;symbolic name of 2FH in internal RAM memory
LIMIT_R       EQU    10100001B     ;binary value of symbolic name – right obstacle
LIMIT_L       EQU    10011000B     ;binary value of symbolic name – left obstacle
OBSTACLE      EQU    10111001B     ;binary value of symbolic name – front obstacle

RD_PA:
MOV      R0,#CS55A   ;load to R0 index register address of PortA
MOVX     A,@R0;read portA
       MOV    R5,A   ;memorize new combination of portA in R5
       MOV    A,27H  ;load immediately accumulator with contents of bit addressable
       ;internal RAM (the last combination of PortA) which address is 27H
       ANL    A,#80H ;clear 7 lower bits of accumulator
       ORL    A,R5   ;add logical bits of new combination of PortA with MSB of ;last
       combination
       MOV   27H,A   ;memorize in 27H the new combination
       JNB    27H.1,R_LIM  ;if right sensor=0(detected obstacle) then jump to right
              ;limit
       JNB    27H.0,L_LIM  ;if right sensor=0(detected obstacle) then jump to left
              ;limit
       CLR    A      ;clear accumulator
       MOV    SENS_BUF,A   ;clear sensor buffer
       SJMP   RD_PA_N1     ;jump to the label RD_PA_N1
R_LIM:
       MOV    SENS_BUF,#LIMIT_R; load rigt limit 7-seg. sign to the sensor buffer
       SJMP   RD_PA_N1 ;jump to the label RD_PA_N1
L_LIM:
       MOV    SENS_BUF,#LIMIT_L; load left limit 7-seg. sign to the sensor buffer
RD_PA_N1:
       MOV    A,27H  ;load immediately accumulator with contents of 27H
       CJNE   A,#0,RD_PA_N2;if accumulator (27H) does not equal zero then leave
              ;procedure
       MOV    SENS_BUF,#OBSTACLE; load sign of the front obstacle to the buffer
              ;if the (27H) is not zero
RD_PA_N2:     ;if any sensor signals sensor buffer stays clear
       RET    ;return from procedure
```

The same bit addressable memory location (27H) is utilized in the direction control procedure where instead of display signs the on/off signals are sending to the adequate relays via PortB of 8255.

3. Conclusions

As was mentioned, the presented physical model of robot, on this stage of design, was only able be guided by plant rows. The fully autonomous turn to the next row of plants could not been done without the planar orientation. Referring to the sensor systems, the further stages of development should take into consideration an use of electronic gyroscope or compass. Also we are going to design a new microprocessor system based on more advanced microcontroller, e.g. Atmel's Atmega16 (ISP programming and program flash memory).

Another idea of robot development is an application of distributed microcotroller system using CAN bus or cheaper RS485 network. This network could be very useful, when the machine vision system is applied.

The mechanical construction of presented robot also needs some improvement. Mainly the suspension should be redesigned towards the independent system.

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Scientific Article for the Field Robot Event 2004

The buildup of Challenger and D-Bug

Introduction

In this article two small autonomous vehicles will be described, about how it was designed and constructed for future agricultural machinery development. The two robots were constructed by a student team.
The team consisted of six members with the name "DC Tech". Four of the team members are students of the chair group Farm Technology of the study Argo Technology at the University of Wageningen. The other two members are trainees of the chair group. The internship is for completing their technical engineering education (Middle Technical School).
The commissioner of the project was Mr. Lie Tang. Mr. Tang is a researcher and teacher at the chair group. He gave the Team the assignment to develop a robot for winning the Robot Field Event. Further all the robot should possess good educational value for departmental teaching, which implies that it would need to be equipped with adequate computational power and can perform relatively complex tasks.

The field robot competition is a competition where several research and student teams of international universities and institutes compete. The event takes place at Wageningen on a maize field. The maize field consist of maize rows which have an inter row spacing of 75 cm and an intra row spacing of 10 cm. Last year the rows were straight, the robot only had to know when to turn back. This year there will be a curve in the field, so this makes it more difficult to stay between the maize rows. Winning the competition means that the robot must be build as cheap as possible, it has to drive autonomously between two maize rows then turn back and the end of the row. This all has to be done as fast as possible. There is also a freestyle element in the competition to show the extra features of the robot.

After finishing the tests, the robot called the "Challenger" should be fast enough to compete with the others teams. The sensors of the Challenger can be swapped to place them on the second robot.
This robot is a walking robot. The walking robot called DC bug is not a robot, which can compete with the other teams, because of the low walking speed. But the robot is used for the freestyle part of the competition. D-Bug will also be used for educational purposes after the competition.

Research

The research is divided in the frame, sensors and communication between the electronic parts. At the end a short morphological overview will be given to show which choice is made and why.

Buildup of Challenger and D-Bug

Frame

The frame of the robot is very important, because it has to carry all the hardware, which is very breakable. The driving system must be strong to the environment where the robot will be in work. The environment of the field robot event will be on agricultural land. The properties of the land are as follows:

- It's has a very loose top layer
- The layer can get slippery
- The land is full of maize rows, which should not be touched by the robot.

This means that the robot should have a limited size with al lot of traction and power to get forward.

Table 1: Comparison of different drive constructions.

Type of drive	Stability	Fast Speed	Against Slip	Manoeuvrability
Tracks	Good	Good	Good	Good
2 wheels	Bad	Good	Bad	Good
3 ≥ wheels	Good	Good	Bad	Good
Legged (≥ 4)	Good	Bad	Good	Good
Hovering	Good	Bad	Good	Bad

In the table a drive with tracks have the best results. The table is based on theory. In practice during the Robot field contest, were where good robots with tracks. The winner even had tracks. This confirms the theory. But 4 wheeled driven robots are proven to be a good drive too. Only when the soil is very wet the wheels slip, and the robot has to have intelligence to control the power for every wheel, to prevent the robot to get stuck.

Sensors for detection

A research of different studies at autonomous vehicles shows that there are six types of sensors, which are efficient to detect obstacles. These sensors differ in price, from cheap to very expensive. Every sensor has its own negative and positive properties for different applications. The sensors are not being restricted to detection of obstacles, but also for navigation. A sensor can be used to make an accurate map of the surroundings.

CCD Camera

The first type of detection sensor is the CCD Camera. The camera is a passive sensor, because it uses the light of the environment to be able to “see”. The camera has a resemblance with the human eye. When two cameras are used, it is possible to make stereovision possible. Stereovision is the ideal feature. With stereovision we can estimate distances.
Even though stereovision approaches the human eye, there a big disadvantages. The biggest problem is illumination. Without proper illumination we cannot detect obstacles efficiently. Sensors on autonomous machines must be reliable day and night. This is a big difference with the human eye, which adapt to the surrounding light intensity.
Another problem is seeing the difference with the obstacle and the background. If the obstacle has the same colour as the background, for example a row of crops, the use of cameras will be useless. The brain of humans is trained to recognize differences in colour patterns. That is how we filter out the background.
Dirt that blows in front of the camera can also been seen as an obstacle. The lens of the camera can be stained by dirt, which gives bad results of the analyses of the images.

Ultrasonic Sensor

The second type of sensor is the ultrasonic sensor, also called sonar. Sonar is the most used sensor for obstacle detection, because it is cheap and easy to operate. It is being used by science and hobby.
To use ultrasonic sensors for an autonomous vehicle, it is necessary to mount the sensors in a circle shape. Then it can be possible to detect in all directions.

There are three major disadvantages of ultrasonic sensors. The first one is the bad accuracy of the reflected sound (echo) if the object is in an angle of the sensor. A lot of the reflection travels away from the source.
Second problem is that there are false signals coming to the sensor. These are being caused by external noise sources or close by installed sensors “cross talk”. These false measurements, cannot always been filtered out with algorithms. The last problem for ultrasonic sensors on autonomous vehicles is the limited detection distance. If the vehicle drives 15 km/h and detects an obstacle, it can be too late to stop on time. Because the interaction of the too limited distance detection of the ultrasonic sensors via the CPU to the actuators has a delay.

Laser scanner

The third type of sensors is a laser scanner. Laser scanners use a laser beam, which is being reflected on a rotating mirror. The laser beam is reflected by an object and analysed by the scanner.
Lasers are in different categories. Category 1 laser can damage the eye. The other category uses pulsating beams. This type of laser beam is better because it is not harmful for the eye. Another advantage of pulsating laser beams is that the measuring errors can be filtered out. With laser it is possible to pinpoint the exact location of an object. Laser scanners give a better result using less computer power, then for example; cameras.
With the use of laser beams it is not necessary to have the presence of a light source. The angle of detection can be 180 degrees or more, with a resolution of about 0,25 degrees.
The laser scanner has one big disadvantage. The “spray” of laser beams is 2 dimensional. That means; if an obstacle is above or under the spray it will not be detected. The sensor is also sensible for dirt. Rain, snow and leave fall causes measuring errors.

3D Laser scanner

The 3D laser scanner is the fourth detection sensor. The reason that there is a difference made between the 2D and the 3D laser scanner is the major price difference and complexity. 3D laser scanners are very slow; it takes about 80 seconds for 8000 pixels. The price of a 3D laser scanner is about $150.000, 00. This is way too expensive for being used on the vehicle.

Infrared sensor

Infrared sensors are the fifth type of sensor to detect objects. Infrared sensors are cheap and easy to use. There is a difference between passive and active infrared sensors. Passive means that the sensor only receives light, which is in the infrared spectrum. An active infrared sensor emits its own infrared light. This beam is being reflected by the object and is being analysed by the sensor. The range of the sensor can be made very large; thereby the detection angle can be made bigger too.

The biggest disadvantage is the influence of the sun on the sensor. The use of the sensor outdoors can be possible. The sensor has to be modified by the use of filters; this can be an optical or an electronic filter. The measuring errors can be made to a minimum with the use of such filters. Only the accuracy can be decreased by the use of the filters.

Radar sensor

The last type of sensor is the radar. These sensors are expensive to purchase. Not many researches use this kind of sensor. Dirt, rain and snow have no influence on the radar sensor. The narrow radio beam from the radar is capable to be used for the measurement of the angle of the position from the object to the radar sensor. When the radar is properly adjusted, it can be used for making 3D images of the environment.

Requirements of the sensors.

There are six types of sensors discussed. Every sensor is treated separately with their negative and positive properties. Now the sensors are being discussed for the use in the field.
There are 5 criteria for the selection of the best object detection sensor. The sensors have to operational in every weather type, every light illumines, detection range of at least 3 meters, quick reaction (analysing) time and the purchase price. The ideal sensor is the sensor, which meets all these requirements.

Light

On the farm, the day begins in darkness of the morning and it gets lighter every hour till noon. After noon, the light intensity decreases again. Despite the weather changes can influence the light intensity, it is important that the sensor can function in all light intensities. Hereby the conclusion is that the CCD camera will not function well. The infrared sensor needs a filter, because of the sun influences.

Detection distance

An autonomous vehicle on the field with 10 km/h makes a distance of 2,8 meters per second. The obstacle detection sensor has to able to detect and analysed that object within that time. Therefore the detection distance has to be bigger that the 2,8 meters.
Also, the time of the interaction with the actuator (wheels) and braking distance have to be considered.

Reaction time

For a detection sensor, it is important to have a quick reaction time. With the 3D laser scanner, it takes about 80 seconds for one frame. That is unacceptable for real-time systems. CCD cameras are reliable to the computer power behind it. The rest of the sensors are fast with detecting and analysing the object.

Costs

With the most research, projects the costs are not the biggest priority. For our autonomous vehicle, it is important to keep the costs as low as possible. Hopefully, that the more expensive sensors are made cheaper in the future. Like the 3D laser scanner and radar is still too costly.

Table 2: Comparison of sensors

	Operational in all weather conditions	Operational in all light intensities	Detection of at least 3 meters	Quick reaction time	Costs of purchase
CCD Camera			*	*	*
Ultrasonic		*	*	*	*
Laser scanner		*	*	*	*
3D Laser		*	*		
Infrared			*	*	*
Radar sensor	*	*	*	*	

Communication

Communication between the different parts of the intelligence is needed to let them "talk" to each other. In Figure 1 is shown the levels of intelligence in the robot. All these different levels need to communicate with each other. This is needed to get information from one level to another, so the other components can anticipate on changes from outside. Because there are different types of communications possible it is needed to take the one most efficient for the robot. These different types are grouped in two ways: the first is the hardware establishment of the communication, is it performed by wires or wireless, the second is the software handshake behind the data transmitted, these are also referred to as protocols. In this chapter is discussed how the protocol is chosen, and also how chosen have been made to accomplish the right decisions between the different groups working on the different levels.

Buildup of Challenger and D-Bug

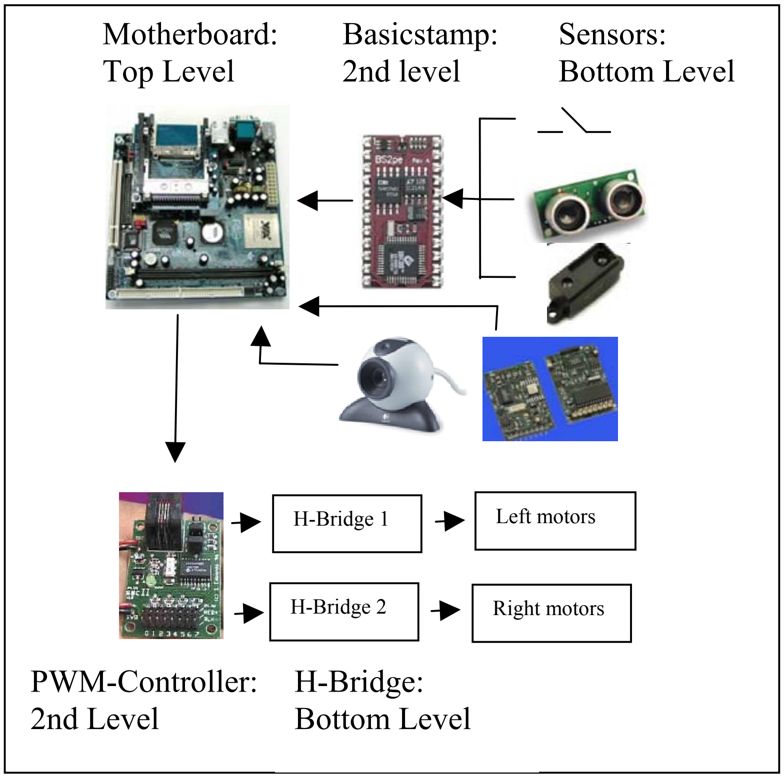


Figure 1. Different parts of the intelligence

Establishment of hardware communication

Because of the decision of onboard control by the motherboard, this means all of the data handling is performed on the robot itself, it is easier to use wires to establish the hardware part of the communication. All the levels of intelligence can be hooked up physically, hereby the errors that could come up when using wireless, wireless is more affected by surroundings than non-wireless, and there is simply no use for using wireless if all the levels of intelligence are placed on the robot.

Realisation of connections

The different connections within the intelligence part are, according to Figure 1:

- Top level
  - Motherboard to PWM-Controller
- 2^{nd} level
  - Basic Stamp to Motherboard
  - PWM-Controller to H-Bridge
- Bottom level
  - H-Bridges to Motors
  - Ultrasonic Sensors to Basic stamp

- Infrared Sensors to Basic stamp
- Push buttons to Basic stamp
- Web cam to Motherboard
- Compass to Motherboard

The Motherboard contains two serial ports; this means data can be transmitted through these ports in a serial way. There has been installed an additional PCI Card that contains another 2 serial ports. The PWM-Controller has to receive the data in a serial way with the RS-232 protocol; this protocol is explained in the next paragraph. So the connection has to be according the RS-232 recommendations. Connecting together two serial devices involves connecting the Rx of one device to the Tx of the other, and vice versa. The diagram below indicates how you would go about connecting two serial devices together, without handshaking.

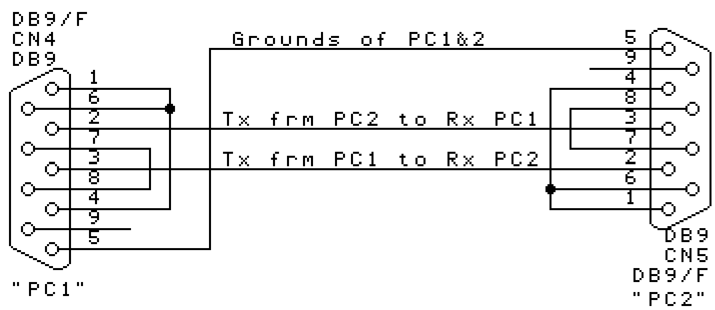


Diagram 1. Connection between 2 serial devices

The above also applies for the Compass and the Basic stamp. From the PWM-Controller to the H-Bridges we need several wires that carries information that the H-Bridges need to run the motors. From the H-Bridges to the motors there is a need of quite big enough wires, this because al the power needed to run the motors is going through these wires. So far for the motor driving part. For the sensors part we need them to connect to the Basic stamp. This is done by connecting the sensors to an individual input at the Basic stamp. This is also been done for the push buttons and the infrared sensors as well. The Web cam has an USB connection for the motherboard. The motherboard has several USB sockets so this is no problem. Further on in this chapter the focus lies on the communication between the top level and the 2nd level.

Different Protocols

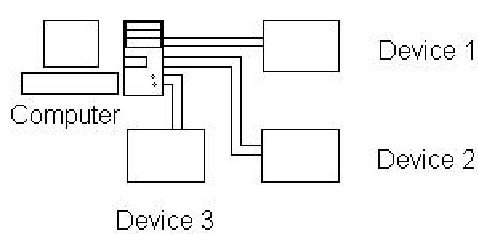


Diagram 2. RS-232 communication

The only connections where a need for a protocol arises are the connections where serial communication is applied. This because all the other connections are between sensors which cannot process any data, only send data. These devices are also not connected to a serial port. The different protocols that might be used were the following two: RS-232 and RS-485. Both are serial communication protocols, which are standardised. RS stands for Recommend Standard and the number 232 is the number of this standard. Most all devices that are connected to the serial port of a PC communicate with the RS-232 protocol. But for industrial applications more protocol had been developed. Because RS-232 and RS-485 are the ones most commonly used the need to do more research was not

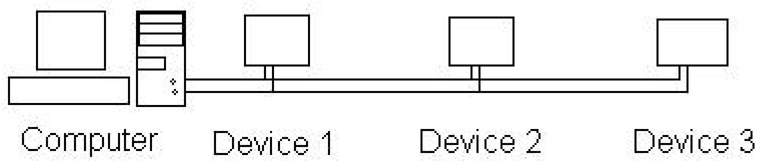


Diagram 3. RS-485 communication

there. The main difference between these two protocols is that with RS-485 there can be more than one device on the communications line, parallel and with RS-232 only one per communications port. and show how this is implemented.
As can been seen from the Diagram 2 and Diagram 3 both have advantages and disadvantages. With RS-232 there is a need for more communication ports on the Computer side if more devices need to be hooked up. So this could be a great disadvantage, but with RS-485 there is need for more hardware to control the data flow. This because, within the protocol of RS-485 there is an address for which device the data is meant. But all the devices needed on our robot are RS-232 oriented, so this piece of hardware is not available unless developed. Adding a PCI card to the motherboard, which has 2 more additional serial communication ports, can solve the disadvantages of RS-232. Although with this option some money has to be spoiled, with the other option there would be valuable development time spoiled.

Construction

The two robots have a totally different frame, but they mace use of the same sensor belt. The ultra sonic sensors are mounted on a aluminum frame what can be fit on both robots. It also can be adjusted in height to adapt the sensor height to the plant size. On this frame also the web cam and infra red sensors can be mounted, bur they were not in use for this robot event.

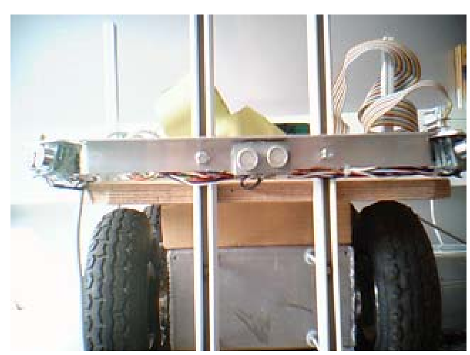


Figure 3: Ajustable sensor belt

Buildup of Challenger and D-Bug

Challenger

The Challenger is build on the same frame as the last years agrobot. In the aluminum case the four wheel motors, two h-bridges and the two 12 volt batteries are mounted. Four 200mm wheels are fixed to the motors. On top of the frame all the electronics are 9in a metal case. Main thing in the case is the 600 MHz motherboard. Connected to that are the 20 GB hard disc, the PWM-controller and the basic stamp. The case is easy removable so it can also be used a desktop pc. This is very handy for the programming.

After the test runs it turned out that the wheels have very limited grip on loose soil. To overcome this problem a track is wrapped around the two wheel pairs. In this case the grip is improves and also ensured that the wheels on one side have the same wheel speed.

D-Bug

The D-bug frame is a standard hexapod homebuilt kit bought from the internet. In this kit also a basic stamp was included. The robot is powered by a 7.2 volt battery pack. According to the data sheet the robot should be able to lift 1.5 kg. But in conditions with uneven soil it turned out that it was already quite difficult to lift the battery pack and the sensor belt.
In the first test run the six legs dig too much in the loose soil. This caused al lot resistance. To improve the walking some flaps are mounted under the legs. This keeps the legs stable on the soil.

Main program

For both the Challenger and the D-bug the same program setup is used. In both cases the program consisted of two parts, a protocol for the orientation in the row and a protocol for the headland turns. To control the challenger the program is run from the harddisc, for the D-bug, what has no hard disc, it is adapted somewhat so it can be run from the basic stamp.

In the row

For orientation in the row the information of tee ultra conic sensors is used. The front sensor and the two sensors in the corners. In the program three zones are identified:

- Save zone;
- Warning zone
- Danger zone

The robot is in the save zone when the thee sensors have a nothing in sight within 20 centimetre. When this is the case the robot will go straight forward. When one of the tree sensors has something in sight within 20 centimetres the robot is in the warning zone. In this situation the robot will make a slight turn away from the side were the plants are the closets. When one of the sensors has something in sight within 10 centimetres the robot is in the danger zone. Now the robot will make a sharp turn away from the plants.

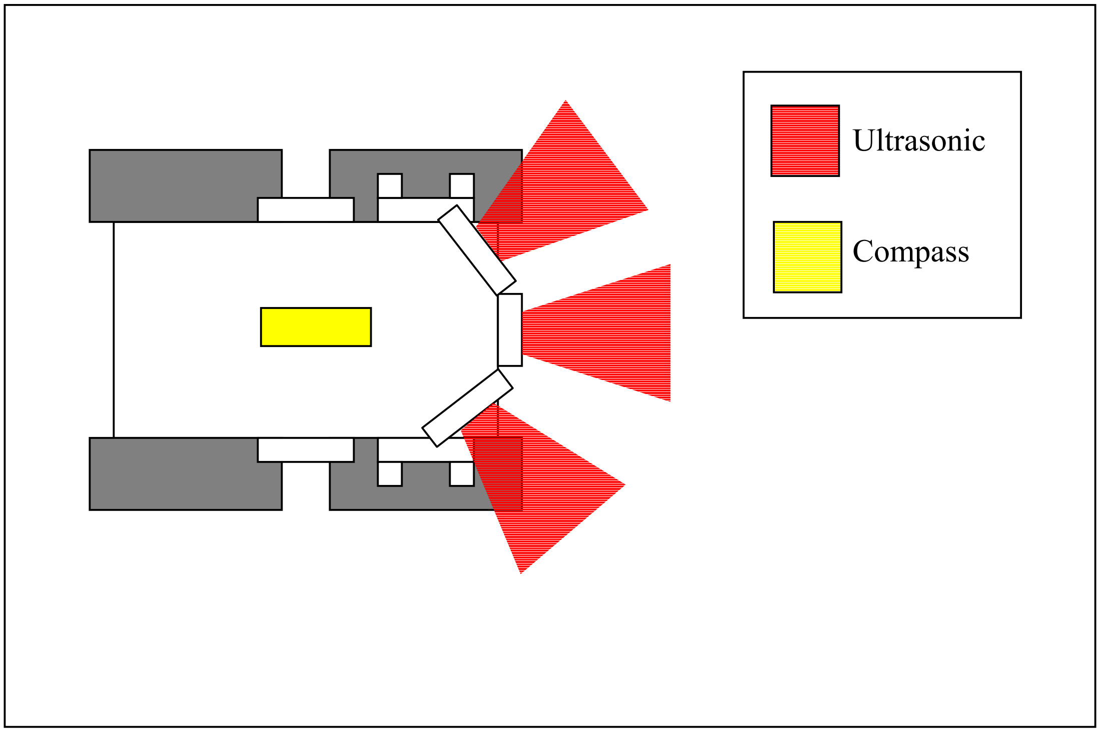


Figure 2. Positioning of the sensors

Headland turn

Then the three sensors have noting in sight within 200 centimeters the robot is at the end of the row. Now the turning protocol is run. This starts with a flag variable. When this is 0 the robot will turn right, when it is 1 the robot will turn left. Every time when the turn protocol is run the flag is flipped. In the case of a turn to the right the robot starts with driving backwards slowly until the right corner sensor get the last plant in the right row, from now on the anchor plant, in sight. When this happens the robot drives slowly forward until the anchor plant disappears. Than the robot will turn around his central axis until the anchor plant is back in sight. This will continue until the robot has made a 180 degree turn. This is controlled by the compass. When the headland turn starts the heading is memorized, when the actual heading differs 180 from the memorized heading the robot will go straight forward into the next row.

Conclusions and recommendations

During the contest it appeared that there are three main things to improve the orientation of the challenger.

First of all the orientation in the row is quite nervous. This is caused by the direct control. After every new sensor information the robot reacts directly. When the robot is too much towards to the left row, it will correct itself towards the right. The result of that is that the robot is too much towards the right row. This way of nervous reacting can be overcome by including historical sensor information into the programming. I this way it must be possible to keep the robot more in the center of the two rows. Also the web cam can provide more useful information to improve the orientation in the row.

Secondly the headland turns on the north side of the field did not go a well as the turns at the south side. The reason for this is that the output from the compass is going from 359 to 0 when it is pointing at the north. This was probably not handled very well in the programming, or the sensor output is not reliable around the 0 degrees.

The third problem was that during the headland turn the wheel track was driving over the last of last two maize plants. The turning protocol with the anchor plant was working very well, but due to the position of the sensor the wheels damaged some plants. This probably will not happen when the sensor is at a different position.

Besides these three things some more can be improved. The web cam is not used at all. When information of the web cam is used besides the information of the sensors this may improve the orientation in the row. When this is better it is possible to let the robot run on 24v in stead of 12 volt to double the speed.

Navigating between corn rows

HOW TO MAKE AN AUTONOMOUS FIELD ROBOT

Abstract

Designing a field robot means connecting many disciplines to each other. Without knowing the field requirements it is not possible for a computer scientist to develop a field robot. For an agricultural engineer it is even impossible to develop a robot without knowing the sensor, hardware and software possibilities. Bringing these people together means connecting different views for development of a field robot.

CornTrack is a robot, build by two agricultural engineers. For the development of the robot a lot of time, money and sleep has been invested. The result was a robot based on an agricultural point of view.

Keywords

Field robot, agriculture, autonomous, low cost, student competition, Wageningen University, CornTrack, nitro methane

Introduction

For a long time, agricultural engineers have been trying to increase the production of field crops. Trough the development of all kinds of mechanical instruments, it is possible to spare work time. Nowadays, the research done for this purpose is focussed to precision farming. The main point of precision farming is the focussing on a field of 1 by 1 meter. In that way it is possible to manage one field in different ways, based on the field and crop properties on the specified surface.

New ways of precision farming are developed by using unmanned vehicles. Because the location in the field is already known, it is also possible to adapt vehicles to go to that place autonomously.

The objective of this rapport is to show the development of a prototype field robot, used for navigating between corn rows. The student project is an animation and beginning of the real development of autonomous agricultural vehicles. In many ways the project can be an example for real designing.

The rapport begins with a study how a field robot should be designed in *material and methods*. After that, the design of CornTrack, an autonomous field robot, is described under the heading *results and discussion*. After that the *conclusion* is presented. In chapter five, a *discussion* follows.

Research

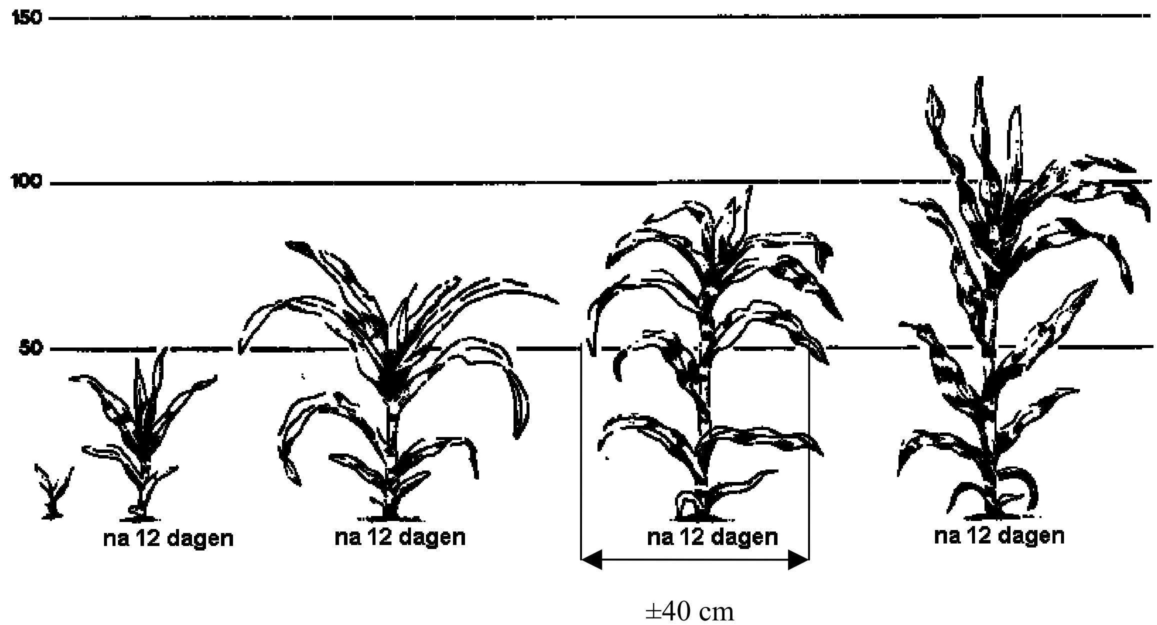
For the development of the robot it is firstly important to know in what area the robot should work, after that it is possible to adapt the robot to the properties

1.1 Key elements for designing a field robot

Developing a robot means first of al thinking about the framework of the platform. Field and plant properties lead to limitations for the robot. In this chapter we will discuss the size, weight, runtime, and maintenance of a field robot. In many cases these parameters will depend on each other, but also for each of the separate parameters there are several needs.

Size

The size of the robot depends on several things. First of all the size depends on the kind of plants the robot should drive in between. Normally a standard row-distance is used for different types of plants. For maize, the row-distance in most European countries is 75 cm. The maximum width depends on the way the plants are growing. Grow-stage research, as shown in figure 1, points out that the leaves of a plant are using almost 20 cm to both sides at 25 cm height.



This points out that a field robot, running in maize, can have the square dimensions of 35 cm width and 50 cm height at front sight without destroying the plants.
Since stability depends on size, the size should not be too small. Tractor wheel tracks, lumps, rocks and plant rests, normally have a size up to 7 cm. Also bigger disturbances are possible. Some sensors cannot work at an unstable platform. For that reason a robot should have a size, as big as possible in the field. Especially the wheels should be at least 14 cm high.

Weight and traction

Connected to the size, the weight of a robot is important for the development of the platform. Since the power requirement depends on the weight of the robot it should be as light as possible. Also ground compaction is an important thing for the development of a field robot. This is also highly related to the kind of wheels that are used.
Therefore the wheels should have a big contact area to the ground. This can be reached by using more (driven) wheels, high and broad wheels and low pressure. Using more driven wheels means also better grip on the ground, especially when disturbances occur. Sometimes a wheel is not contacted to the ground; a solution for this problem is then suspension. For economical reasons it is sometimes better not to have suspension. A three wheel vehicle does not need suspension.

Runtime

The future of field robots is a totally autonomously inspection of the field. This also holds that a robot can go from field to reload station by itself. To have a big energy load in a low density, fuel power has to be used instead of battery power. The power load (caloric value) for fuel (petrol or diesel) is about 45 and 50 * 10^6 J/kg. One kilogram lead acid battery can hold for max $0.1*10^6$ J. Besides the weight aspect, fuel is also easier to load in a short time. Since computer units and sensors need electrical power, a small battery in combination with a dynamo is needed.

Maintenance

An autonomous robot is not in direct control by a human being. That means the robot should have no maintenance moments. This implies that almost no moving parts can be implemented. These moving parts are mostly used by traction and by the steering mechanism. Therefore smart design is also needed.

To prevent moving parts in the steering mechanism, skid-steering can be implemented. Using skid-steering the possibilities to steer are less complex, the steering mechanics are in this way cheaper. A disadvantage of skid-steering is the higher power requirement caused by the friction.

When a robot is driven by electronic engines, it is possible to drive the wheels without reducing gear. Using a fuel engine, as mentioned before to extend the runtime, will cause a need for more reducing gears. This will decrease the maintenance of the robot.

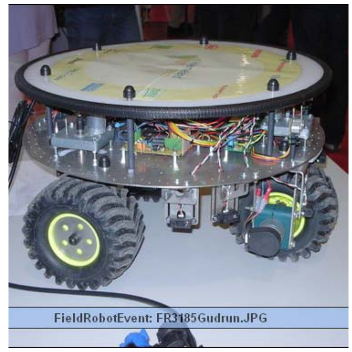
As shown, designing a robot is weighing several values, based on practical use, field properties and the economic situation.

1.2 Key elements for detection of maize rows

Besides designing the platform sensors, integration is a main point for designing a field robot. There are several ways to detect corn rows in the field. It is possible to see the maize either as an obstacle or as a different colour. Detection of the row is possible trough knowing past places, seeing colour rows, or detecting distances like a wall.

Colour based detection

Colour detection can be done by using a camera in combination with a wavelength filter. Placing the camera at the front of the robot, the output will be a green field at both sides of the screen. Based on the fields, the direction of the robot can be made. Problems will arise when weed is between the rows, or when the rows are meandering. Another problem, using a camera, is that it only shows the area in front of the robot. There is nothing visible for the robot at the sides or at the back. To solve this problem more cameras can be used. This however implies the need for more computer power. A solution for this can be a rotating camera or platform. For a rotating platform al wheels can turn. See pictures below.



Detecting based on colour can also be a combination of colour and row detection. Now the camera is placed above the field. The top down view in combination with a good filter will give a direction of the rows. Row ends and beginnings of rows are better to detect now. Problems will come up when crops are higher or totally spread over the field.

General disadvantages of using colour based detection are the costs and programming difficulties.

Obstacle based detection

Beside colour also obstacles can be detected. The easiest way of detecting an obstacle is of course a mechanical whisker. Especially when rows should be detected, a whisker is a very accurate sensor. Beside that the position of the whisker is very easy to measure. Using an infra red (IR) or sonar sensor will give a distance from sensor to obstacle. Combining more sensors at different places and under different angles will give a row-like output.

Because it is measuring only the distance between sensor and object, there are uncertainties about what the obstacle will be.

Row detection

To know the direction of the rows as mentioned above colour and distance measures can be used. Another way of detecting the directions is storing past ways. This can be done by using GPS, reference points in or at the ground.

GPS

An advantage of using GPS is the knowledge of the exact location of the robot and his past way. Since RTK-GPS has a precision of 2 cm it is could be very useful. In that way, the passed points can be stored, but also detected diseases can be stored by place. Then it is possible to return to the same location whit specified machines, like a spreader for example.

A big disadvantage using RTK-GPS is the price. Without software the receiver is about 8,000 euro.

Reference points

By placing reference points at the field it is also possible to know where the robot is. Reference points can be made by placing transmitters at already known places. Also detection and recognition of place specific properties is a possibility for reference points. This should mainly be done by a camera.

1.3 Ethics

Besides al engineering questions, developing a robot should also deal with ethical questions. Questions like: Is it allowed to 'steel' work? How many 'rights' can you give to an autonomous robot? Who is responsible when sometimes wrong, unsafe decisions were made? How far can a human being control everything he wants even with robots? What can be done against misusing a robot?

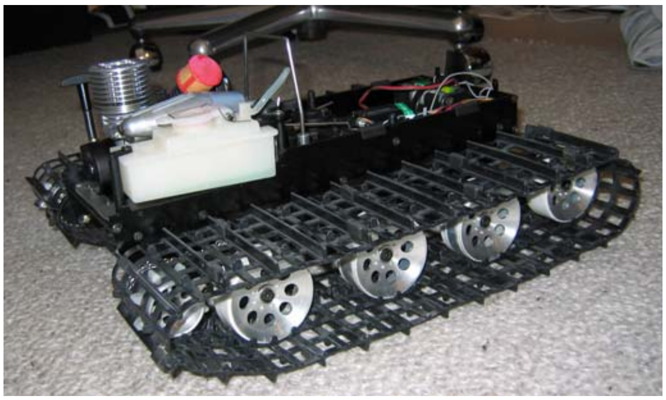
Many books are written about this subject, but the main thing in developing robots, is knowing the purpose for the robot. This does not direct lead to utilitarianism, but only than it is possible to evaluate the use of robots for that special reason.

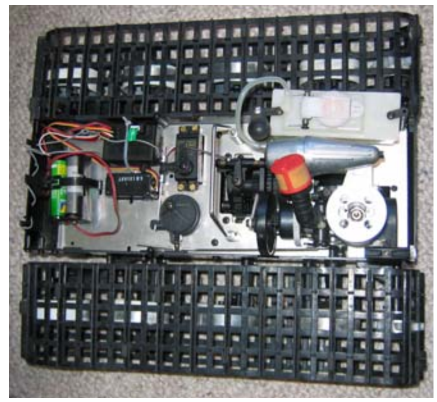
2 Results

2.1 Platform

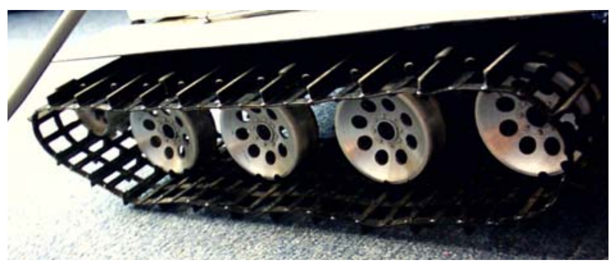
To make an autonomous field robot we followed the specifications made in chapter 2, taking in account the economical situation.

Integrating size, weight and maintenance, we based our robot on a model of a so called 'Pistenbully'. The pictures give several views.





Tracks



By using tracks we are combining grip, low ground compaction, skid steering, maintenance, suspension and stability in a desired size. The tracks have a contact surface of 2 x 9*36 cm.

Engine

The engine is the original Kyosho GS-11R engine. Fuel for this engine is nitro methane, a mixture of oil, methanol and nitro methane. The 1.8cc engine has a maximum power of 0.23 Kw and can reach 2,000-20,000 rpm.

The automatic gearbox between wheels and engine has 2 speeds forward and 2 speeds backward. The motor and gearbox are controlled by 1 servo.

Steering is done by two disc brakes connected to both tracks. The brakes are also controlled by one servo.

2.2 Sensors

Distance

For the Corntrack, we used 4 infrared distance sensors. These sensors are cheap and quite exact. 2 sensors were installed in front for measuring in front of the robot. The other 2 sensors were installed in the middle of the robot for measuring the distance between the robot and the plants.

Speed

Since our ways for measuring can only be done by measuring voltages, it wasn't possible to measure speed. For a fuel driven vehicle, this must be done, because a clutch is between the engine and gearbox. We developed a sensor that showed whether the vehicle was driving or not.

Mechanical whiskers, Camera, GPS, Reference points

It was not possible for us to implement other sensors in the robot. This was due to a combination of a lack of financial support, knowledge, computer power and time.

2.3 Control

For a framework of the signals, a drawing is made in attachment 1

Computer

The computer we used was a 300 Mhz Single board computer AR0B1551 from Micropower. A second hand 3 Gb laptop hard disk was installed for data storage. For quick and stable running, Windows XP professional was used.
The program for the Corntrack was written in Visual Basic 6.0.

Servo Control

A serial servo controller was used for regulating the speed and the steering. This controller was driven by the serial port from the computer.

2.4 Flowchart and program

Start driving

It was necessary to start the program with a key press because the program needed to start in a row. Therefore, we need a laptop with a network cable to the robot to start the program.

Between rows

Navigation between the rows happens with use of the distance sensors. The computer stores the last measurements and filters the measurements from plants in the next row out of it. The steering is based on the difference between the sum of the measurements left and the sum of the measurements right.

Headland turns

When both sensors in front do not detect a plant for a certain time the headland turn starts. First the engine stops driving and the steering servo is set to the steering position. The robot waits until the compass gives the current direction. The motor starts driving again until the direction is changed 180 degrees. Then the steering servo is set to straight on and the program continuous between the row.

Obstacles and emergency

There are no facilities for avoiding obstacles jet. There is an emergency stop. It's possible to stop the engine with a remote control.

2.5 Field experiences

Sensors

The infrared sensors have a small sideward range. Therefore it is necessary to store some measurements. This is quite difficult for programming and needs quite a lot computer power.
The infrared sensors are fast and easy to read for the computer.

Control

Controlling a fuel engine is not as easy as controlling an electric engine. The steering with the disc-brakes is quite difficult to control because of the difficult connection between servo position and steering. So it is possible that the robot hits the plants sometimes.

3 Conclusion

It is technically possible to design a robot. But the main part of a robot, how the inside works, is more important than the outside. This is especially true for prototype scale systems. In this project, the agricultural view is used very much. The knowledge for programming and hardware development is less good.

In the results at the field it was visible that the robot works, and did not brake down. At the other hand it was also visible that the software could not stand up to the professional teams.

It is possible for agricultural engineers to make a robot in a few weeks. Even in spite of time and financial shortages. Most of all knowledge of development of software is important.

4 Discussion

4.1 Mechatronics

From a mechatronical part of view next year the robot should have some changes.
CornTrack should be able to load higher weights. The current weight of the robot is about 5.5 kg. Because of that the suspension was broken during testing. Some changes where made and at this moment the robot has no suspension at the middle wheels. When changing the plastic suspension units into metal, it is possible to use suspension with higher loads.
Also bearings have to be implemented in the wheels and the motor should have more power. The gearbox should be closed because oil and fat are attracting dirty things and sand. Because of that the maintenance is now high and the power requirements are higher caused by the increased friction.
For safety reasons, the “engine-murderer” should be better designed. The servo is now closing the exhaust pipe but that did not work very well. The rubber should be more mouldable.
Caused by the duralumin chassis, it is not that ridged, and some past should be made stronger, by putting an extra layer. Especially the transmission axle at the front is connected in a weak way, and should have some changes.

4.2 Electronics

We are using an electrical system that needs 5 V exactly. With lead batteries it is not possible to have that voltage directly. To realize this we use a regulator that needs 8 V to make 5 V of it. That means 3 V (almost 40 %) is converted into heat. We need a smoother system for this, so battery weight can be decreased or duration can be increased.
Besides that, because the platform has a fuel engine with the high energy density, we need a dynamo to change the rotating energy in electrical energy. This will also increase the drive-time. For that it is maybe possible to have a drive time of some hours, using a bigger fuel tank.

4.3 Sensors

During the last Field Robot Event many robots where equipped with sonar distance sensors. The advantages of these sensors (direct clear response when anything in sensible field is been detected) are very useful for designing a robot for driving between crop rows.
Looking around with one ore more cameras means a higher improvement for navigating between the rows. When using 3 cameras, one at the front and 2 for both sides, it is also possible to rotate

at the headlands in a very smooth way, and always be connected whit the crop row. Image processing and investments should be made for that.
For a functional field robot GPS is required as well. In that way it is possible to come back to the same plants or same area, seen before and marked with specialities. Using GPS for a robot is only useful with a precision of 5 cm. RTK GPS is the only way to reach that precision. For our robot this means, an investment of 8000 euro and also soft- and hardware should have further development. For a small robot like CornTrack it is almost impossible to have the mechanical performance to hold the extra equipment and batteries for electrical power.

4.4 Programming

Looking back to the 2^{nd} Field Robot Event the beginning of a robot was shown. Many program diseases where seen.
Since the steering is done by two disc brakes, it is not possible to program the differences of the breaks. External influences of moisture, sand and vibrations are uncertainties. Also the traction of the tracks are not predictable. Using some standard settings of maximal steering (in fact maximal braking) are in therefore not sufficient for exact steering. Especially at the headlands many robots show that the settings for steering during a specified time is not very accurate. On muddy soil these programming diseases were often visible.
Therefore, steering with two disc brakes needs a control system, to control the speed of both tracks. After that it is possible to steer the robot whit speed settings in stead of break settings. The accuracy of the robot will improve.

5 Acknowledgements

We would like to thank everyone, who has helped us to work on this robot. Especially, we would like to thank our financial sponsor, the Wageningen University Found. We would also like to thank our other sponsors: For the computer, Micropower. For the compass, Multimotions. And for general support, SBG Innovations. We would also like to thank Kees van Asselt for the free use of his room and some materials.

Without the Farm Technology Group, there would have been no possibility to work on this project. Thanks for organising the Field Robot Event and the general support.

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Wageningen University Found

www.wau.nl/fondsen

SBG Innovatie

www.sbg.nl

Multimotions

www.multimotions.com

Micropower

www.micropower.nl

CornTrack

www.corntrack.tk

Cropscout – a mini field robot for research on precision agriculture

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Abstract

In this paper Cropscout, a small-scale experimental platform for research on precision agriculture, is described. Technical details as well as results obtained during autonomous navigation between artificial maize plants as well as in a real maize field are presented.

1. INTRODUCTION

Cropscout is a small multi-purpose experimental autonomous robot platform that builds on the experiences with EyeMAG, a small vision controlled autonomous robot that took part in the 2003 edition of the field robot event in Wageningen, The Netherlands (Van Straten, 2003).

Cropscout is a small-scale experimental platform for research on precision agriculture in applications such as weed and disease detection. Also, it serves as a test bed for autonomous robot control algorithms using sensor fusion techniques and artificial intelligence to deal with the variability and uncertainty in the working environment, robots are confronted with when applied in agriculture and horticulture.

The development of Cropscout fits into the long term strategy of Agrotechnology & Food Innovations Ltd. aiming at a sustainable high-tech agriculture and horticulture. Robotics is one of the instruments to pursue that goal. Examples of earlier research on agricultural robots are CUPID, a cucumber harvesting robot (Van Henten *et al., 2002, 2003*), BELEAF, a de-leafing robot for cucumbers (Van Henten *et al., 2004)* and Automaatje, a gps-controlled autonomous vehicle.

For the Field Robot Event 2004, the organizing committee defined the following tests for autonomous robots taking part in the competition:

1. Robots had to navigate between two straight rows of maize plants, turn at the end of the rows and return between the next pair of rows,
2. Robots had to navigate between two curved rows of maize plants, turn at the end of the rows and return in the next pair of rows,
3. The same as one (1) but now on a muddy track,
4. Free style operation in a maize field.

The rows of maize plants on the competition field had a length of 10 m. The inter-row spacing on the track was 75 cm. The intra-row spacing between the plants was 13 cm.

Cropscout was designed to compete in all four challenges. In this paper, the technicalities of Cropscout are described and results of test-runs under artificial conditions as well as real field conditions are presented.

2. MATERIALS AND METHODS

2.1. General construction

Cropscout was built on the chassis of a scale-model of a crawler with two tracks. See Fig. 1.

Figure 1. Cropscout

The chassis houses a 12 V accumulator. Besides being the power supply of the robot, the weight of the accumulator also improves the grip of the tracks and its low position in the robot frame improves over-all mechanical stability. Cropscout weighs 9 kg. The main frame of Cropscout measures 260 (width) x 410 (length) x 250 (height) mm. Ground clearance amounts to 25 mm. Two Graupner BB700 electromotors drive each of the two tracks individually. The plastic box on top of the chassis contains the control hardware. Pairs of sensors were mounted on each side of the robot to detect the presence of plants and to measure the position and orientation of the robot between the rows. For this purpose infra-red range sensors, ultrasound range sensors, whiskers and a digital camera were used. The camera (FlyCAM CF) was put on an elevated camera mount for a better overview over the rows. This type of camera directly mounts on an Ipaq pocket pc which was used for image processing as well as interfacing of the robot with the outer world.

2.2. Sensors

As shown in Fig. 2, Cropscout is equipped with a wide range of sensors to detect the presence of plants and to measure the position and orientation of the robot between two rows of plants, for navigation purposes. The 11 sensors used, include infra-red range sensors, ultrasound range sensors, whiskers and a digital camera operating in the visible light spectrum. Sensor redundancy was intentionally implemented for two purposes. First of all, sensors based on different physical principles (i.e. infra-red reflection, ultrasound reflection, direct touching and visible light reflection) perform different under the widely varying environmental conditions encountered on a maize field. For stable navigation, it may be better not to rely on a single type of sensor. Secondly, sensors may suffer from hard failures. For failure detection, failure identification and failure recovery more sensors are needed than actually required for the navigation task.

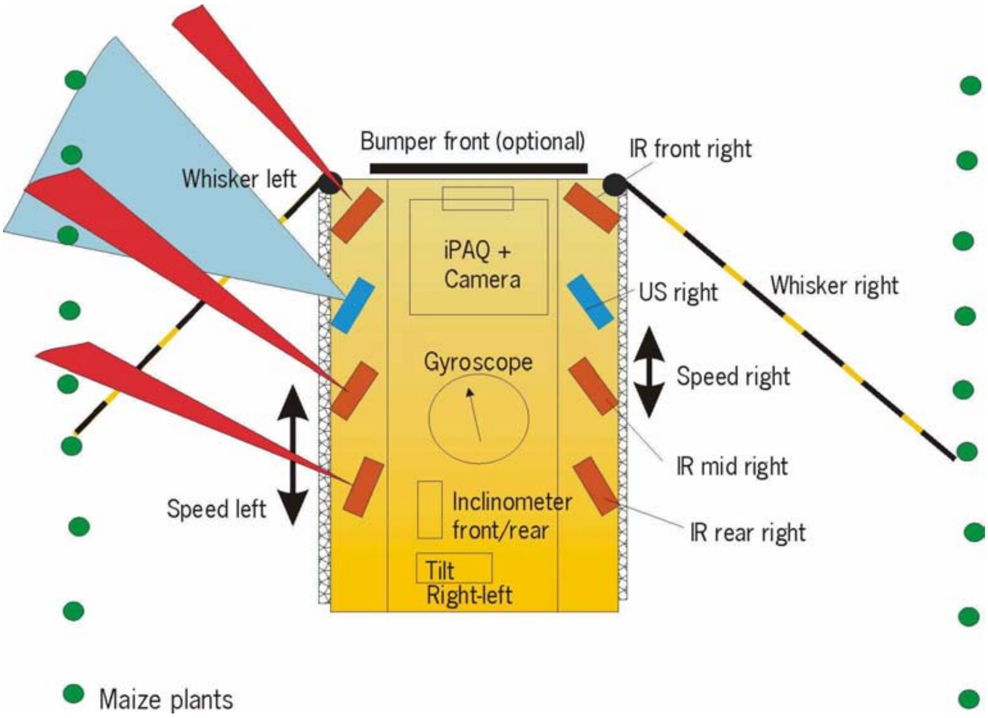


Figure 2. Sensors on Cropscout.

2.2.1. Short range and long range infra-red range sensors

Figure 3. The Sharp GP2D12 (left) and GP2Y0A02YK (right) infra-red range sensors

The Sharp GP2D12 and GP2Y0A02YK range sensors, shown in Fig. 3, cover a range between 0.10 m and 0.8 m and a range between 0.20 m and 1.80 m, respectively. These sensors are based on the following principle. An infra-red led transmits a pulse every 40 ms. The reflection of this pulse by objects within the sensing range is measured with an IR sensitive receiving device. The sensors produce a voltage between approximately 0 and 2.5 V. The sensors have a non-linear response to the distance between sensor and object as shown in Fig. 4. Before they can be used for distance measurements, these sensors have to be calibrated. The non-linear function $d = c_1 v^{c_2}$ was fitted to calibration data.

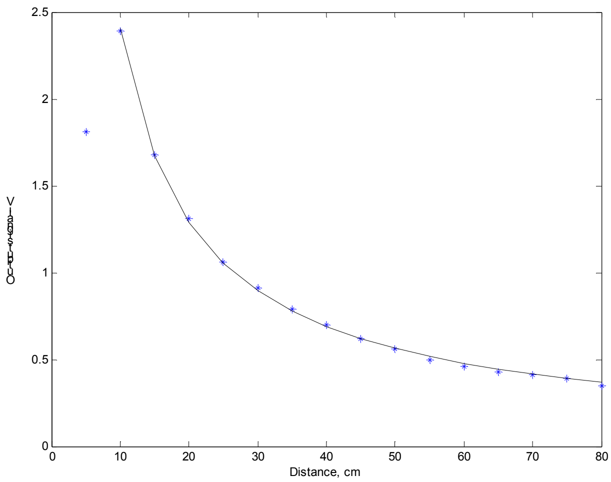
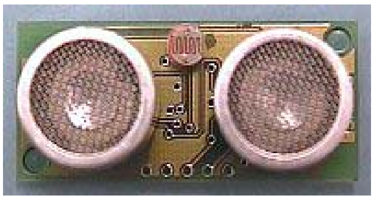


Figure 4. Output signal of the Sharp GP2D12 range sensor as a function of distance.

The main advantage of this sensor is that it offers a distance measurement at a reasonably low price. But this sensor has some disadvantages as well. First of all, the sensors have a very narrow beam width. Therefore small objects are easily overlooked. Secondly, the reflection of the infra-red beam strongly depends on the reflection properties of the material it is confronted with. Thirdly, the measurement is influenced by sources of light lying within the beam-width of the infra-red receiving device. Finally, the measurement signal tends to fall off rapidly once the sensor approaches the object too closely as shown in Fig. 4. This may cause instability in the robot operation if this is condition is not prevented.

2.2.2. Ultrasound range sensors

The Devantech SRF08 ultrasound range sensor shown in Fig. 5 has a measurement range of 0.03 to approximately 6 m with an accuracy of about 0.03 to 0.04 m. The SRF08 uses sonar at a frequency of 40 KHz to detect objects. A 40 KHz pulse is transmitted and the receiving device listens for reflections. Based on the travelling time of the transmitted pulse the distance to the objects can be estimated. The SRF08 is a wide angle device. The transmitter and receiving devices have a 3 dB beam-width of approx. 30 deg. This range sensor is able to detect 16 returning echoes, thus allowing the measurement of the distance to 16 reflecting surfaces in the field of view of this sensor. The measurement time is 65 ms.



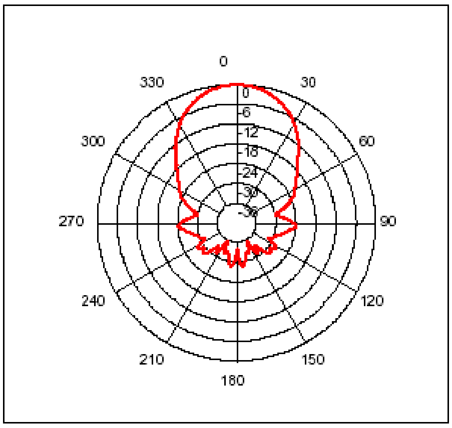


Figure 5. The Devantech SRF08 ultrasound range sensor (left) and its radiation pattern (right).

The SRF08 is more expensive than the Sharp range sensors. The main advantage compared to the Sharp sensors is its wide beam width. Small obstacles will not be overlooked. However, this also is a disadvantage. On Cropscout the SRF08 sensors are mounted relatively close to the ground. To prevent undesired reflections from the soil, the sensors were tilted backwards. A disadvantage of the SRF08 is its slow response time, thus obstructing high sampling rates. Multiple reflections and interference of reflections may cause incorrect readings. Finally, using two or more sensors simultaneously may suffer from mutual interference. Then, sensors have to be activated sequentially or sensors have to be physically isolated thus preventing interference. On Cropscout, the two sensors are used simultaneously. Interference is prevented by pointing them in almost opposite directions.

2.2.3. Whiskers

Two whiskers were mounted at the front of the robot. The whiskers consist of the tip of glass-fibre fishing rod connected to a potentiometer. When a whisker strokes an object such as a plant, this will change the deflection of the whisker. A deflection is translated into a voltage. The deflection of the whiskers ranges between 0 and 90 deg. The whiskers are spring loaded such that they fully extend in a fully open workspace.

Whiskers have some advantages. They are extremely cheap compared to any other distance-measuring device. Also, they produce a stable signal, compared with the relatively noisy signals of infra-red sensors and the ultrasound sensors. In a way, the current whisker construction acts as a kind of moving average filter, thereby reducing unwanted noisy responses. The current whisker construction has two disadvantages. First of all, it is a contact sensor. To prevent crop damage, spring loading is kept very low. Also, the whiskers are made of very flexible material to achieve a ‘soft’ touch. Secondly, in the current construction, the whiskers look backwards. So, care should be taken to use these sensor data during navigation because as a matter of fact they represent the historic position of the vehicle and not the current position of the vehicle.

2.2.4. Digital camera

A FlyCAM CF, mounted directly on the iPAQ pocket PC's compact flash port, is used as an image sensor for the detection of rows and navigation along the rows as shown in Fig. 6. A wide-angle lens was added to the camera to increase the field of view. The Pocket PC is programmed with Embedded Visual C++. For image acquisition, a software development kit (SDK) including libraries for this the camera was used. Images were captured with a resolution of 160x120 pixels, 1.3 frames per second. Commonly used row detection methods such as e.g. the Hough-transform are performing very well but require much computer power. A good overview of the different techniques developed for agriculture can be found e.g. in Astrand (2000). The simple "pixel-counting" algorithm used successfully for the EyeMAG vehicle encouraged the team to look for a technique with low computational load. Our approach is to analyze only a few image-rows which is comparable with the work done by Tillet and Hague (1999). Woebbecke showed (1995) that good contrast between living plants and background (soil and residues) can be achieved using the normalized RGB (red, green and blue) chromatic values of a color image. The RGB-intensities of the image are normalized prior to the segmentation to be independent from variable illumination. Figure 7 shows an example of a segmented image of a maize field with results of the row detection. As row detection algorithm a template matching procedure was performed. The location of the crop rows in the image can be predicted from available prior information. Idealized templates for certain image rows were built using a Gaussian bell-shaped curve per row. The template was fitted onto a limited number of lines of the image row using cross correlation as illustrated in Fig 7. From these data, the center of the path and a navigation direction could be calculated.

Figure 6. Graphical user interface of pocket PC used for camera vision based row detection and navigation (left), the FlyCAM CF camera (top right) and close-up of the camera construction with wide-angle lens (bottom right).

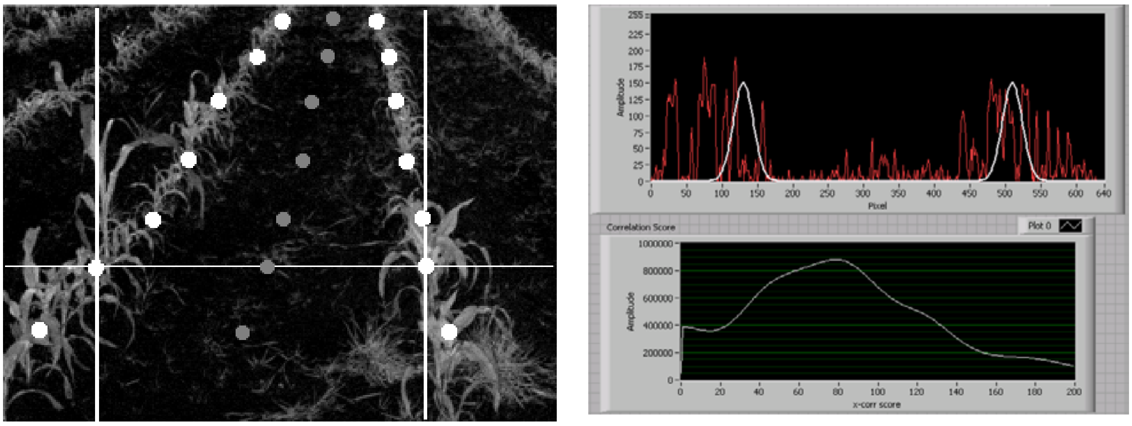


Figure 7. Segmented image with result of row detection on seven lines of the image (left), the Gaussion bell-shaped curve on top of one image line (top right) and the result of the cross correlation (bottom right).

2.2.5. Gyro

An ADXRS150 gyroscope of Analog Devices was used to measure changes in the yaw angle of the vehicle. This sensor is used for controlling the head-land turns.

2.2.6. A two axes inclinometer

A two axes inclinometer was used to measure the role and pitch angles of Cropscout.

2.2.7. Pulse counters on motor axes

Pulse counters were mounted on the motor axis to produce insight into the speed of the individual tracks. Though, the motors could be driven directly by the micro-controller, it was found that slight differences in performance between the two motors as well as differences in the static friction of the two tracks led to undesired differences in trackspeed.

2.3. Control hardware

As shown in Fig. 8, a Micro-key 20CN167 micro-controller is at the core of Cropscout. It contains a Infeneon C167 20 MHz 16 bit processor and carries 1 Mbyte of flash ROM, 256 kbyte of sRAM and 8 kbyte EEPROM. It has 16 analog input channels (10 bit) and 52 multi-purpose digital I/O channels including 4 PWM channels. Software is written in C and compiled on a PC and downloaded through a serial interface.

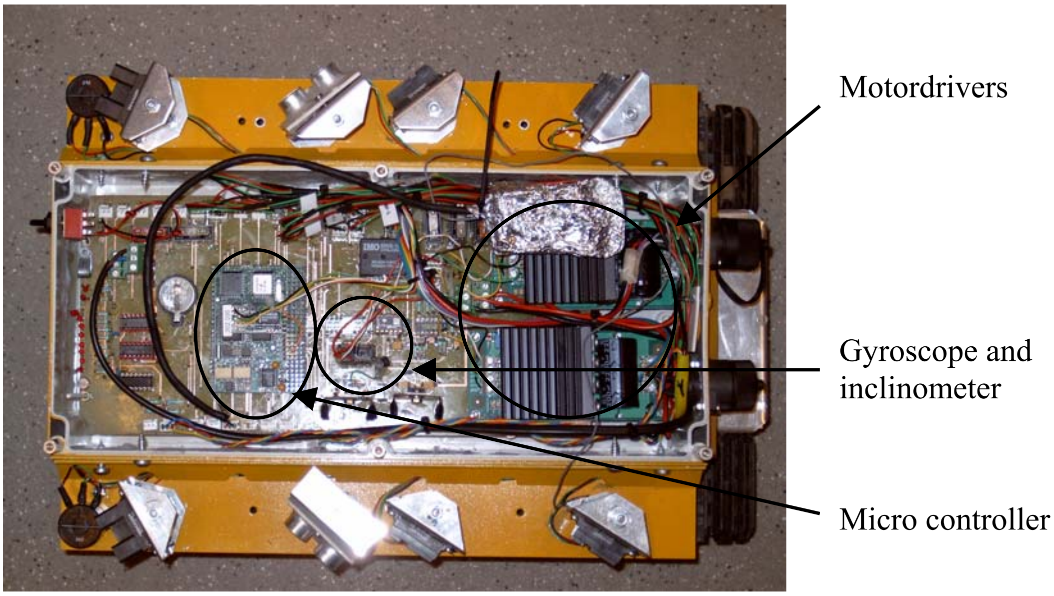


Figure 8. The interior of Cropscout.

An electronic circuit board was developed to facilitate interfacing of sensors with the micro-controller. On the circuit board, two MD03 motor drivers were mounted together with some miscellaneous electronic hardware needed for signal preprocessing and EMC control.

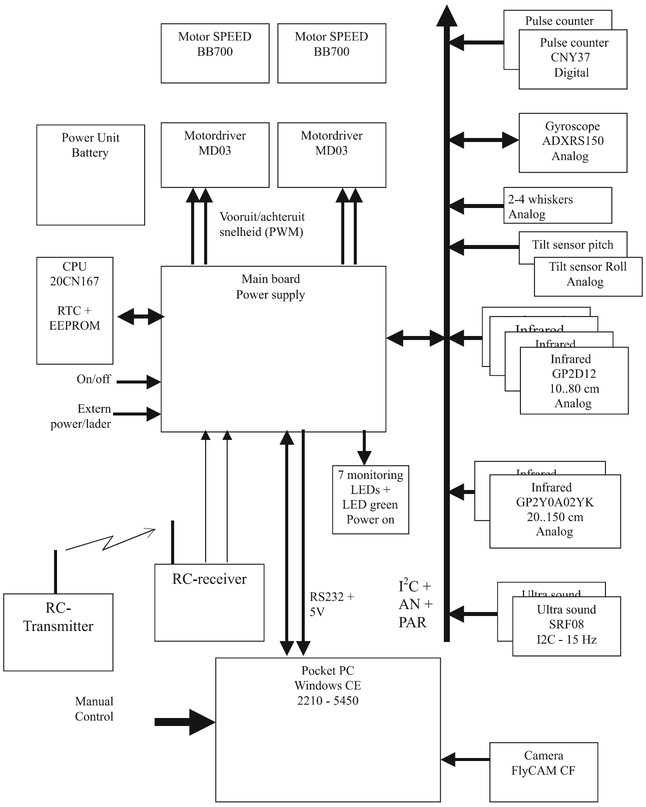


Figure 9. Schematic diagram of the electronic hardware of Cropscout.

The 20CN167 is an embedded controller without interfaces such as a keyboard and display. To facilitate interfacing, *i.e.* manual input of parameters, manual control of the robot as well as data storage of measured sensor signals, an HP iPAQ H5500 pocket

PC is connected to the micro-controller through a serial interface. The pocket PC is also used for image processing.

A schematic diagram of the electronic hardware is shown in Fig. 9. It is also possible to control Cropscout using a 2-channel remote control system. This offers the opportunity to run Cropscout through various test runs and to store the measured sensor data for evaluation and controller design. Also, the remote control can be used as an emergency break.

2.4. Control software

Cropscout has three different operational modes: radio controlled operation, manually controlled operation through the iPAQ pocket PC interface and autonomous operation. If the remote control is on, autonomous control and iPAQ control are disabled. If the remote control is off, the micro-controller detects the presence of the pocket PC. If the pocket PC is present, Cropscout waits for instructions from the pocket PC. Autonomous control can be enabled in this way. If the pocket PC is not present, the micro-controller switches to autonomous operation. So, Cropscout is able to run without pocket PC. The micro-controller software is programmed in C on a PC, compiled and down-loaded into the controller. The iPAQ is programmed in C in a Windows CE environment.

Both radio controlled operation and manually controlled operation can be used for testing individual robot components under artificial test conditions or under field conditions.

The autonomous mode has three different states:
1. Search for rows,
2. Navigation between rows,
3. Turn to next pair of rows.

2.4.1. Search for rows

Before Cropscout is able to navigate between rows, it has to detect rows of plants. This occurs at the start of an autonomous run when sensors may not yet have detected plants. This will certainly happen after completion of a turn, when Cropscout is positioned in front of a new pair of rows.

At a relatively slow speed, Cropscout travels along a straight line using the gyro until the two rows of plants are detected by the sensors. Then, Cropscout switches to the navigation between rows mode.

2.4.2. Navigation between rows

Cropscout navigates between rows using the sensors chosen by the user. The sensor choice is entered through the iPAQ user-interface. This allows for development of various control algorithms based on individual sensors, to develop sensor-fusion based control algorithms and to test the robustness of control algorithms under simulated sensor malfunctioning conditions.

It is the objective to drive Cropscout along a trajectory exactly between both rows. The offset from this trajectory is measured by the pairs of sensors mounted each side of Cropscout and the camera. The offset is translated to a control signal to drive the individual tracks. Given a fixed linear base speed, *i.e.* both tracks running at the same speed, navigation boils down to implementing a rotation of the vehicle frame, which can be achieved by introducing a difference between the speed of the two tracks. The navigation algorithm also includes acceleration and deceleration of the linear frame speed depending on the accuracy with which Cropscout follows the trajectory and the accuracy and consistency of the sensor values. If the offset is small and the confidence in the sensor data is high, Cropscout accelerates. Deviations from the trajectory and reduction of the confidence result in a deceleration.

2.4.3. Turn to next pair of rows

Once the end of the rows is reached, a turn is implemented. Cropscout turns using the gyro signal. Track speed is limited during this procedure to prevent undesirable behaviour.

2.4.4. Detection of rows

The sensor-based detection of the rows of maize plants plays a crucial role in Cropscout control. Switching from the ‘search for row’ state to the ‘navigation’ state and to the ‘turning’ state *etc.*, is fully determined by the detection of the plant rows.

The detection of the rows is based on a voting algorithm in which each sensor votes pro or against the presence of a row. This voting procedure is repeated several times. Votes are counted and if a majority of sensors votes in favour of the presence of rows over and over again it is decided that rows are present. The same procedure is followed continuously to detect the out of row condition in the same way.

2.5. Test tracks

2.5.1. Artificial maize rows

Because during the early stages of development of Cropscout, a maize field was not available, first testing and tuning of Cropscout was done using two rows of in total 4 m papers models of maize plants, having a height of 0.30 m and an intra-row spacing of 0.13 m as shown in Fig. 10. Each row consisted of two parts, which allowed to implemented soft bents in the rows.

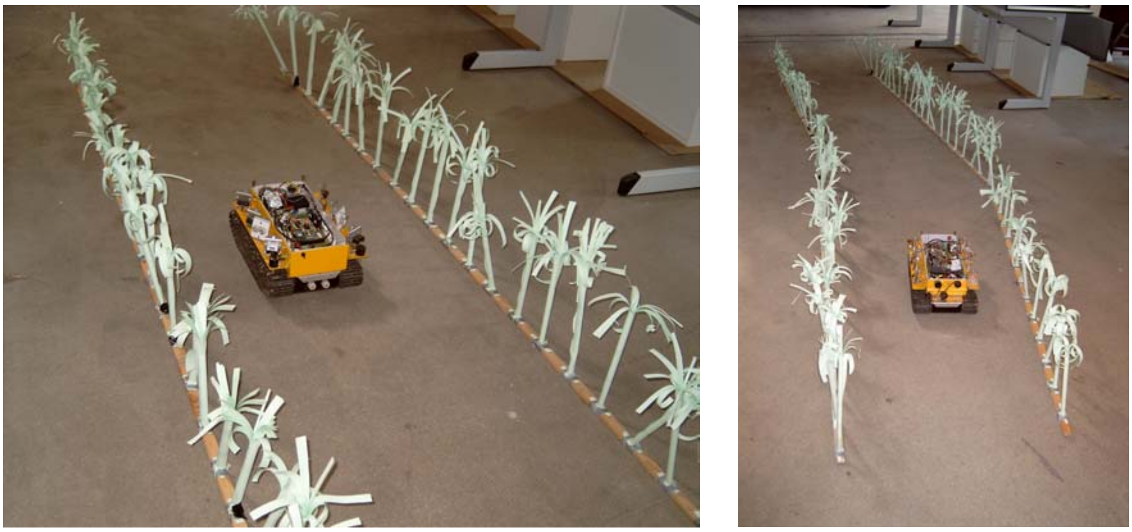


Figure 10. Cropscout between the artificial maize plants.

2.5.2. Real maize field

The layout of the test tracks in a real maize field during the 2004 Field Robot Event is shown in Figure 11. Inter-row spacing was 0.75 m. Intra-row spacing was 0.13 m.

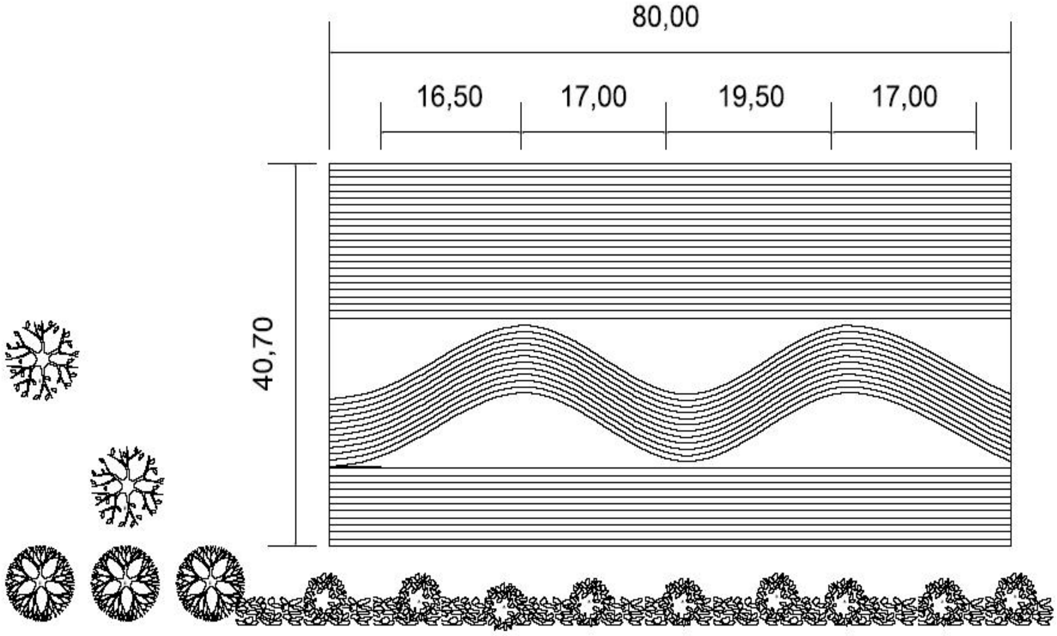


Figure 11. Straight and curved test tracks on a maize field during the 2004 Field Robot Event, Wageningen, The Netherlands (drawing by courtesy of FRE organisation 2004)

3. RESULTS

3.1. Artificial test track

Using data collected on the artificial rows of maize plants, the row detection algorithm was tested. For this purpose, Cropscout followed a remotely controlled straight course between the rows. Results are presented in Fig. 12. The figure shows raw data of the front mounted left and right hand IR sensors and the ultrasound sensors. For proper interpretation, note that a low value of the IR sensor indicates a long distance between object and sensor. The ultrasound sensors directly produce a distance measurement. So, low values correctly indicate a short distance between sensor and object. Cropscout started travelling between the rows of plants. It is interesting to note that this is detected by the wide-angle ultrasound sensors but not by the narrow-angle IR sensors. To deal with this situation, the state 'search rows' has been implemented. Cropscout travels along a linear track until rows are identified. Then, Cropscout locks to the rows and starts navigating based on the available sensor signals. Fig. 12 shows the row detection as well as the status of the control algorithm. A value of zero means 'off', a value of one means 'on'. Cropscout control switches from search modus to navigation. Once the end of the row is detected it switches to turning. After completion of the turn it switches to search modus again and then to navigation.

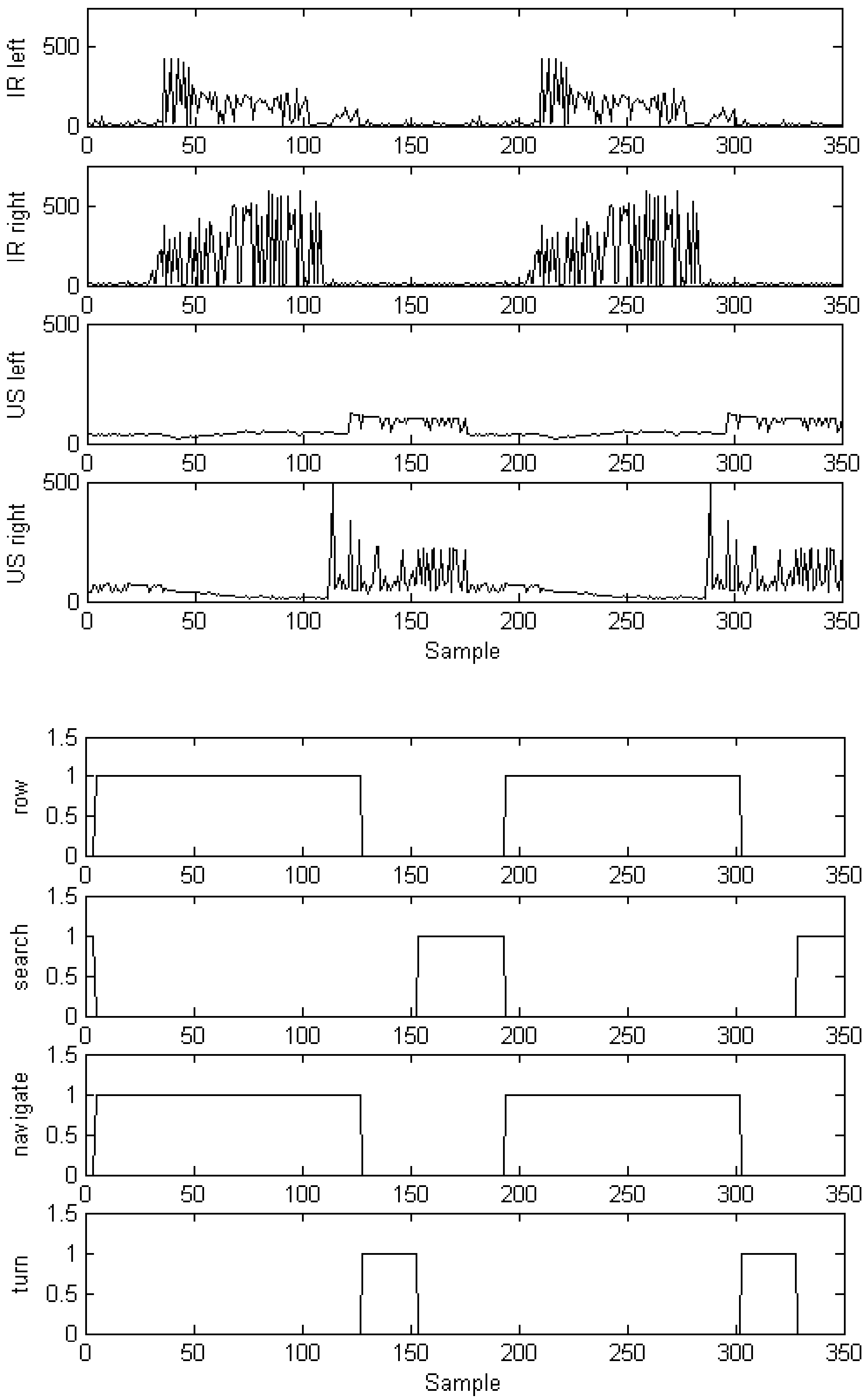


Figure 12. Test of the row detection and mode switching algorithm using data obtained on the artificial test track (the top four figures show the measured sensor data, the bottom four figures present the row detection and status of search modus, navigation modus and turn modus of the control algorithm.

3.2. Real maize field

Passing all tests flawlessly, Cropscout obtained the first prize during the Field Robot Event. Though some of the competitors travelled at a higher speed, Cropscout operated fully autonomously and completed several times the straight dry track, the curved track and the muddy straight track including several turns without human interference. During the free-style session Cropscout followed a red curved line on the ground and identified potato plants positioned on both sides of the line. See Fig.13.


Figure 13. The test tracks (left) and Cropscout in the free style session (right) during the Field Robot Event on June the 18th 2004 in Wageningen, The Netherlands.

4. DISCUSSION AND CONCLUSIONS

In this paper a multi-purpose autonomous robot platform was described and results of tests on an artificial test track and real field were reported. Cropscout is easy to handle due to its limited weight and size. Small tests of filtering and control algorithms can easily be implemented and tested on a small scale before use in a full-scale application. Also, the electronic hardware platform offers abundant space to implement and test all sorts of algorithms. Additionally, remote control, manual control through the iPAQ user interface and autonomous control, offer flexibility for experiments.

Results of the row detection and mode-switching algorithm tested on an artificial test track illustrated the viability of the algorithm used. These results were confirmed during tests on a real maize field. During the Field Robot Event 2004, Cropscout passed all tests without human interference, obtaining the first price.

ACKNOWLEDGEMENTS

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Field robot "Eye-Maize"

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ABSTRACT

A group of undergraduate students attending a course of electrical engineering with emphasis on electronics decided to take part in the Field Robot Event 2004 in Wageningen. The work is evaluated in replacement of theoretical tests for the modules “Optoelectronics” and “Microsystems Technology” (each 5 credits) and has been proposed by Norbert Emeis and Arno Ruckelshausen as lecturers.

The goal was to make a concept and to realize a low-cost robotic vehicle using optoelectronic sensors and a microcontroller-based platform. The vehicle is called “Eye-Maize”. The total costs are about 1.400 €.

At the Field Robot Event Eye-Maize successfully drove between the straight and curved rows with reasonable speed. Moreover, the U-turn worked well for dry soil. Problems occurred at the U-turn for wetted soil due to slip. The integration of additional devices – like acceleration sensors or an electronic compass – might solve this problem in the future.

Fig. 1: Eye-Maize in action

KEYWORDS

Field robot, student competition, optoelectronic sensors, CMOS camera, maize

1. INTRODUCTION

The project was conducted by the students besides their normal study program and not as a fulltime project. This project is the first try of the students to take part in a competition with a self-made device at all. One main goal of the project was to keep the costs of the robot as low as possible. Therefore commercially available standard components were used wherever possible. This led to the use of a model vehicle as the mechanical base, a standard microcontroller board for the control and triangulation sensors for the maize detection. Shortly before the end of the project a low cost camera with integrated controller became available and was integrated in the robot.

2. CONCEPT

The concept of the field robot Eye-Maize (see figure 1) is based on a modified commercially available console, low-cost optoelectronic sensors and a microcontroller-based processing for plant detection and drive as well as power control. The corresponding electrical block diagram is shown in figure 2. Low-cost distance sensors as well as a CMOS camera result in redundant information being processed by an Infineon microcontroller. Moreover a touchscreen serves as an interface to the user, thereby allowing a flexible change of software strategies being stored in the memory. An Atmel microcontroller takes care about the power supply as well as speed and steering algorithms.

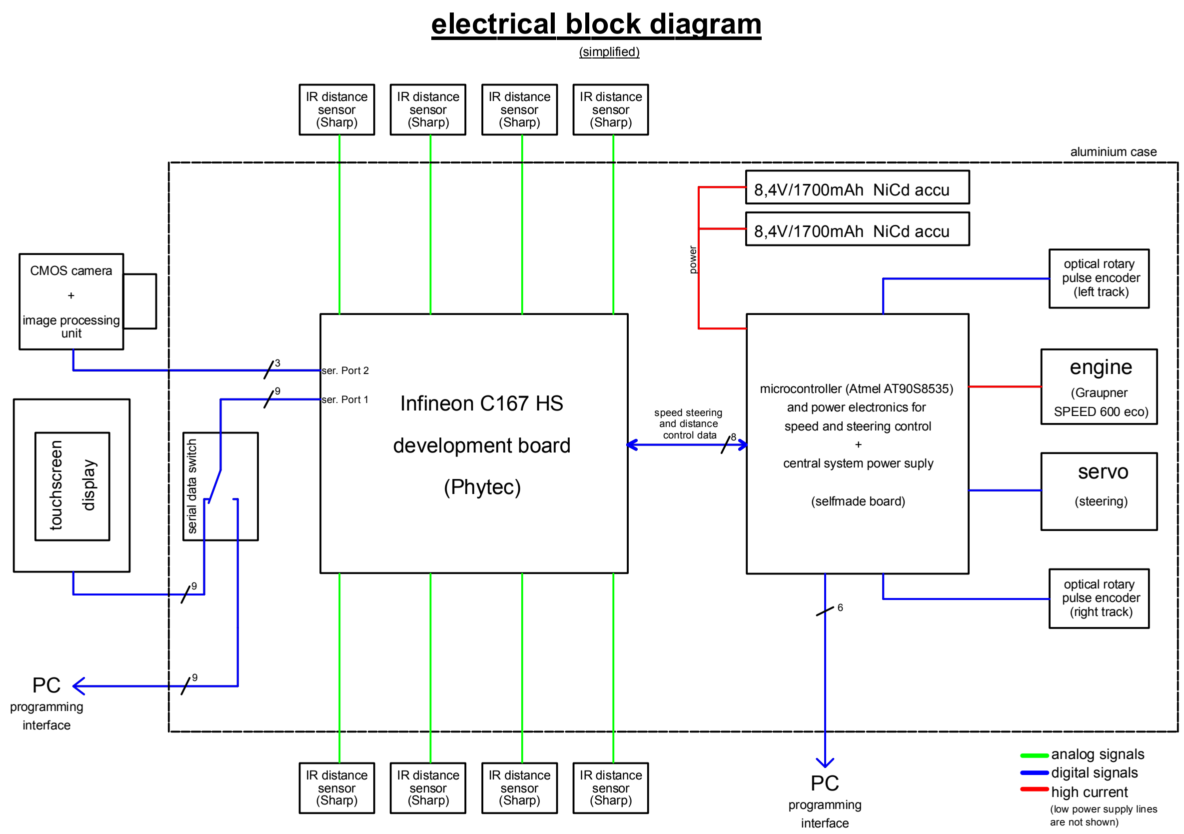


Fig. 2: Electrical block diagram of the concept of Eye-Maize

3. HARDWARE

Base unit

The model "Blizzard" (see fig. 3) of a civil, track based model, made by "Kyosho" was used as the base of the whole vehicle. It was decided to build an aluminium box on the top, to house the electronics and the battery. The box protects all equipment inside against rough conditions as expected in the field.

The vehicle has one electric engine, which is connected to both tracks via a differential gear. The vehicle can steer to the left or to the right by applying brake force to one side of the tracks using a standard model servo.

Mechanical data of the robot “Eye-Maize”:

length (without touchscreen)	37 cm
width (without tracks)	24 cm
width (with tracks)	31 cm
height (without sensors and camera)	17 cm
height (with sensors and camera)	51 cm

Fig. 3: Model vehicle "Blizzard" from Kyosho

Distance sensors

There was already experience at the University of Applied Sciences Osnabrück with respect to low cost distance sensors (e.g.: Sharp GP2Y0D02YK /1/) and some microcontroller development boards from Phytec /2/. To make use of those experiences it was decided to start the electronics development with these devices.

For detection of obstacles in front or at the sides of the vehicle triangulation sensors of type GP2Y0D02YK were used. (see fig.4). The data sheet points out, that this sensor can measure distances between 20 cm and 150 cm. Tests within the project showed an optimum range between 15 cm and 65 cm for these sensors.

Fig. 4: Sharp GP2Y0D02YK IR distance senor

Sunlight and voltage changes did not affect the output signal. Due to the slow conversion speed two negative effects were observed at high vehicle speeds. The maximum output voltage drops down a little bit and the distance measurement when passing one single object can be split up into two different measurement cycles.

The sensors are mounted so that they “see” the ground at a distance of more than 65 cm. The sensors were tested onboard and stand-alone with a mobile test system. At all tests, the speed of the moving sensor was recorded. The sensor output voltage is about 2.6 V at a small distance, which decreases at longer distances. This behaviour is shown in figure 5.

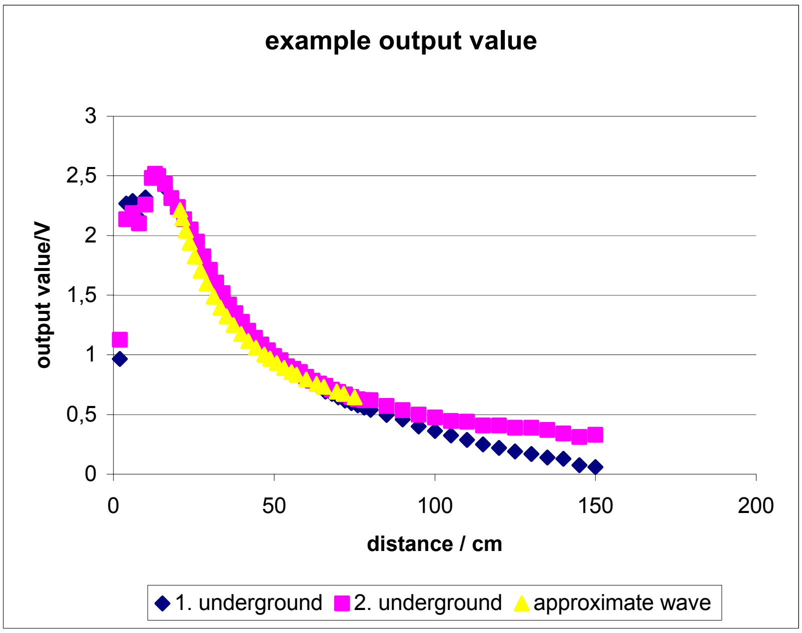


Fig. 5: Voltage versus distance measurements for the Sharp sensor

The sensors and the camera used on the top of the box are protected by small metal caps from the sun and wet conditions. All sensors were mounted next to the middle of the vehicle. This offers a good protection against mud and eliminates the dead range of about 15 cm. Each sensor can be adjusted individually without affecting other sensors.

The sensors are connected to the analogue inputs of a Phytec development board with an Infineon C167 microcontroller.

CMOS camera

Fig. 6: CMOS camera CMUCam2

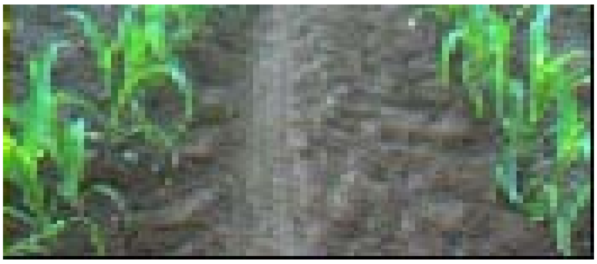
The CMOS camera, "CMUCam2" /3/ mounted on the top (see fig.6), has its own additional microcontroller for image preprocessing and can be programmed to show a special behaviour.
The camera consists of a SX52 microcontroller interfaced with an OV6620 "Omnivision" CMOS camera /4/ and communicates via a RS-232 serial port.

The camera has different features, the following list just mentions some of the features used in this robot project:

- Take pictures with a resolution up to 160*255 pixels.
- Adjust the camera's image properties
- Track a user defined colour with a speed depending on the resolution up to 50 frames per second.
- Find the centroid of any tracking data
- Customize the information in the output data.

Because of the visual conditions and the algorithms, a *Virtual Window* was created which reduces the size of the original image. The size can be modified to show a part that includes the objects of interest. By calling the camera function *Track Colour*, the camera registers every pixel of the chosen colour in the defined virtual window and returns the x and y coordinates of their centroid. Furthermore the bounding box and the number of pixels in the tracked region are returned.

The camera offers the choice to use the "normal" RGB colour space or a colour difference coded signal: the YCrCb colour space. The latter is used here because it turned out that this offers the higher reliability for the maize recognition.



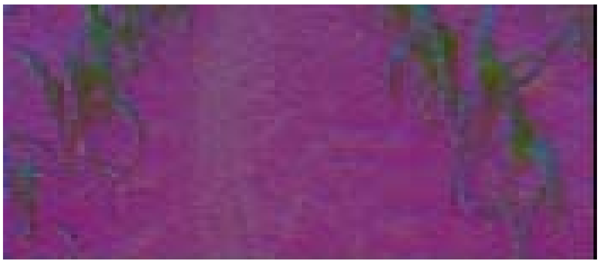
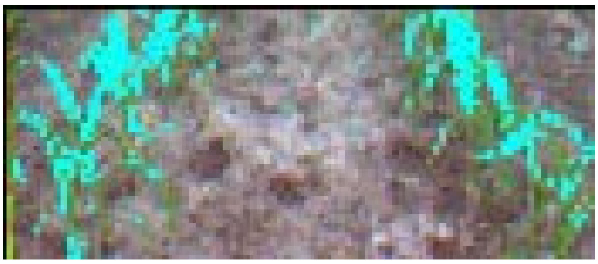


Fig. 7: Two adjacent maize rows in RGB colour space (left) and YCrCb colour space (right) as seen by the CMUCam2.



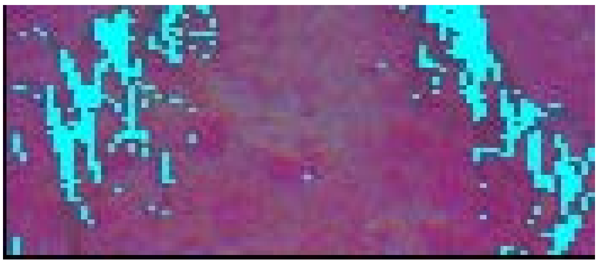


Fig. 8: Two adjacent maize rows in RGB colour space (left) and YCrCb colour space (right). In both cases the tracked colour has been marked by the CMUCam2.

It was decided to track the green colour of the maize plants. The data is then transferred to the Infineon microcontroller and the results are taken into consideration by corresponding algorithms.

Phytec development board with Infineon microcontroller

The "Phytec" development board "phyCore-167 CS/E", equipped with an "Infineon C167CS", is used as the main controller board of the robot (see fig. 9). It collects all information from the triangulation sensors, the camera, the user input (touchscreen), and the drive control board. It calculates the travelled distance, interprets the sensor signals and transfers the steering and speed commands to the drive control board.

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.

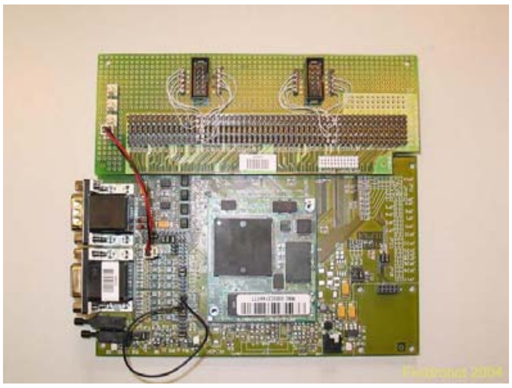


Fig. 9: Phytec development board with Infineon C167 controller

Drive and power control with an Atmel microcontroller

This board (see fig.10) acts as the power supply for all devices. It is directly connected to an 8.4 V NiCd accumulator which can deliver a maximum current of 3.4 A. The board uses a linear voltage regulator to provide a voltage of 5 V for the microcontrollers, sensors and the Phytec development board. The board includes the low voltage drop electronic power switches for control of the main engine. The circuit is designed for a current of about 15 A with a peak of 30 A. It is fused to 20 A. The polarity of the power for the dc engine can be reversed using relays. An internal closed loop control sets the current for the engine to adjust the velocity as calculated by the "Phytec" board.

For distance and speed measurements light bars are internally attached to both tracks of the vehicle (see fig. 11). These light bars are also directly connected to the "Atmel AT90S8535" controller. Additionally the steering servo and some expansion ports are connected. Data communication with the "Phytec" development board is maintained through a simple parallel communication with a self-made protocol. The controller is programmed via a standard isp cable.

Fig.10: Power board with Atmel controller

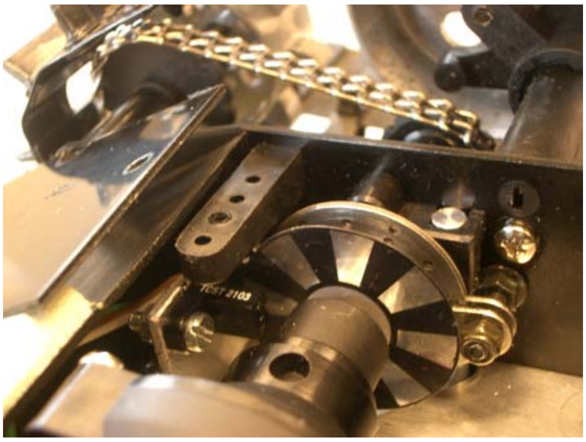


Fig. 11: Light bar for speed measurement

Features of the Atmel controller include:

- AVR RISC architecture
- 8 kb FLASH program memory
- 512 byte SRAM
- 0 .. 8 MHz (crystal speed is 4 MHz in this application)
- one 8 bit timer and one 16 bit timer with PWM possibilities
- low power consumption (3mA at 4MHz)
- good availability and excellent price/power ratio

The electronics of the fully assembled robot is shown in figure 12.

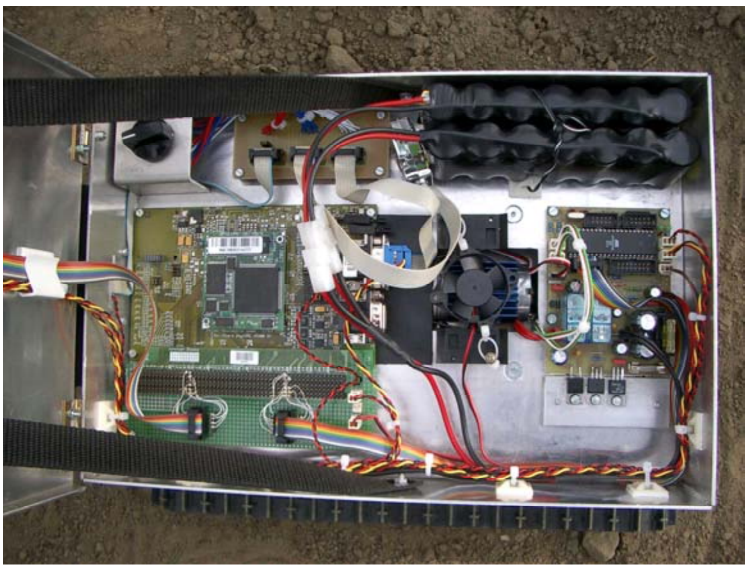


Fig. 12: Electronics of the fully assembled robot

4. SOFTWARE

Both microcontrollers were programmed in C. Graphical development tools were available for both platforms. Keil µVision Version 2.0 and 3.0 /5/ was used to program and simulate the programs for the Infineon C167 CS controller, while Atman AVR /6/ and AVR Studio 4.0 were used for the Atmel AT90S8535.

Software for Infineon microcontroller

The tasks of the software include processing the data from the distance sensors, the CMOS camera, and the drive control. Furthermore the control of the touchscreen and sending the driving data to the motor controller has to be performed. In summary, more than 3300 lines of programming code have been generated, including about 1500 software branchings. Different strategies can be selected by the user via the touchscreen.

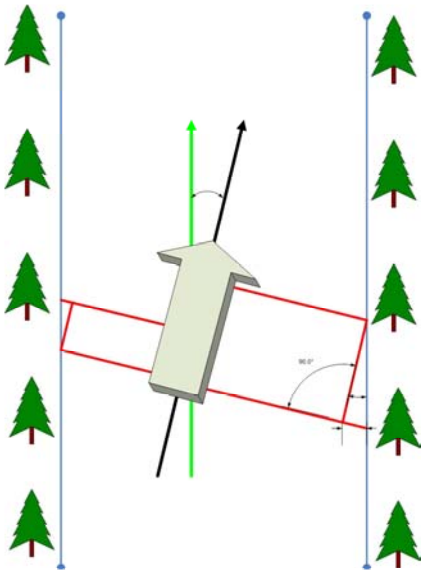
Row driving:

Different concepts for interpreting the sensor data have been developed and corresponding algorithms have been implemented. It is possible to run Eye-Maize in the following modes:

a) Distance sensors (no camera signal is used)
b) CMOS camera (no distance sensor information is used)
c) Sensor fusion of distance sensors and CMOS camera information

6 distance sensors work as “side sensors” (3 on each side”, while 2 upper distance sensors (see figure 1) give additional information ahead. The sensor signals have been weighted and averaged distances and angles of the vehicle are generated. Moreover, a security algorithm has been developed where the region ahead of Eye-Maize is split up into 3 different zones (one center zone, two zones close to the maize rows). Thus upcoming problems of the current course can be detected. Figure 13 shows an example for a geometry of navigation, figure 14 a test run in the laboratory.

The camera has its own image processing on board, which divides the actual picture into two different boxes and recognizes the amount of green maize rows and the brown floor. After this the centroid area of green parts, seen by the camera is reported. The advantage of the camera system is the usage of reduced data. The navigation algorithm calculates the current angle of the vehicle with respect to the plants from all sensor types and can also decide if the received values are valid. For calculation at least 2 valid sensor values are necessary.



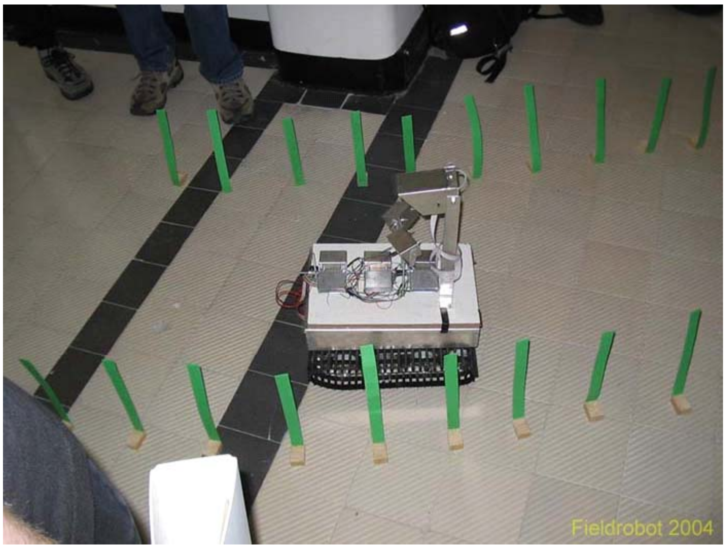


Fig. 13 Geometry for navigation

Fig. 14: Test setup in the laboratory

U-turn

At the end of the row the robot moves straight on, until the sensors are reporting no more plants (for a pre-defined time). Additionally the camera can also recognize the end of a maize row, if it does not detect any green plants any longer. After a small security delay of about 60 cm, the robot is driving a pre-programmed u-turn and tries to find the next row based on the known distance between rows. During the u-turn the camera is set into a sleep mode. The U-turn direction after leaving the first row can be selected before starting the robot using the touchscreen.

Software for Atmel microcontroller

The secondary controller was realized on a small power board, developed by one of the students. An Atmel AT90S8535 controller seemed to be a good choice because of its price/power ratio, the availability and the simple programming with an isp connector. Furthermore some experience with this controller was also available.
The duties of this controller are power regulations for all devices, a closed loop control of the engine and the steering, processing of two light bars used for measuring the travelled distance and acting as a slave for the main microcontroller board.

The Atmel software is mainly triggered by external events with a control algorithm running all the time. All timers of the controller were used to get a very simple inner structure of the software. One timer was used for the parallel data communication with the primary controller, one timer offered two PWM signals which are used to control engine and steering servo and the third timer was used for the control algorithm. There was not much interference because all program parts have a fast program execution, compared to the timer base. The controller is running at 4 MHz clock rate. This crystal controlled frequency is only half the speed possible for the controller, but it gave the team some advantages to control the steering servo.

5. PROJECT TEAM

For a fast and effective realization of the project, the students formed several small groups. Each group took responsibility for planning and realization

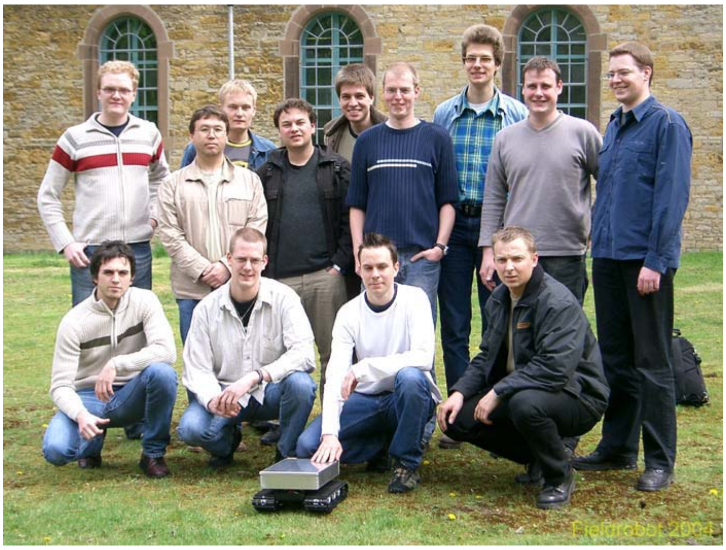


Fig. 15: Student project team
(upper row from left to right: Johannes Henkel, Johann Schulz, Maik Schotmann, Ralph Klose, Torsten König, Jens Fleischhacker, Axel Mühring, Frank Diekmann, Tobias Nolte
lower row: Nicola Mocci, Martin Meier, Evert Nord, Daniel Negd)

Microcontroller group: The microcontroller group was responsible for programming the Infineon C167 controller with self-made algorithms. This group created the brain of the field robot.

Camera: This group had to find a small, cheap, easy to implement camera and had to write the necessary algorithms. A very cheap camera, with its own image processing processor was found. The group programmed the camera and mounted it on the robot.

Base group: The Group developed the power and drive control board, programmed the driving control and the specific hardware functions. Furthermore the motorization of the model vehicle was optimized. The engine and gear ratio were changed to achieve a better torque, needed in the field. Many small mechanical tasks were also done, like assembling of the whole vehicle and final mounting of the sensors.

Power group: The needed capacity of the battery was calculated and it was decided to use a NiCd accumulator. Additionally this group checked the usability of a self-made IR-differential sensor to detect the maize plants. Due to some minor disadvantages (the sensor is only producing useful data when the robot is moving) this sensor is not currently integrated. Nevertheless the IR-sensor offers good recognition of plants due to their good reflections for infrared light.

Sensor group: This group had to find out the best sensors for the use within this project. Only non-mechanical sensors were considered to achieve a better mechanical robustness. Many sensors were tested and finally affordable, standard distance sensors from Sharp were chosen. Some other sensors, like differential GPS were not put into consideration because of their high price. Furthermore it is assumed that exact GPS data are rarely available for normal fields.

6. RESULTS AND DISCUSSION

In the very last test runs prior to the Field Robot Event the three strategies have been tested successfully. However, due to the shorter development time for the CMOS camera implementation, the modes giving priority to the distance sensors showed better statistical results and were used.

In the competition the driving of Eye-Maize between the rows was fine, this was true for the more straight lines as well as for the curved structures. Moreover the U-turn at dry soil worked well. That was more than what the authors expected.

However, at wetted ground the slip correction did not work well. In the present stage of Eye-Maize the U-turn is done “blindly” as described above. Slip correction data for dry and wet soil have been included, but the parameters for wet soil did not fit well to the real field situation. For future developments there is a need for an additional information about the position of the vehicle. It is expected that the integration of an acceleration sensor or an electronic compass can solve this problem.

Acknowledgment

The whole team of the University of Applied Sciences Osnabrück would like to thank its generous sponsors:

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Farnell inOne GmbH, Oberhaching, Germany
Leibniz-Institute of Agricultural Engineering/ATB, Potsdam-Bornim, Germany
Phytec Technologie Holding AG, Mainz, Germany

Moreover, all students thank Norbert Emeis and Arno Ruckelshausen, who fought the bureaucracy and made this very exciting project possible. Many thanks to the assistants of the different sections, especially Andreas Linz and Matthias Bruns, who helped us several times .

Last but not least, thanks to the Wageningen team for organising this great FIELD ROBOT EVENT.

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/4/ www.ovt.com/pdfs/ds_6120_6620.pdf
/5/ www.keil.com
/6/ www.atmanecl.com

List of companies (suppliers, sponsors):

Amazone:	AMAZONEN-Werke H. Dreyer GmbH & Co. KG; Am Amazonenwerk 9-13, 49205 Hasbergen; Germany; www.amazone.de
ATB	Leibniz - Institut für Agrartechnik Bornim e.V. / ATB; Max-Eyth-Allee 100 D-14469 Potsdam , Germany , atb@atb-potsdam.de
Atmel	2325Orchard Parkway ; San Jose, Ca 95131; USA: www.atmel.com
CMUCam2	The Robotics Institute at Carnegie Mellon University. 5000 Forbes Avenue, Pittsburgh, PA 15213, USA ,www-2.cs.cmu.edu/~cmucam/cmucam2
Farnell	Farnell InOne GmbH; Keltenring 14: 82041 Oberhaching bei München; Germany www.farnellinone.de
Infineon:	Infineon Technologies AG ;St.-Martin-Str. 53: 81669 München; Germany www.infineon.de
Kyosho:	KYOSHO Deutschland GmbH; Nikolaus-Otto-Straße 4; 24568 Kaltenkirchen; Germany ;www.kyosho.de
Phytec:	PHYTEC Technologie Holding AG; Robert-Koch-Str. 39; 55129 Mainz ,Germany www.phytec.de,
Sharp:	SHARP Microelectronics Europe ; Sonninstraße 3; 20097 Hamburg ; www.sharp-sme.com

Gudrun participating in the Field Robot event

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Abstract

Gudrun, 'she who fights with wisdom', was built to have fun exploring new technology. Next to this main objective, the authors were curious to what extent electronics, found on standard agricultural implements, can be driven and what type of sensors are worth further investigation. With limited time resources towards the field robot event, it is of utmost importance to use a modular drive concept, re-use as much existent hardware and software components as possible and integrate these in an efficient way. This approach led to a three wheeled chassis, suitable for low cost mass production. On the chassis, various sensors were tested to verify suitability for navigation between maize rows.

Introduction

Over the past decades, most agricultural implements went through a process of automation. Many functions, from straightforward remote control to accurate speed and position dependent adjustment of operation parameters are now steered by electronic control units on implements and provide an operator interface through general purpose board computers. Although this automation process increased labour efficiency, these implements are still under direct control of human operators. The next step in development of agricultural implements to further increase labour efficiency will therefore be a more autonomous operation.

Fully autonomous operation, or robots performing field operations, are at the horizon. On the way there a field robot contest is a tempting challenge and the task of this project is to determine what distance lies between electronic control elements used today and fully robotic operations in future.

Objectives

Design a robot that will win the contest of navigating autonomously through row crop cultivated maize. As simple as that, and with the limited time to be spend a challenge for any engineering team. We formulate the primary objective therefore as an investigation to combine electronic controls, already used in agricultural implements, with cheap and readily available sensors to design a small autonomous vehicle. Of course, with our implement manufacturer background many more objectives need to be formulated: for instance, make it reliable, make it cheap and simple to produce and be sure that there are customers for it. But these are the long term objectives that for now stay in the background within this project.

Materials and Methods

The design and software developments tools are the IDEAS 3D cad/cam system for chassis parts and the CodeWright and Softune embedded development environment for coding of data acquisition and control algorithms. The electronics control boards are standard boards used in agricultural machinery with slightly adapted input circuitry to match the various sensor interface specifications. Table 1 lists the parts.

Table 1. listing of materials for Gudrun 2004 edition

Group	**Item**	**Number**
Chassis	Laser cut RVS base plate	1
	Polymer top cover	1
	‘nuts & bolts’ mounting materials	N
Wheel assembly	RC scale model wheel and hub	3
	Accord seeder motor as drive motor	3
	Rau pressure regulator motor as steer motor	3
	Laser cut RVS wheel fork	3
	Polymer wheel assembly bearing	3
Electronic Control Units	Kverneland mechatronics Multi I/O type C	1
	Kverneland mechatronics SWB sensor module	1
Sensors	Infrared distance sensors SHARP GP2D02	6
	Ultrasonic distance sensors SRF08	2
	Magnetic compass module CMPS03	1
	Solid state gyroscope Murata ENC-03J	1
	Solid state roll & pitch VTI Hamlin SCA100T	1
	Wheel speed optical encoders	3
	Wheel steer angle analog encoders	3
Batteries	Lead acid 12V / 7.5 Ah	2
Special act add-on	Dual nozzle sprayer boom	1

The electronic control units are interconnected by a CAN bus running the ISO11783 (ISObus) communication protocol. The ISO11783 communication implementation provides access to standardized data acquisition (Task Controller & File Server) and operator interface components (Virtual Terminal, figure 3) common to modern agricultural implements and it enables the convenient use of Kverneland programming and configuration tooling. Most of the sensors are selected on the ability to digitally interface to the control units.

Within the system architecture, three major components are distinguished: 1) chassis drivetrain control, 2) environmental sensor data acquisition and 3) mission control. The responsibility of the drivetrain controller is to position and control individual wheel angles and wheel speeds to match the required chassis motion. The environmental sensor data acquisition modules responsibility is to acquire infrared and ultrasonic distance measurements and process these to provide a view of the environment. The last component, mission control, contains the actual logic to perform a certain task. This component is build up from several layers where for instance the abstract task 'navigate through adjacent rows' is split up in more specific tasks where certain environmental sensor data interpretation rules and chassis control algorithms come into play. Of these three components, both the chassis drivetrain control component and the mission control component are currently implemented in a single controller (figure 1), while the environmental sensor data acquisition is located in a separate controller. To ease future implementations, this system architecture is implemented in such a way that the components can easily be relocated to match processing power and communication bandwidth facilities within or outside of the vehicle.

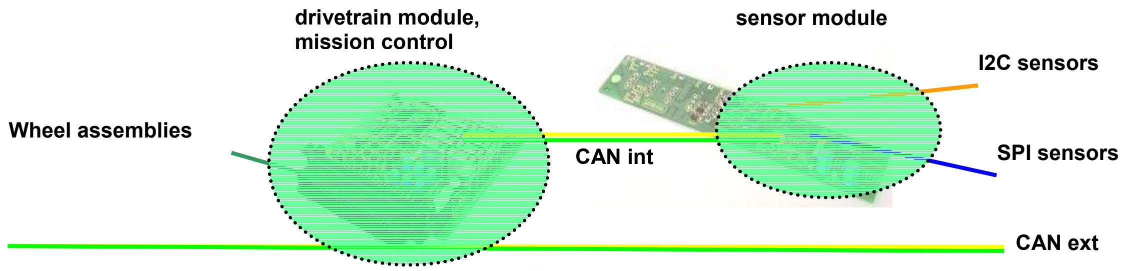

figure 1. electronic control interconnections

Results and Discussion

Figure 2 depicts the 3D design of chassis and location of sensors and control components. All three wheel assemblies are designed to have identical parts in order to minimize the overall parts list length. Due to the use of a single base plate, the required assembly time is low and the access to sensors and control boards good.

The interaction between mission control and chassis drivetrain control was reduced to a narrow interface consisting of the parameters:

- front angle, defines what is front on the vehicle
- motion vector, defines vehicle motion direction and speed
- steering angle, defines radius of steering of the vehicle

Based on these parameters, the drivetrain module controls the individual wheel angles and wheel speeds by means of digital PID controllers. This approach resulted in an autonomous platform that can be positioned accurately in the terrain conditions that are common to row crop maize cultivations.

The environmental sensor data acquisition performed best when the infrared distance sensors array was tuned to have two sensors looking forward, two sensors at 30 degree angles from front direction sideward and two sensors looking near straight sideward.

With this environmental sensor set up, the row crop guidance algorithm uses to front 4 sensors to adjust steering within the rows to avoid collision with the maize plants. The sideward facing sensors where used to detect the end of the row and start the 180 degree turn into the next row. This 180 degree headland turn, even when made at dead reckoning only, was accurately achieved by the drivetrain controller. Within the rows however, the environmental sensors data interpretation needs to be improved and the chassis motion and heading sensors should be integrated in the row guidance algorithm to increase stability and robustness against 'missing plants'.

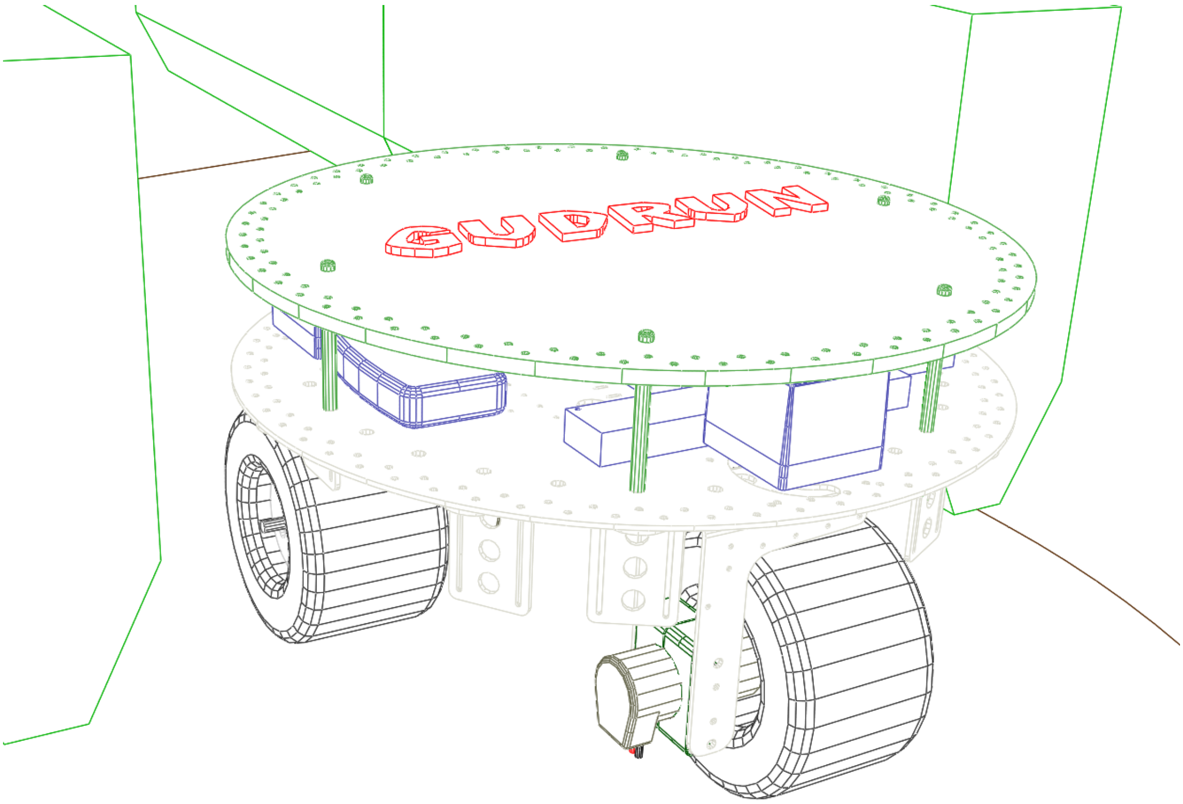

figure 2. Results of 3D design process

figure 3. Presentation at robot fair, connected to a virtual terminal operator interface.

Conclusion

With an end score in the mid range of the 2004 contest ranking, gudrun has proven to be a successful first step to design an autonomous vehicle able to navigate through a maize crop (figure 4). The team behind gudrun demonstrated that close cooperation between mechanical design and electronic control expertise can lead to an innovative product in a very short time span. Also, the re-use of implement automation components that are already common on agricultural implements shortened the development time and this re-use illustrates that the gap between current implement design and autonomous operations isn't that wide anymore.

figure 4. crop conditions during contest, with gudrun in action.

Weblinks

Participant and Field Robot Event info:

http://www.kvernelandgroup.com/
http://www.fieldrobot.nl/

Sensors and components suppliers info:

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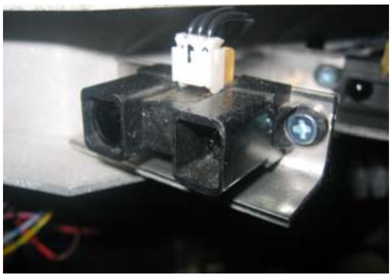
http://www.robot-electronics.co.uk/
http://www.totalrobots.com/

Isaac2 – Infrared Self Acting Autonomous Crawler Second Edition

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Abstract
Field robots are the cutting edge of science in Precision Agriculture - and fascinating hands-on learning objects for the upcoming e-generation. Hence Wageningen University invited high-school and university teams to participate in an international open-air field robot contest. These teams have to compete with self-constructed robots, navigating and operating autonomously in a maize field.

Keywords
Field Robot, agriculture, autonomous, student competition, Wageningen University, Hohenheim University, Isaac, Crawler, Infrared sensor

Introduction
ISAAC2 is created for the second Field Robot Event in Wageningen/NL and is conceived as an executable operative and less interference-prone robotics. Isaac two is a consistent enhancement of ISAAC1. Autonomous navigation in our vehicle is realized by optical sensors which are based on infrared sampling, assisted by an electronic compass-module. Furthermore we integrated speed logging. A tracked vehicle is still used as the basic module, where six infrared sensors and the compass module have been affixed. The vehicle is operating on the field autonomously without remote control.

Material and Methods

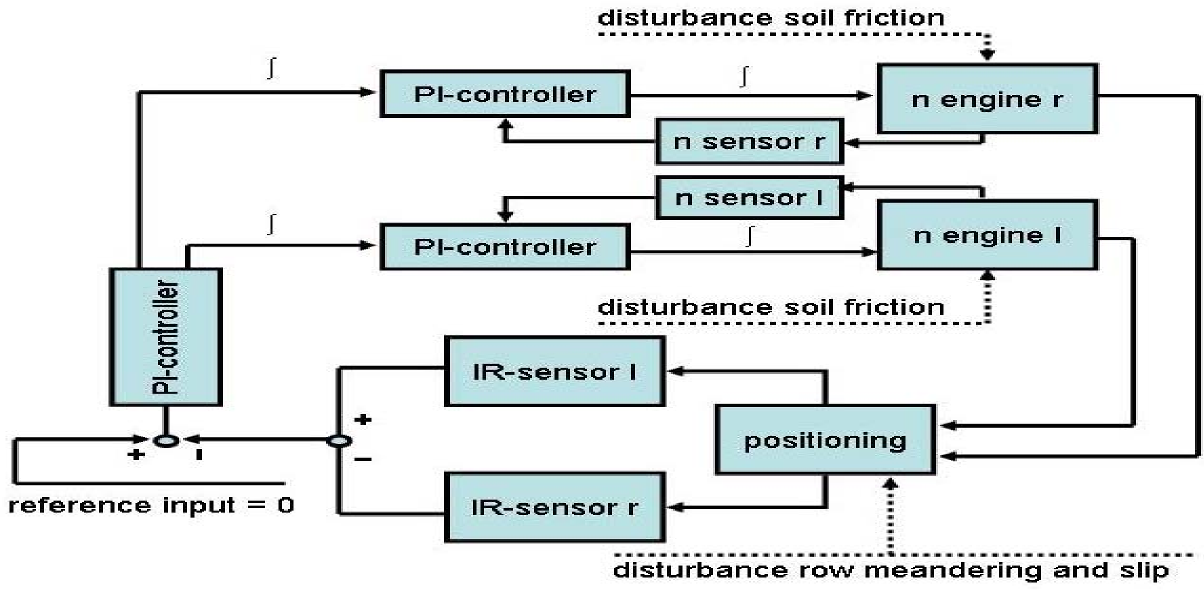
ISAAC2 is constructed like ISAAC1 as an autonomous crawler. In its first conception ISAAC2 was intended to use the following components: Heading Signal from a digital compass module, distance signals from six infrared sensors und speed signals from both chains. ISAAC should process this data in one computer module, running with 16MHz and using a flash-memory of 128kB. This module is able to be in-system-programmed via ISP-Port. The module is able to run two PWM engine drivers, several LEDs for man machine communication and an RS232-interface for external computer communication/data logging.

In its final version we changed this device and finally used to two cruise control models from model cars. Concerning the sensor- and processor-techniques we started as planned.

Isaac2 navigates inside the rows using two infrared sensors in front. It achieves a selection of raw direction using the compass module. It recognises the end of a row by missing reflection from the side mounted IR-sensors. These side mounted sensors are activated after a predefined distance (approximately 90% of row-distance). This distance is measured with two frequency sensors being placed inside the gearbox.

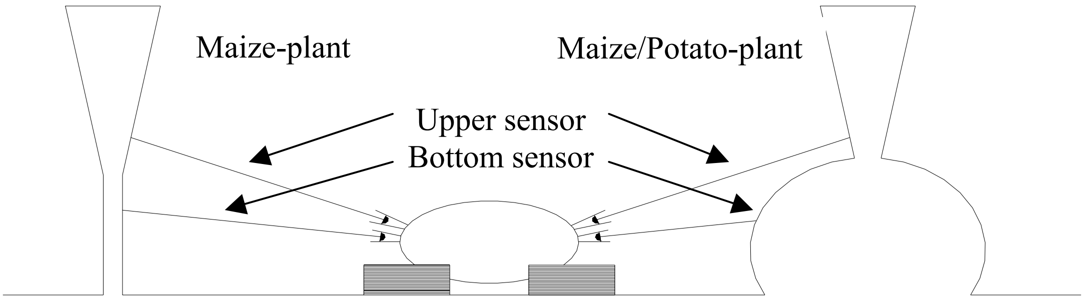
Turn over on head land bases on a relatively turn based on the signal from the compass module. Isaac measures the actual value at the end of the row and stops one chain, until the value reached plus 90 degrees. Isaac drives forward a self defined distance, acquired by the last two IR-sensors, measuring row distance. This row distance plus a programmer defined value (for maize-thickness) is associated proportionally to a quantity of amplitudes from the freq sensors. The second turn stop is defined as a difference of 180 degrees to the stored value at the beginning, in order to avoid inaccuracies from twist while driving at the head land. Slip of the tracks while driving forward can be ignored under all conditions.

Driving performance is improved by a control cycle with freq sensors and pulse duration modulation by dint of a proportional plus integral controller. The controller-cycle had the following characteristic and was easily been integrated into the software:



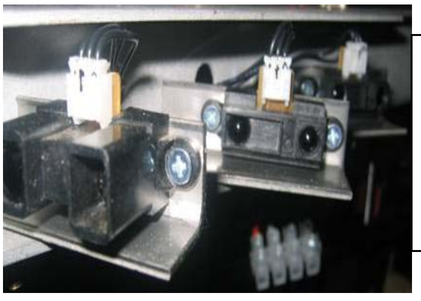
This control-cycle prevents a build up of the oscillation between the rows. The course becomes better, as closer Isaac is to the middle lane because the needed course correction is smaller. Every correction results in breaking and loosing speed. The two signals from the distance sensors are summarised and being approached towards zero. When the direction differs more than 35 degrees from an average compass value since the last turn, the robot stops and aligns to this value, stored with a time delay of two meters. This assures reorientation in the case of loosing orientation.

The freestyle session, recognising potatoes inside a maize-row, can be solved by infrared sensors using different attack angles towards the row. The side face of potatoes and maize verifies. We reach a recall factor up to 50% found potatoes, depending on plant conditions. A potato by increasing clearance from the soil has a decreasing width, in opposite to a maize plant. The following sketch shows the principle:



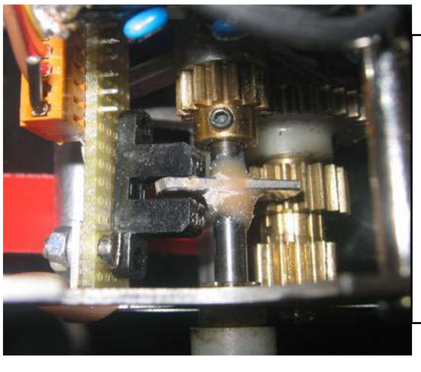
In case the lower sensor gives a predefined space of time a closer value, than the upper sensor, a potato-plant will be reported. This space of time is defined as a programmer defined distance (10 to 15cm, depending on the size of tomato plant) correlated to the acquired speed. The detection will be reported via a flashing LED on top.

Our sensor techniques:

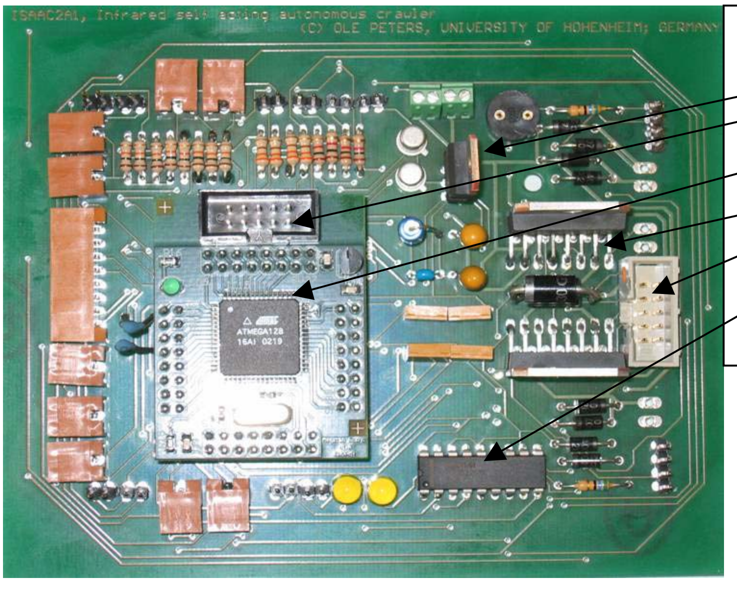


Infrared sensor devices left side
1 x SHARP GP2Y0A02YK (20 – 150 cm)
2 x SHARP GP2D12 (10 – 80 cm)
Giving analogue voltage signal inversely proportional to the distance of the nearest object

Compass and temperature module
Model: 2XCM-I 2axis
The module gives a RS232 interface signal of orientation and temperature.
Accuracy exactly horizontal: 0,5 degrees
Accuracy on Isaac: better than 2,5 degrees

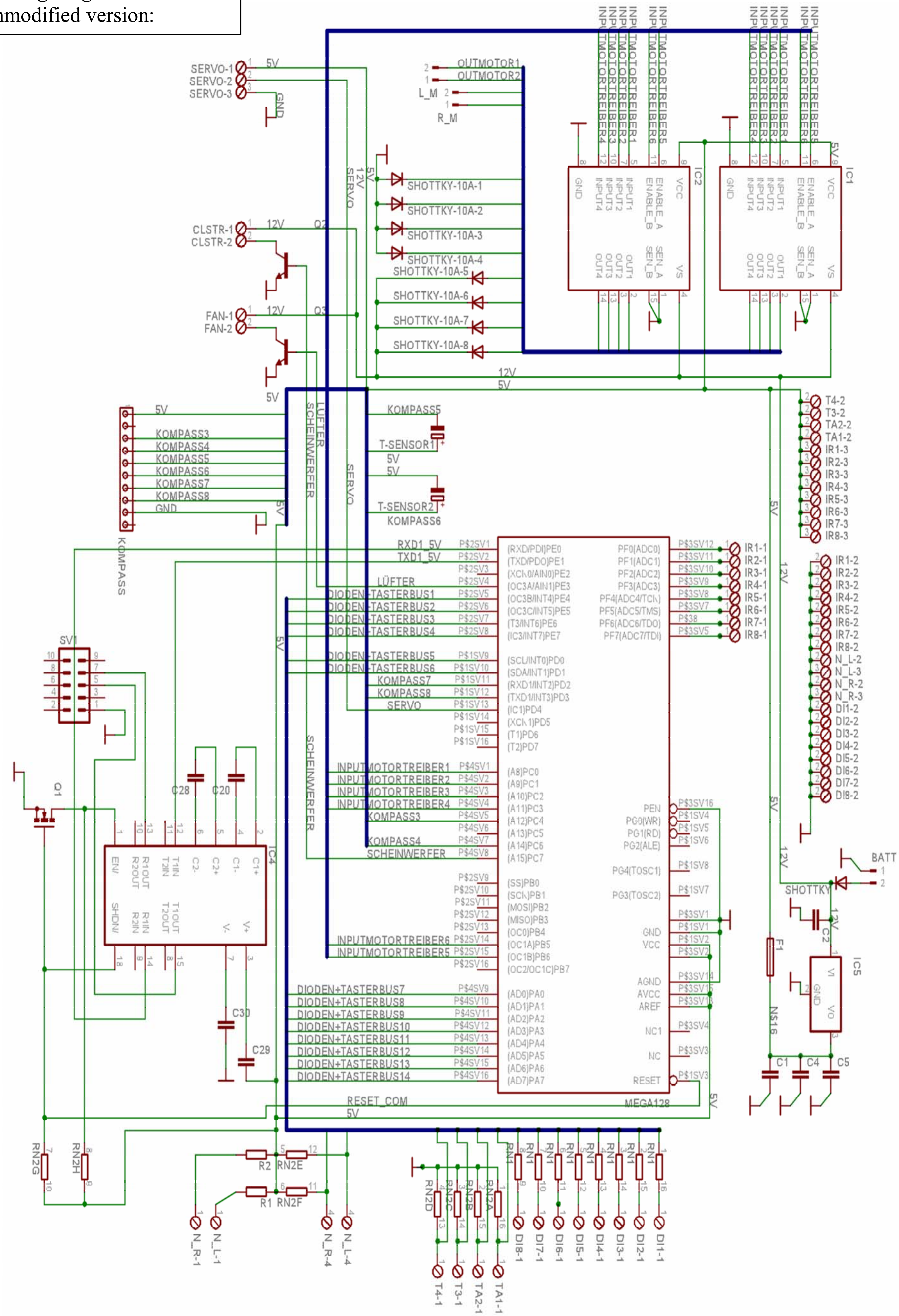


Revolution counters within the gear box:
Frequency Sensors Vishay TCST110
Extremely cheap version, 21 cents each side. Photoelectric relays give a voltage signal in terms of amplitude from 1,2V up to 4,8V per revolution, at full speed the signal reached 60Hz. This signal was difficult to process within the processor unit.



Main Board, unmodified version.
- 5V-Regulator (7805)
- ISP-Interface
- Processing unit
- L298 bridge driver, later replaced
- RS 232-interface
- MAX3222 interface driver

Wiring diagram Isaac2
unmodified version:

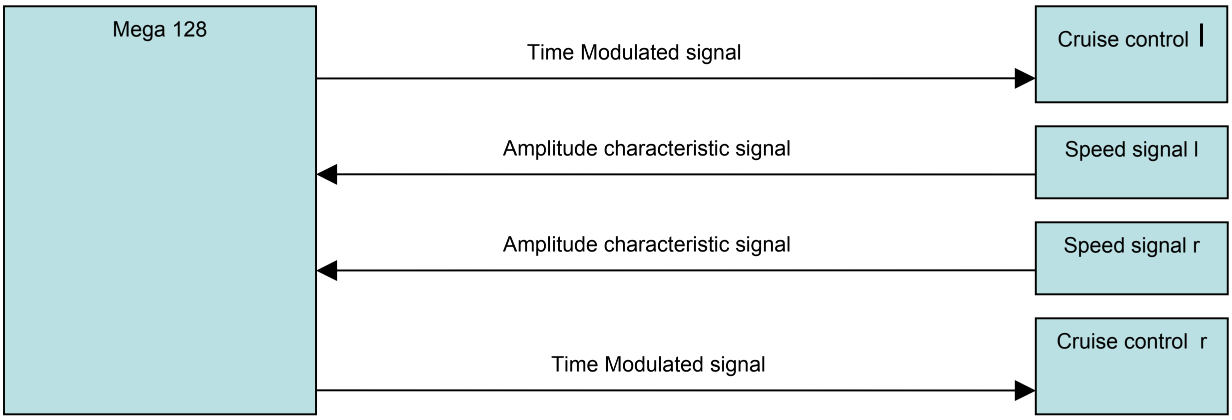


Problems

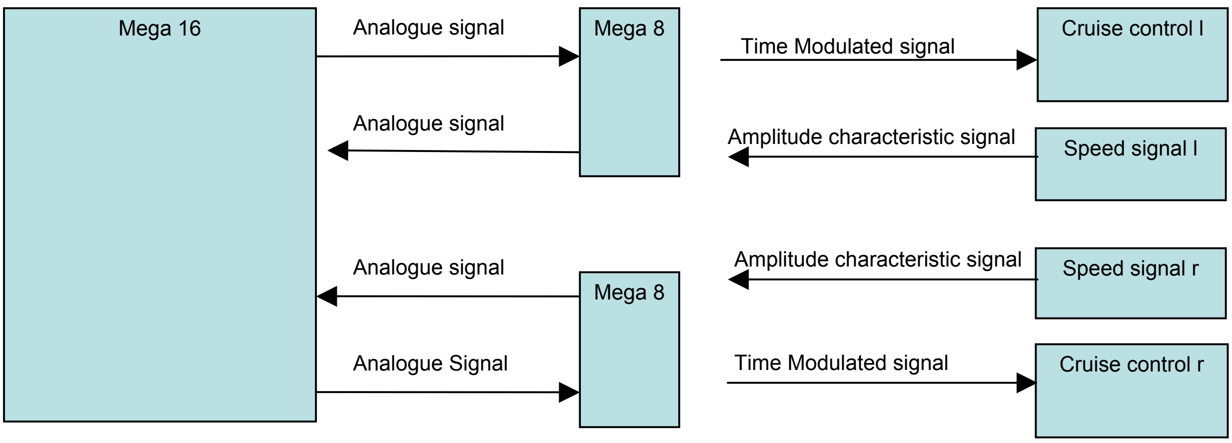
We were not able to use last years L298N Engine drivers that had a maximum channel output of 4 amperes. We had several problems to find out why the engine drivers burned through at load. We were using two channels at 2 Amps per side, but in difference to last year we switched them (in attention to a better heat distribution) to cross these two components. This means we used this two L298 parallel, instead of two separated devices. We supposed a too big line drop between the single layers. Then changed this alignment, but poorly this didn't result in the expected improvement. In regard of the small amount of time left (less than 24hours until departure at that time) we had to use more expensive cruise control modules, the same as used in car models. We raised Isaac's supplementary voltage up to effectively 14,4V from high-power NiMH-Accumulators, in contrast to his last years 12V from a Pb-Accumulator. The starting and brake current easily were too high. More isn't even better; we didn't expect such a big difference between 12 and 14,4V.

These ready made cruise controls are designed for up to 20Amps per channel. Enough for our needs. These modules are driven as a regular servo, e.g. used in model planes. This triggering resulted in a new problem. They need a short signal of one to two milliseconds exactly every 20 milliseconds. This "waiting for the next impulse" occupied our processing unit so much, that the processor was not able to count the signals from freq sensors. We were not able to utilise the processors multi tasking ability. This meant we had to wait about 16 milliseconds at the end of each loop line. As a result our data handling became very delayed.

The first drawing shows the used version:



This is enhanced version that would have enabled better data analysis:



The chassis turned out to be an additional problem. The gear box and engines were almost 20 years old. The chains were based on a snow cat, constructed to work on snow and not on rough, cloddy terrain. So we had to raise chain tension, which led to problems with mounting and suspension of the chains. To cut a long story short, the chassis was just swamped with this demand. Finally we got a bearing breakdown inside the gearbox at the launch of the contest.

Our conceptional formulation has been an autonomous robot being able to navigate absolutely autonomous and fulfilling its tasks under changing conditions. Our idea has been a robot needing no calibration or adjustment to field conditions. We wanted to realise this determining characteristic with following techniques:

- Headland turn over aided by a compass module allowing an exact 180° turn, not depending on turning forces.
- Adjusting the course to the row width. The parameters of steering were adjusted online towards the row character, not by a predefined row width. Isaac drives autonomously in the middle and detects row width for headland turn.
- Path measuring by engine speed detection, not measuring time, depending on driving forces.

Because we could not process this different data which we were able to acquire, most of these plans could not be realised. The consequence of refitting it with three smaller processing units would have been a new construction of the main board.

Conclusions

It is worth mentioning, that we were a group containing exclusively students. Most of our knowledge had to be acquired; this knowledge was just in small fractions part of our course of study. Those hours of work were taken entirely from our free time and we did not get any marks or credit for the work.

Within this Project we collected experiences with:

Electronic design
Programming
Controlling with different control cycles
Manual skills concerning Electronic, Electric, chassis building

Within this project we used the following software:

- *Mind Manager: developing the conception*
- *AutoCAD 2000: design of the top cover and light barrier*
- *Eagle 4.11: conception of wiring diagram and circuit board*
- *Bascom AVR and PonyProg: programming*

In consideration of our problems, we are very glad with the result. Until the evening before departure Isaac did not move an inch. After this we had a broken axle, a bearing breakdown in the gear box, no serial interfaces for compass module and Laptop (this actually based on a missing software activation of the interfaces inside the processing unit which did not need to be activated on last years version of our processing unit) and no speed gauging. The main problem was the 20 milliseconds break caused by program duration in order to supervise cruise control.

However, just thereby this project fulfilled its intended purpose. We had to be creative until the last second and finally solved this task in our way. Afterwards being sure to start working differently next time.

Thus, the participants learned additional skills in electronics, programming and organising such an project.

The field robot event should stay a student contest.

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Shops:

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[2] http://www.conrad.de: electronics e.g.

[3] http://www.embedit.de: processing unit

[4] http://www.robotertechnik.de: compass module, infrared sensors

Sponsors:

[1] http://www.ats.uni-hohenheim.de

[2] http://www. may-tec.de

Acknowledgement

Without the encouragement and assistance of the professors and technical advisors of the Institutes of Agricultural Engineering and Agricultural Engineering in the Tropics and Subtropics, both University of Hohenheim, our project would not have been possible in this way. The support of our institutes was great. We were able to use the whole equipment without restriction. Also financial support was quick and in no way limiting. Thank you very much.

Sponsoring of the agricultural dealer Maytec GmbH, Schwabach, who paid the entry fee was very important for us, too. Thereby we were able to participate.

We have to thank the organization committee at Wageningen University for this great competition and all their work. We spent great days in Wageningen. Thank you very much.

The making of the RSFR-1
Rockingstone Field Robot

Competitor for the Field Robot Event 2004
17th and 18th of June 2004
http://www.fieldrobot.nl

20th May, 2004
Wageningen, Netherlands

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Abstract

The Field Robot Event 2004 is hosted by the Farm Technology Group of Wageningen University. It will be the second event following the successful event in 2003. Wageningen University has invited high school and university teams to enter an international open-air field robot contest. The teams will compete with self-constructed robots, navigating and operating autonomously in a maize field. Non-educational organisations were also allowed to enter.
The robot we developed for the event is built upon the chassis of a Tamiya TXT-1 RC car, with four wheel drive and four wheel steering. Modifications that were made to the car include an extra gear box for better handling of lower speeds, and an IR rotation counter for measuring distance and speed. The single motor is driven by a Rooster ESC, which in turn is controlled by a PIC16F84. The PIC16F84 also drives the two steering servo motors, and counts the revolutions made by the IR rotation counter. Eight sonar distance sensors are used for estimating the geometry of the surrounding rows of maize. The sensor data is read and processed by a Basic Stamp II microcontroller from Parallax. The overall 'master' control is done by a second Basic Stamp II microcontroller.
The four wheel steering property of the robot gave us the great advantage of maintaining a steady parallel path through the rows of maize. Another advantage is that the robot is completely forwards and backwards symmetrical. This allows us to manouver the robot from one row to the next without having to turn 180 degrees, and ables the vehicle to drive backwards upon reaching an obstacle or dead end.
The disadvantage of the sensor configuration is that the geometry of the rows of maize can only be estimated for its direct surroundings, and will therefore limit its 'maximum safe speed'. For planning the path across larger distances, we have considered adding a laptop PC with a WebCam. We have already partly development the image processing software, but decided against its use due to limited time, increase in costs and increase in overall robot weight and stabillity.
We are confident that the RSFR-1 robot will be a serious contender.

Keywords

Field robot, autonomous, agriculture, maize, corn, competition, Wageningen University, Wageningen UR, Farm Technology Group, Rockingstone.

Introduction

The science of robotics is finding its way into many fields of application. The Field Robot Event 2004 is hosted by the Farm Technology Group of Wageningen University. It will be the second event following the successful event in 2003. Wageningen University has invited high school and university teams to enter an international open-air field robot contest. The teams will compete with self-constructed robots, navigating and operating autonomously in a maize field. Non-educational organisations were also allowed to enter.

The four main tasks to be performed by the robots are as follows:

1. Navigating between straight corn rows.
2. Navigating between meandering rows.
3. Navigating between straight rows on muddy soil.
4. Freestyle session. Example: recognition of potato plants among the corn.

Rockingstone is mainly an IT company, but also has a Robot electronics shop in the center of Wageningen. Naturally we were therefore excited to particpate in the event. The city of Wageningen is building a reputation of being the *City of Knowledge*, and we would like to do our share to contribute and show our knowledge. Our approach to designing and building the robot is mainly the result of a sequence of experiments and analyzing results. The criteria which has had the most influence on our choice of parts and strategy is:

1. Low cost
2. Reproductivity (off-the-shelf components)
3. Symmetrical design
4. Scientific analysis

The robot is still in development, and still will be after the event. A robot builder's job is never done!

Material and Methods

At Rockingstone Technology Center we have many parts in stock and have the ability to order componont from wholesalers. We could therefore freely choose the desired components (although costs would be a limiting factor). Although the final design would result from research and testing, we did have some wishes and approaches in mind which we would like to see in the final implementation. We thought it would be very advantageous if the robot would be forward and backward symmetrical. This would give the robot the ability to drive backwards as well as forwards along the rows of maize. One of the most difficult tasks of the Field Robot event is the turn-action to enter the next row of maize. A symmetrical design might offer the possibility to eliminate the need for the robot to turn 180 degrees. Although just a thought, we did keep this in mind when choosing the parts and components.

The chassis

The first step in chosing parts was to choose a suitable chassis. We first looked into building the chassis from scratch, but found that the hours that would be spent on it would leave us with too little time on the remaining part of the project. So instead of re-inventing the wheel, so to speak, we decided to purchase an existing chassis. Another advantage of this is the reproductivity of the robot. If the robot had to be duplicated, then off-the-shelf components has to be used where possible. In choosing a suitable chassis (frame, wheels/tracks, engine), the following criteria played an important role:

Property	**Criteria**
Ground clearance	Must be large enough to clear rough and wet terain.
Power	The engine must be powerful enough to handle extra weight.
Manouverability	Must allow for easy steering corrections and turning.
Grip	Wheels must not slip on rough or wet terain.
Dimensions	Not too wide, must be able to move freely within 75 cm.

Possible options for the chassis we looked at were:

- Robot kit
- Remote Control (RC) car

Most available robot kits are for indoor-use only. Many models have small wheels and not much grip or power. We considered the track based platforms which offer a great grip, but we found that it does not offer enough ground clearance and manouverability. We decided against the use of differential steering, so track based platforms were dropped. The problem we had with differential steering was that there were too many steering actions required to correct the path along the rows of maize. During the phase of correction, the robot would not remain parallel to the rows of maize. We found that the ideal steering method was independent front and back wheel steering. This offers the

advantage of being able to remain parallel to the rows of maize, even when corrections need to be made along its path.
RC cars come in many models (RC tanks, buggies, trucks, etc.). Having looked at what is available, the best models seem to be the "Monster Truck" models. The RC Monster Trucks are designed for rough terain, and therefore have a large ground clearance and 4-wheel drive grip. Some also allow 4-wheel steering. Market leader Tamiya has three different Monster Truck models:

- Juggernaut
- Clodbuster
- TXT-1

The Dutch wholesaler had only the "TXT-1" in stock (which did dissapoint us a little because it is the most expensive of the three). We purchased the kit and assembled it. Here are some specifications of the TXT-1:

- 4-wheel drive with differentials on each axis.
- Gear box driven by two standard 540 motors.
- Large wheels (160 mm diameter)

Figure 1: The chassis of the Tamiya TXT-1

The TXT-1 comes with two 540 motors, but without an Electronic Speed Controller (ESC). A standard H-bridge motor driver is insufficient because the motors can draw currents up to 200 A (!). This high current is due to the small amount of wire turns in the motors. RC car motors are designed for high torque and speed, which is only obtained with small numbers of turns in the motors. We purchased a standard ESC from Novak, a model called the "Rooster".
The kit also comes without batteries. We could not do testing without special batteries, as our laboratory voltage supply could not offer the large currents required. We

purchased a RC battery pack especially designed for these types of cars. We considered the use of lead-acid batteries, but these proved to be too heavy, making the vehicle unstable. The battery pack (2000 mAH) would be able to power the vehicle for 20 minutes of continuous driving.
ESCs for RC cars are designed to be controlled by a RC receiver. The control signal is a 1 KHz PWM (Pulse Width Modulation) signal. In the field of hobby robotics, control signals for servo motors are also PWM signals, except that they operate at 50 Hz. We wanted to operate the ESC with the standard 50 Hz PWM signal, but had to do some testing to see whether the ESC would respond to this signal. The ESC would not react if the internal circuitry had a high-pass filter allowing only high frequency PWM signals. Luckily our tests showed that the ESC responds well to the 50 Hz PWM signal. To prevent any so-called "jittering" and "singing" of the motors, we attached three capacitors to each motor.

The kit also comes without steering servo motors. The steering servos needed to be high-torque servos due to the large contact space of the wheels with the ground. We purchased two high torque servo motors so that the vehicle would have independent front and back steering capabilities. This property kept the design within our preliminary wish to keep the vehicle forward and backward symmetrical.

The sensors

Choosing the right sensors is probably the most important part of the project. They form the 'eyes' of the system and is necessary to navigate through the rows of maize. The ideal sensor would be one which would give real-time accurate distance measurements to the all objects along its path. For guiding the robot along the middle of the path between the rows of maize, idealy it would be required that the robot stays at equal distance from either side of the robot to the maize, both at the front end and back end. To determine the distance from the maize and to determine the angle of the robot to the center line of path, at least two sensors on each side of the robot are needed. We considered the use of several different kinds of sensors, as listed below. Each of the sensors were tested (except the mechanical whiskers) and discussed in the following paragraphs.

Sensor	**Type tested**
Mechanical whiskers	none
Infra-red distance sensors	Sharp GP2D12 IR Sensor
Ultra-sonic distance sensors	Devantec SRF-04
CCD camera	Phillips Vesta webcam

<u>Mechanical whiskers</u>
The mechanical whiskers is the most primitive kind of sensor which make electrical contact when an obstacle is detected. The mechanical whisker can be reliable at detecting a solid object, but has the disadvantage of not being able to judge variable distance and the whiskers can get stuck amongst the maize. We did not perform any tests.

Infra-red distance sensor
The infra-red (IR) distance sensor is quite reliable and cheap and its signal is inversely squared proportional to the distance of the detected object. The signal strength / distance function is a parabola, and is therefore most sensitive for objects at close distance. The advised operation range is between 10 cm and 80 cm. The great advantage of the IR sensor is that it continuously supplies an analogue signal, and reacts almost instantaneously to surrounding objects.

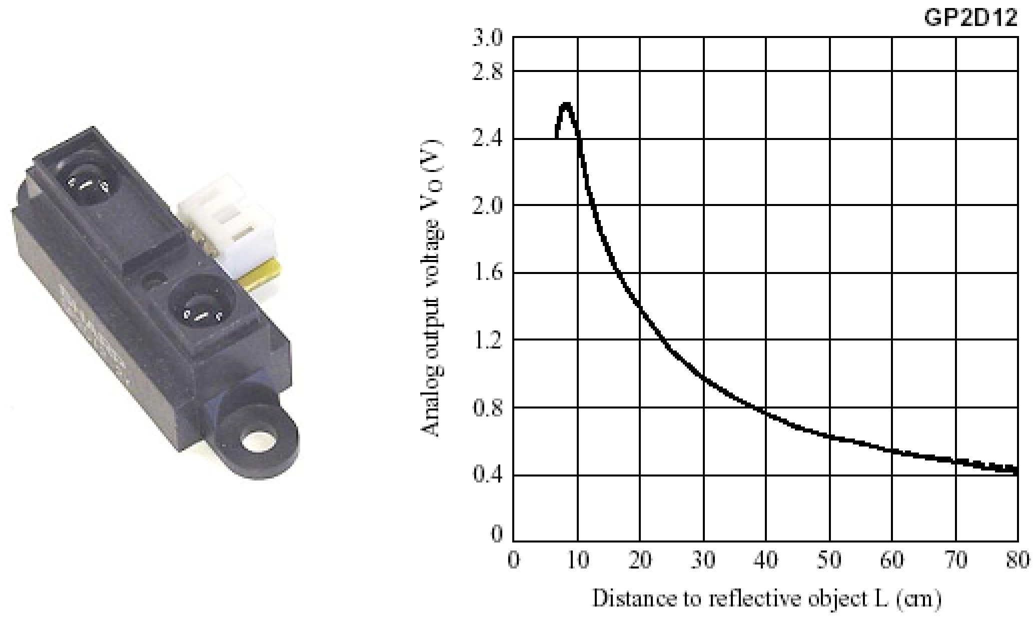


Figure 2: The Sharp GP2D12 IR Sensor and a graph of its output voltage against distance.

The disadvantage of the IR sensor is that its signal strength is also a function of the reflectivity of the detected object. The graph shown in figure 2 is the result using white paper. For a darker object the graph would be lower along the y-axis. An object with high reflectivity is detected closer than an object with low reflectivity, even when the objects are actually at the same distance. We found that plant and leaf surfaces have varying reflectivity, and it is therefore difficult to judge the exact distance. Another property of the IR sensor is that it has a narrow detection angle. When using this sensor to detect rows of maize, the signal strength will alternate whilst passing maize stems and "gaps". The advantage of this is that it is good at determining the presence of the wall of maize and the end of the row. When reaching the end of the row, the control system can conclude whether the end of the row is reached as no stems are detected anymore within a set distance. The disadvantage is that when detecting gaps, there is at that moment no measurement of the distance to the maize. Another disadvantage is that the distance measurement is not very accurate and it is therefore not possible to determine the exact geometry and orientation of the surrounding objects. Determining steering corrections will therefore be rough approximations.

Ultra-sonic distance sensor
The distance sensor from Devantec is a low-cost ultra-sonic sensor, although it is more expensive than the IR sensor. The measurement made by the sensor is triggered by sending a short pulse to its input connection. The output signal is a TTL level pulse where its width is linearly proportional to the distance of the detected object. Actually, measurements show that the length of the output pulse is equal to the speed of sound in air multiplied by twice the distance to the detected object. Its operational range is between 3 cm and 3 m, and is capable of detecting a 3 cm diameter stick at 2 m.
The disadvantage of the module is that the distance measurement is not continuous. In practise, reliable sampling can be done up to 10 times per second. The sensor is reliable in most cases, except in some cases when a flat surface is placed in front where its reflective angle causes the sonic beam to direct away from the sensor. For objects such as plant stems and leaves the sensor proves to be very reliable. Its operational beam is much wider than the IR sensor, detecting objects within an average of 30-40 degrees of its normal.

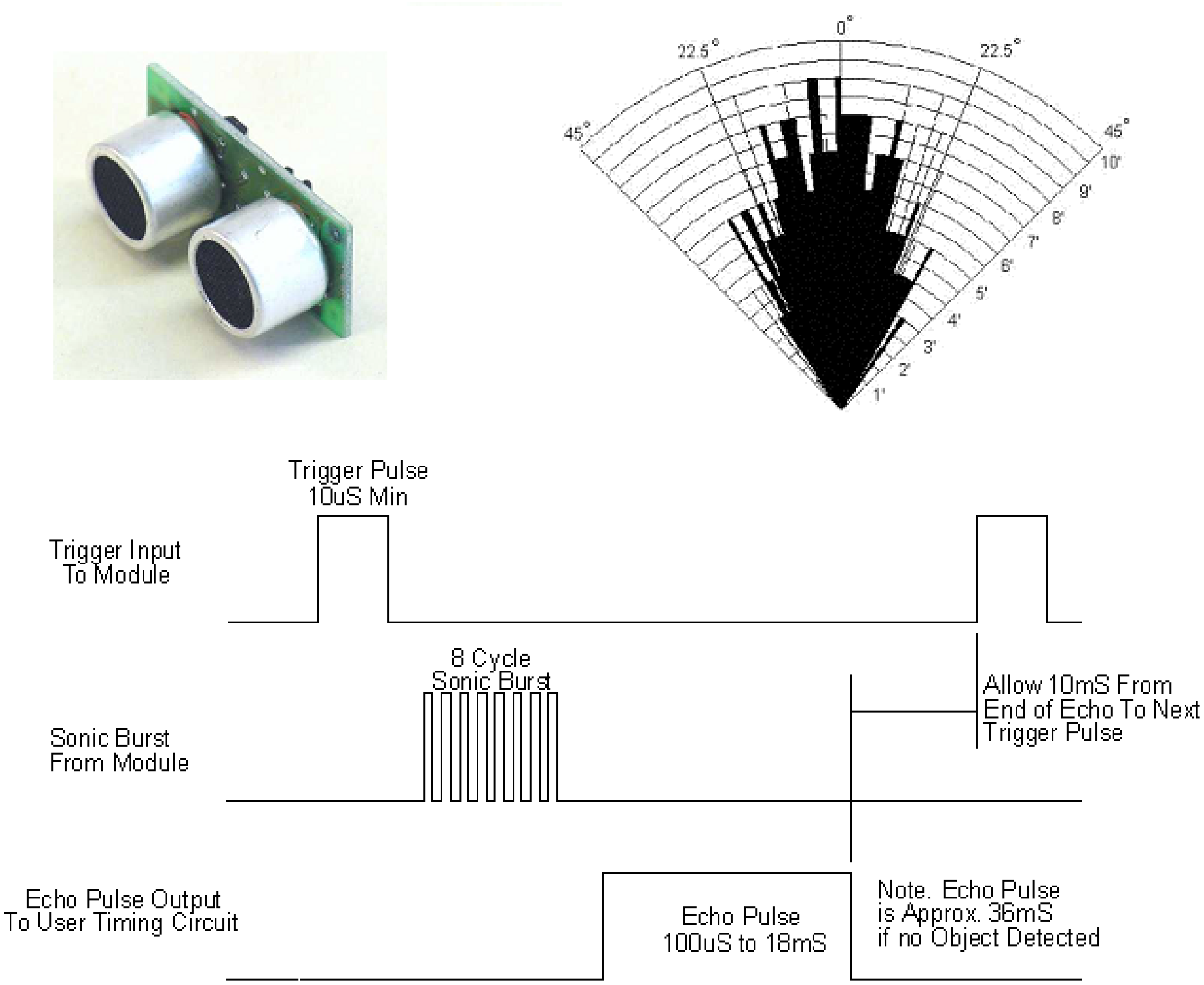


Figure 3: The Devantec SRF-04, its beam pattern (in dB's), and the timing diagram.

The sensor returns the distance to the closest object within its beam. The gaps between the maize will therefore not be detected, but it does offer a distance measurement at all times.

CCD Camera
The CCD Camera is the most advanced sensor we considered. For testing we used a colour Philips Vesta USB webcam with a CCD resolution of 640x480 pixels. To stay true to our original idea of forward and backward symmetry, we used two mirrors to place above the vertically oriented camera (see figure 4). The resulting image as seen by the camera are in effect two images. The top half of the image shows the "forward" vision, and the bottom half of the image is an upside-down version of the "backward" vision. This had the advantage of being able to 'see' forwards as well as backwards at the same time, therefore being able to make accurate estimations of surrounding geometry, even when at the end of a row, and also when travelling backwards. We also considered using another alternative method by placing a mirrored cone above the camera, so that it could have 360 degree vision. Preliminary tests showed however that there was very little resolution left in the transformed image, therefore leaving it difficult to perform reliable image processing.

Figure 4: Two-way vision by placing two mirrors above a vertically aligned webcam.

To determine actual locations of objects using one webcam is only possible using a technique called "odometry". Odometry is based on the principle of faster 'moving' objects being closer to the camera than slow 'moving' objects. Odometry is not really required in this project, because it is sufficient to determine the deviation from the angle of the desired path. This can be done by following the line of the rows of maize. Distinguishing the maize from the ground can be done in several ways. The obvious way is to detect the green colour of the maize plants. Another method would be to detect variations in contrast. We developed a test program in Delphi, using Video for Windows to capture the webcam frames. The resulting application generates a set of output parameters in real-time. The output parameters include left distance from row, right distance from row, and angle from center path. This information can easily be translated into steering-correction commands. The webcam has a great advantage over all the other tested sensors because it can determine the "road ahead". The application can be extended with a "path planner", which continuously compares expected data with actual data. This ables the robot to be able to move faster without unexpectedly crashing into meandering rows. Although this seemed to be the perfect solution to use as a sensor, we did see some disadvantages. The main disadvantage is the requirement of a laptop

computer to process the images. This would be disadvantageous in terms of cost as well as the additional weight to the vehicle. This could be solved by using a PDA Pocket PC with a built-in webcam, but we decided against its use because we would not be able to learn its development environment in time for the event. Another disadvantage we came across is that webcam images become blurred when tracking movement. This was only partially solved when we increased the 'shutter speed' of the webcam.
Another advantage of using the CCD camera is its use for the freestyle event. A proposed task is to distinguish potato plants from maize plants. This can only be done reliably using a CCD camera and image processing software.

Sensors - Conclusion

We finally decided to use the ultra-sonic distance sensors. One of the main reasons we chose these sensors is because we were able to obtain a large collection of these sensors at a relatively low cost. We will however continue the development of the CCD camera method with its image processing software, and probably use this for next year's Field Robot event in 2005. We do therefore recognize that the CCD camera is the best sensor, but we also find it a challenge to "do the best we can" using only ultra-sonic distance sensors. We decided to use eight sonar sensors, two sensors on each of the four sides of the robot. This would be sufficient to determine the surrounding geometry of the surrounding rows of maize.

The controller

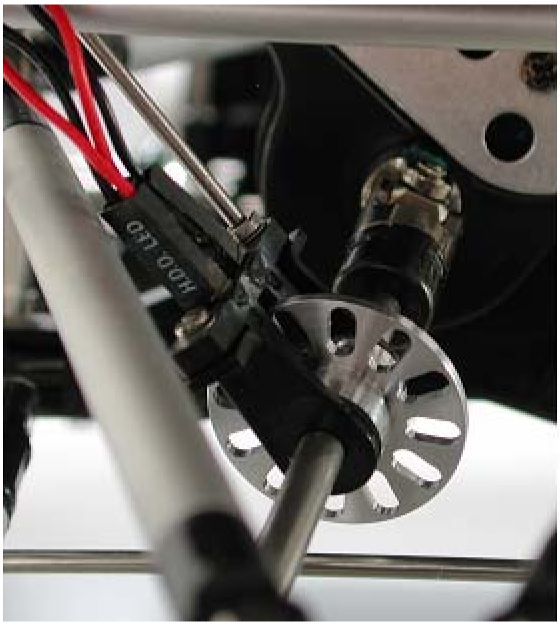
The most popular low-level controller in the field of hobby and educational robotics is the Basic Stamp II from Parallax. Although it has proven itself as a developer-friendly device, there are many other similar controllers which are cheaper and offer more technical advantages. BasicAtom, OOPic and 8052 microcontrollers are just some of the examples. We were able to obtain a collection of Basic Stamp II chips at a relatively low cost, so we decided to use this for our robot.
The Basic Stamp is not very useful as a servo controller because it is has no multi-tasking capabilities. An external servo controller will have to be used for driving the steering servos and the ESC. The Basic Stamp is very useful for processing the sensor data. As there are eight sensors to process, there is little process time left for updating steering commands. We therefore decided to use two Basic Stamps, one for low-level sensor processing, and one for high-level control. Inter-communication is done via serial communication.
Our first experience with the Basic Stamp was with the ARobot from Arrick Robotics. It is a very simple rover robot, but has a very flexible controller board holding a Basic Stamp and a PIC controller. The PIC controller was pre-programmed as a servo controller, and could be operated from the Basic Stamp. As this robot was not used anymore, we decided to use this controller board for the high-level control. For the low-level processing we assembled a next-step kit from Lynxmotion to hold the Basic Stamp.

We did consider the use of a small laptop, as this offered much greater memory and processor speed. We decided against its use because of the additional costs. Basic Stamp chips have very little programming memory, so this posed us with another challenge - to cram as much intelligence into the small programming space.

Implementation - Assembly of parts

During early stages of the implementation of our robot, we found it very disadvantageous that the twin motor configuration drew so much current. Although the specification stated that the vehicle would run 20 minutes on a 2000 mAH battery pack, in practice the figure is closer to 10 minutes. The TXT-1 is designed for speed and all-terain racing, which is nice for RC enthusiasts, but not necessary for the Field Robot event. Tatja van Vark, an instrument maker, helped us out a great deal by modifying the configuration. An extra 3.5 gear reduction was built in, which eliminated the need of two motors. The extra gears are very precise custom-made hand-crafted gears (see figure 5). With a single charge of the battery pack, and now using just one motor, the vehicle now runs over 30 minutes and is still capable of driving over 20 km/hour.

Tatja van Vark also helped us out by building a very ingeneous rotation counter which is applied to one of the driving shafts (see figure 5). The signals from the rotation counter is processed by the PIC on the main controller board.



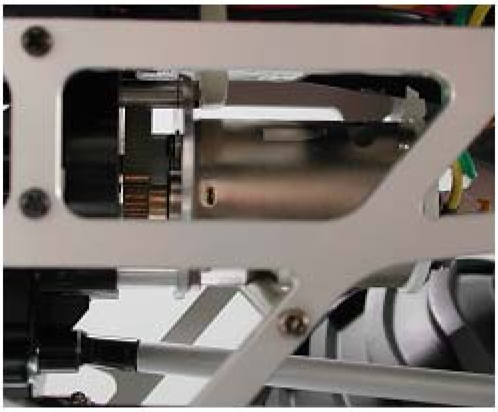


Figure 5: Mechanical modifications; The IR rotation counter and the extra gear box.

The casing that was built on top of the robot was initially meant as a prototype. As it ended up being a quite a suitable attractive casing, we decided upon keeping the case as it is. The only draw back of the prototype casing was that the sensors were placed at a height of 30 cm from the ground. Although the plants were expected to be 40 cm high on the actual event, we did not want to take any chances, so we had to lower the sensors by attaching external sensor holders.

Implementation - Programming

We spent a lot of time implementing the software for both Basic Stamps. For reference, we named the Basic Stamps "BS-A" and "BS-B". BS-A is the Basic Stamp that serves the high-level control, and BS-B is the Basic Stamp that processes the sensor data. BS-

B is responsible for triggering the sonar modules and reading its output pulses. The sonars are triggered one-by-one. This cannot be done too fast in succession, as this results in sensors receiving sonar echoes from other sonar modules. We therefore programmed it in such a way that the order in which the sonar modules are triggered is such that the successive sonar modules are those far apart from each other. For example: first the front left sensor is triggered, then the right back sensor is triggered, and so on. At first, all eight sensors were used, regardless of whether the vehicle is moving forwards or backwards. It is however unnecessary to detect object behind the vehicle when moving forwards. We optimized this by letting the BS-B use only the six relevant sensors depending on whether the robot is travelling forwards or backwards. This is controlled by an extra signal between BS-A and BS-B. BS-A is the main controller, so it tells the BS-B whether the robot is travelling forwards or backwards. We further found that the BS-A should not perform unnecessary measurements when the robot is stationary, or idle. So we added yet another signal between the two modules called the "sonar-enable" signal. This signal is also controlled by BS-A.

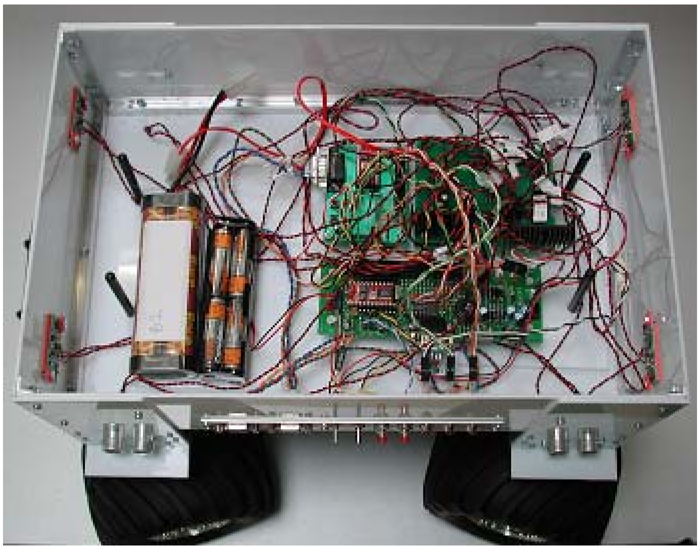


Figure 6: The inside of the RSFR-1, a jungle of wires.

We found that the BS-B module still had enough time and programming space to perform other tasks. We therefore extended its function by letting it calculate steering and speed advice. So instead of sending the measured distances to the BS-A, it sends complete advice to the main controller. The eventual result is that on average the BS-B module performs 5 complete cycles per second. During each cycle the module fetches distance values from all six sensors, calculates advice, and sends the advice through a serial connection to the main BS-A module. Testing showed that this rate was fast enough to react to unexpected meandering in the rows. Although BS-A is the main module, the actual 'intelligence' lies in BS-B. BS-B determines the location of the robot between the rows of maize by calculating the angle that the left and right rows have with the robot. It uses these results to determine both front and back steering corrections that are required to keep the robot in the center of the path. It also calculates the "safe-speed" value. When the robot needs a large steering correction, the robot will need to travel slow. When the robot is already centered and parallel with the rows, then the robot may travel faster. BS-B also determines whether the robot has travelled out of the maize field, which is vital information for deciding when to move on to the next row. In short, BS-B sends these following parameters to BS-A:

1: front steering correction
2. back steering correction
3. maximum speed
4. status ("all ok", "no rows detected", "front obstacle detected")

We found that the sensors sometimes make momentary 'faulty' measurements, as it sometimes detects a close object and sometimes 'misses' it. This can be seen using an oscilloscope connected to the echo signal. A small object close to the sensor sometimes causes the signal to fluctuate between the close object and its background. We solved this by having the module choose the closest distance measured of the last two measurements. This eliminated the fluctuations to such an extent that the problem was solved.

Figure 7: Measuring sonar response with an Oscilloscope

The BS-A module is programmed to translate the parameters received from BS-B into actual commands to the steering servos and the ESC. The BS-A module is also responsible for processing the input commands from the external buttons and switches, located on the casing of the robot. Thirdly, it also receives counter values generated from the IR rotation counter. One of the main shortcomings of the Basic Stamp is that it does not have an internal clock, so the BS-A is capable of measuring distance travelled, but is not capable of reliably measuring the speed of the robot. A method would be to use the internal "WAIT" command and see how many counts have been detected by the rotation counter. This however proved not very practical because the BS-A would not be able to make steering corrections during this period. However, the rotation sensor does prove its value during the phase of "changing lanes". During this phase a two-turn manouver needs to be performed, each with a set amount of distance.

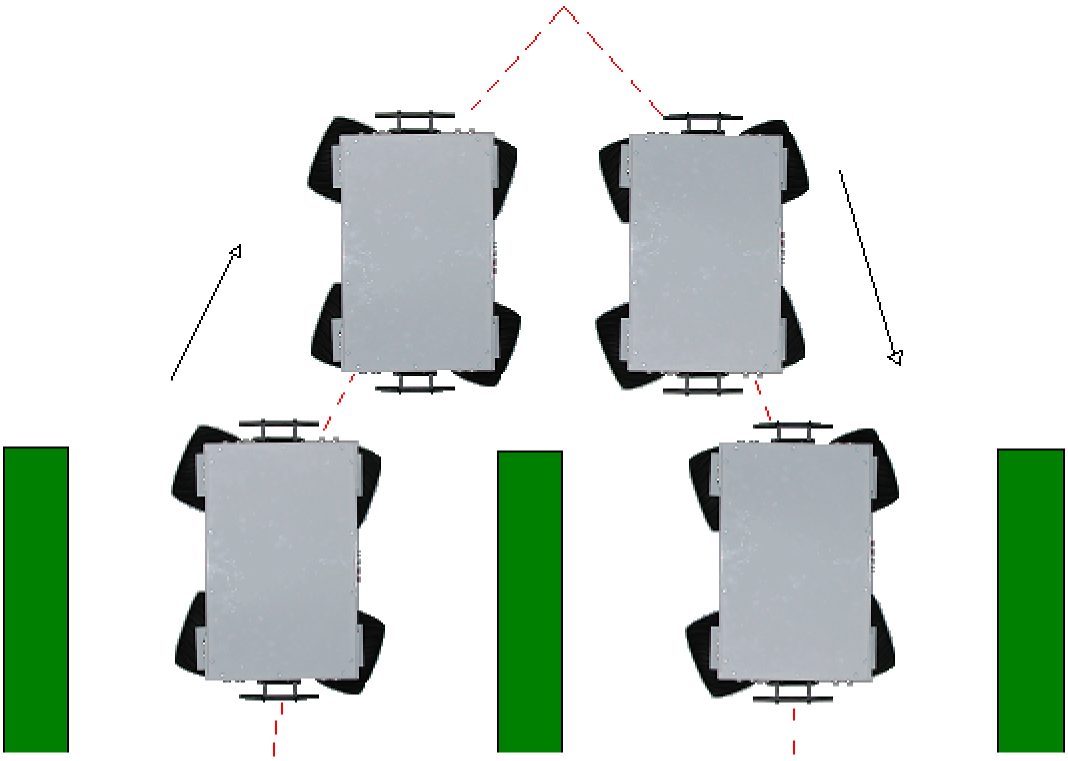


Figure 8: Changing lanes without turning 180 degrees

The changing lanes is done without actually turning 180 degrees (see figure 7), so the robot enters the second lane going backwards. At this moment the BS-A instructs the BS-B module to use the back sensors instead of the front. Its internal calculations are then executed in such a way that steering is correctly oriented.

Results and Discussion

The finalized robot has been tested several times in different conditions. Most of the testing has been done using man-made paper plants to serve as the rows of maize (see figure 8). The robot seems to react well to the rows, visibly making steering corrections. A pleasing result was the way in which the robot uses front and back steering independently from each other. When approaching the rows at an angle, front steering would guide the robot to the center of the path, while the back steering would align the robot parallel with the rows of maize.

Figure 9: Testing the RSFR-1.

It sometimes makes a wrong steering correction due to faulty measurement, but this is corrected immediately with the successive measurement. Some of the testing still left to do is the procedure of changing lanes. The changing lanes works well on the surface we have been testing on, but it might be different when driving on actual soil. We are not making use of the sensors when making the turn, so there is no feedback to see whether the turn is being correctly executed. We are purely relying on steering and moving according to a fixed algorithm. We hope to have enough time before the event to solve this. We think a digital compass will solve our problem. We have ordered the digital compass (Type CMPS03) and hope to have it in time for the event. We have reserved a little more room in the programming space to make this possible. At the moment each Basic Stamp module is 90% full of programming space.

Conclusions

We are pleased with the final resulting robot, now named the RSFR-1 ("RockingStone Field Robot"). It proves itself to be a flexible robot, because it can easily be adapted for environments other than rows of maize. The principle of the robot remains simple, and the costs have remained quite low. Although having attempted to use only off-the-shelf components, we did break the rule by having mechanical modifications made to the chassis. The way our robot distinguishes itself from other competitors is, as far as we know, that the robot is fully symmetrical. It can therefore just as easily travel backwards through the rows of maize as traveling forwards. Personally we believe the competitors who make use of a webcam have the greatest advantage, so next year we will make use of the webcam. The webcam will be used as described in this document, being able to look forward and backward simultaneously. In any case, we do believe that the current RSFR-1 is a serious competitor.

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Tamiya	http://www.tamiya.nl
Tatja van Vark	http://www.tatjavanvark.nl

Acknowledgements

We thank the organisation of the Field Robot event for making this all possible. We hope the public interest into this event will continue to grow in the years to come. We especially thank Tatja van Vark who helped us out with the mechanical modifications.

Glossary

CCD	Charged Couled Device
ESC	Electronic Speed Controller
IR	Infra Red
PIC	Programmable Integrated Circuit
PWM	Pulse Width Modulation
TTL	Transistor-Transistor-Logic

Up and down a field of corn with a toy truck, a webcam and a laptop computer (and a lot of duct tape)

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Abstract

The majority of the robots competing in the 2003 Field Robot Event were guided by infrared or ultrasonic sensing of the distance to the rows of corn immediately to the left and to the right of the robot. These robots were sometimes fooled by a gap in one of the rows, or by a few leaves extending into the row. But missing plants and other irregularities do not disturb the row structure that presents itself to a human who observes the scene from a height of 1.5 or 2 m. The objective of our work was to create a sub-canopy vehicle able to navigate past gaps in the row using information contained in images taken from above the crop. The basis of our robot is an R/C toy truck, to which we added a mast that carries a colour webcam at a height of approx. 1 m. Images are processed by a 1.8 GHz Pentium 4 laptop computer. The thresholded green chromaticity image shows the crop plants. The crop rows are found with a fast algorithm inspired by the Hough transform. We steer toward a point between the two rows of crop at a fixed distance in front of the robot. The steering signal is proportional to the distance between this point and the middle of the image. We achieve processing rates of 10 fps. In field tests in 15 cm corn, our robot was consistently able to cross the entire 200 m field at a speed of approx. 1 m/s without errors. Turns are made using dead-reckoning.

Introduction

Robots may well be the next big agricultural innovation. Precision farming may benefit from the availability of robots that scout continuously for weeds, pests, volunteer plants, or nutrient deficiency - and take action whenever they find the condition they are looking for. Site-specific weed control (Gerhards and Christensen, 2003) is one area where robots may soon be able to help out.

Some research on fully autonomous robots for use in agriculture focuses on automating full-size existing equipment (Torrie et al., 2002; Pilarski et al, 2002; Blackmore et al., 2002). Tillett et al. (1998), among others, have modified smaller equipment. But the spector of a large, powerful tractor going out of control has given rise to the idea of building small, sub-canopy robots with much less capacity to do damage. In 2003, a Field Robot Event was organized in Wageningen in which a number of small robots competed with the aim of navigating through a corn field quickly and without damaging the crop (Van Straten, 2004).

The majority of the robots competing in the 2003 Field Robot Event were guided by infrared sensing of the distance to the rows of corn immediately to the left and to the right of the robot. These robots were sometimes fooled by a gap in one of the rows, or by a few leaves extending into the row. Also, the placement of the sensors close to the soil and the crop caused them to suffer from accumulation of dust and mud and hence performance degradation (Van Straten, 2004).

When observed from sufficient height, the row structure is easily discerned even when plants are missing or when weeds are present, and a sensor placed at some distance from the crop is less likely to collect dust and mud. The objective of our work was to create a sub-canopy vehicle able to navigate past gaps in the row using information contained in images taken from above the crop. While there is ample experience with vision-guided vehicles, both non-agricultural (Sotelo et al., 2004; Urmson et al., 2004) and agricultural (Han et al, 2004; Åstrand and Baerveldt, 2002; Pilarski et al., 2002; Tillett et al., 1998; Marchant and Brivot, 1995), we are not aware of a small (sub-canopy), agricultural robot that is guided solely by vision.

Materials and methods

An observer placed high above a crop field can easily recognize the row structure in a corn field. An image taken with a camera on a mobile robot, however, may show much less information because the height of the camera is limited by the stability of the platform it is mounted on. In the case of a sub-canopy vehicle the height of the camera can be expected to be a severe constraint, although, to some extent, this limitation can be overcome by using a wide-angle camera. We constructed a 3-D, OpenGL-based simulation model to determine the information content of images taken from a range of heights, using a range of different values for the camera's field of view, azimuth and elevation. This exercise showed that the minimum mounting height for the camera would have to be 0.75 m, with a minimum field of view of 60˚.

Hardware

Based on the above, we selected as the basis for our robot a Tamiya TXT-1 R/C 4WD monster truck (Tamiya Inc., Shizuoka City, Japan). This toy weighs approx. 5 kg, at a width of 37 cm and a length of 50 cm, with wheels that measure 16 cm ø by 15 cm. We modified this truck as follows. The mechanical speed control was replaced by an electronic speed control (Tamiya TEU-302BK). Torque at low speed was increased by replacing the original 15-tooth pinion gears with 11-tooth gears (Carson Modellsport, Fürth, Germany). The (hollow) tires were made firmer with foam inserts. We installed high-torque steering servos (12.7 kg.cm @ 6 V, Jamara, Germany). We stiffened the suspension by decreasing the travel of the springs. We installed a ring of magnets on the main axle which trigger a Reed relais to measure driving distance.

The robot is fitted with a mast which carries a Creative Ultra NX webcam with a 75˚ field of view at a height of 1 m (Creative, Singapore) and an electronic compass CMPS03 (Devantech Ltd, Diss, Norfolk, UK) at the top. The compass is connected through an I2C interface to a BASIC Stamp BSp2 (Parallax, Inc., Rocklin, CA, USA) microcontroller; this microcontroller also reads the pulses from the Reed relais. Main control is provided by a 1.8 GHz Pentium 4 laptop computer carried on board. This computer controls the speed controller and the steering servos via a serial port and a MiniSSC II (Parallax, Inc., Rocklin, CA, USA); receives revolution pulses and compass heading from the Stamp microcontroller; and grabs images from the webcam.

Image processing

Full-colour, RGB images are grabbed at 320x240 pixels (Fig. 1). In our current setup, images show a ground area from just in front of the vehicle to 2 m away from it; the width of this area is almost 1.5 m at the bottom of the image. We take a section of this image for processing and resample to increase processing speed. We operate under the assumption that weeds are negligible and use green chromaticity (2G-R-B) to detect the presence of crop material. The histogram of the green chromaticity is unimodal with a peak (at low intensity) that corresponds to the background. We therefore take the 5% brightest pixels (with a minimum brightness value) to represent crop material (Fig. 2). We detect crop rows with an algorithm inspired by the Hough transform (Hough, 1962). This algorithm draws lines that start at the top of the image and angle down between -45 and +45°. The algorithm counts the number of crop pixels on each line. The counts become pixel values in an image where the coordinates represent angle and x-value at the top (the "Hough" space, Fig. 3). In this image, we select all pixels that have a value which is larger than 70% of the value of the brightest pixel and that is larger than a minimum value. This yields the image in Fig. 4, in which two clusters of pixels can be seen. We use dilation to join neighbouring pixels into blobs and then use a blob-finding algorithm to determine their center points. These center points give angle and starting position of lines that cover mostly green material. We divide these lines into two groups: lines that pass, at the bottom of the image, to the left of the robot and lines that pass to the right of the robot. Of the lines to the left, we select the right-most one; of the lines to the right, we select the left-most one. The middle of these two lines, at the top of the image, is the point at which we steer the robot. The signal that is sent to the steering servos is proportional to the distance between this point and the middle of the image. If only one line is detected, we steer just to the left (or the right) of the one line.

Turning

When no crop rows are detected in several successive images, it is assumed that the end of the row has been reached. The turning radius of our robot is too large to turn directly from one row into the next, so we turn by dead-reckoning and reverse a pre-programmed distance halfway through the turn. The half-way point of the turn is determined either by distance travelled, or by compass.

Software

High-level control is performed by a state machine written in Delphi (Borland Inc., Scotts Valley, CA, USA). Images are grabbed using DSPack components (www.progdigy.com/). Most image processing is done in C++ using the VXL image processing library (vxl.sourceforge.net). A three-line BASIC program controls the microcontroller.

Figure 1. View as seen by the robot

Figure 2. The thresholded green chromaticity image reveals the location of crop plants

Figure 3. Hough-space. Horizontal coordinate denotes the point at which a line crosses the top of the image in Fig. 2; vertical coordinate denotes the angle of the line; brightness denotes the number of white (crop) pixels on the line.

Figure 4. Thresholded Hough-space diagram

Figure 5. Hough-space diagram after

Results

Most of the development was done on a lawn on which red/white tape was laid out to simulate rows of plants (we used brightness of the image instead of green chromaticity). In this setting the robot travels accurately at speeds of up to 1 m/s. Due to the elevated placement of the camera, pitch and roll of the vehicle do affect the view from the robot considerably, but this doesn't seem to affect the accuracy of the steering signal generated, probably because the position of the camera relative to the robot is fixed. The robustness of the system is demonstrated by the fact that the robot is not thrown off course when it has to drive over a foot or a large stick placed in its path.

We have made many runs in which the robot crossed an entire 200-m long field of corn without damaging any plants. Plant height increased from about 15 cm at the time of the earliest tests to about 50 cm at the 2004 Field Robot Event.

Executing a turn at the end of a row is more difficult than driving through straight or meandering rows. We turn by dead-reckoning and it appears that turns to the left are executed flawlessly, while turns to the right are much less reliable.

Discussion

Navigating a sub-canopy vehicle using above-canopy images has been shown to work in corn fields with plants varying in height from 15 to 50 cm but the stability of the vehicle is a point of concern. The useful information contained in the images taken increases with the height of the camera, but at the same time pitching and rolling affect the image more. Our system could be improved by using a more stable (heavier) vehicle, a lighter mast and camera, a camera with a larger field of view, or even by stabilizing the camera. Marchant and Brivot (1995) report good results using a camera mounted at a height of 120 cm, but their platform was larger and more stable than our robot. Other improvements are possible. Marchant and Brivot (1995) integrate information from several crop rows into one estimate of vehicle position and heading, while we detect crop rows separately. Their approach was implemented using special hardware, while we use off-the-shelf components. Han et al. (2004) calculate a threshold to distinguish between crop and background pixels. This makes their method less dependent on the particulars of the scenery, but it would have increased the computational load beyond what our laptop could handle. With regard to turning, we have discovered a mechanical asymmetry which explains the fact that turns to the right are less reliable.

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