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.

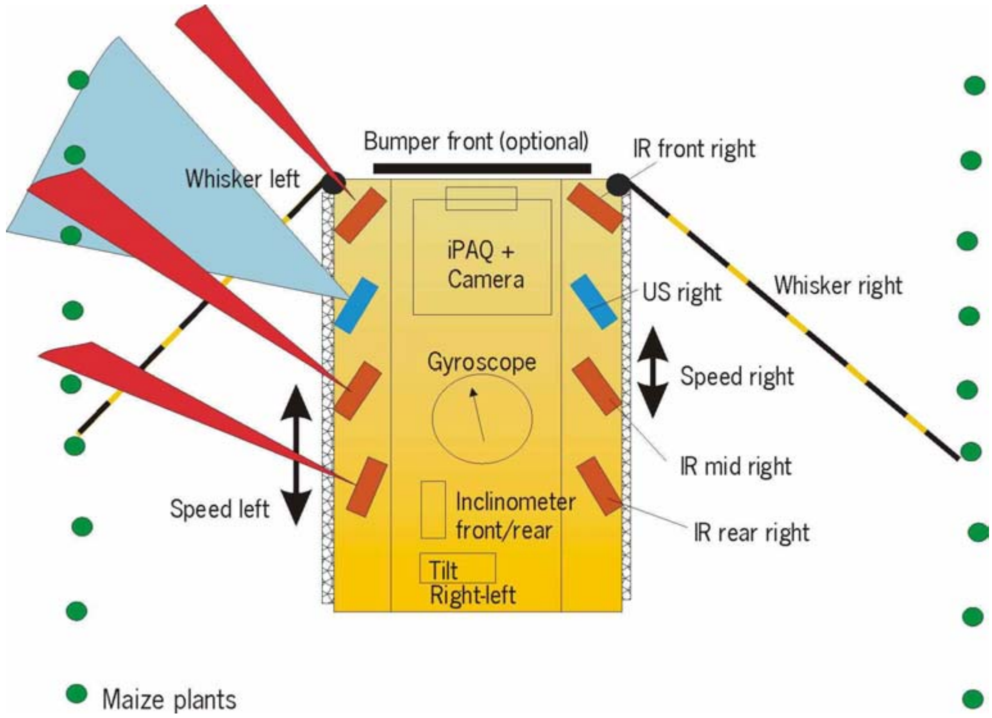


Figure 2. Sensors on Cropscout.

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.

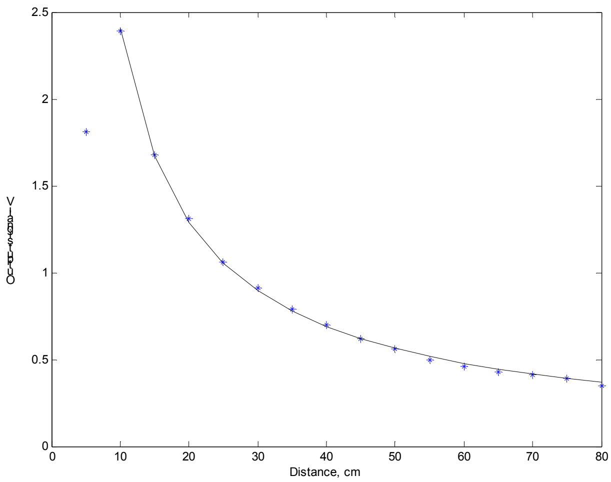
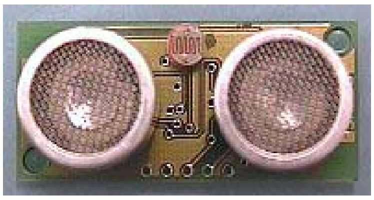


Figure 4. Output signal of the Sharp GP2D12 range sensor as a function of distance.

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.



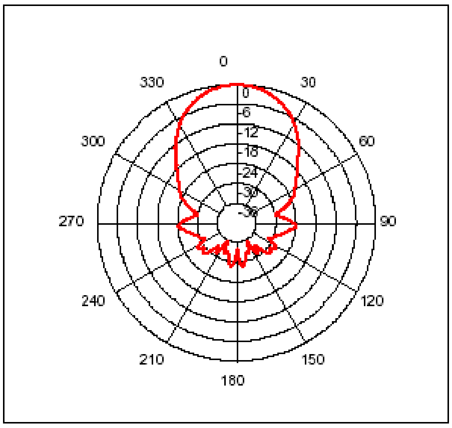


Figure 5. The Devantech SRF08 ultrasound range sensor (left) and its radiation pattern (right).

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).

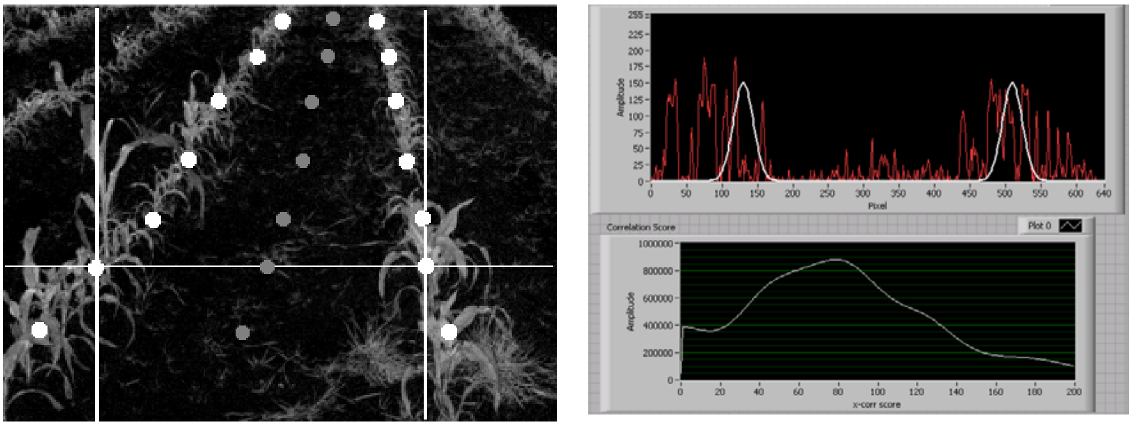


Figure 7. Segmented image with result of row detection on seven lines of the image (left), the Gaussion bell-shaped curve on top of one image line (top right) and the result of the cross correlation (bottom right).

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.

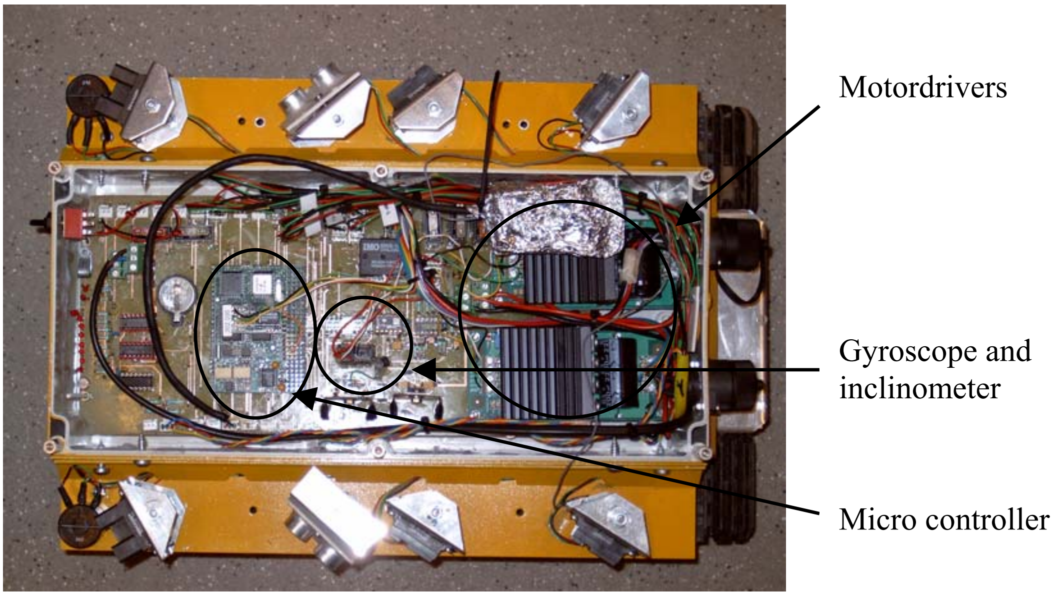


Figure 8. The interior of Cropscout.

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.

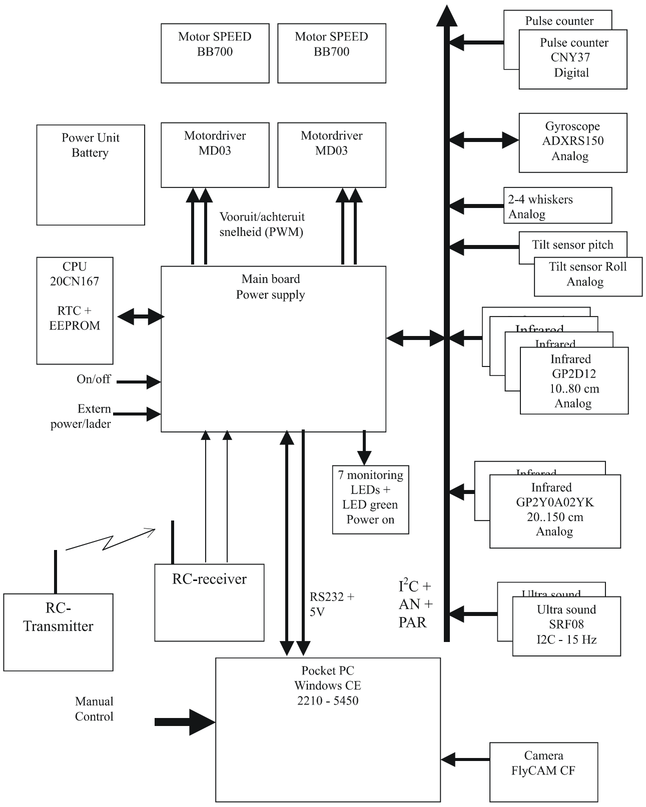


Figure 9. Schematic diagram of the electronic hardware of Cropscout.

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.

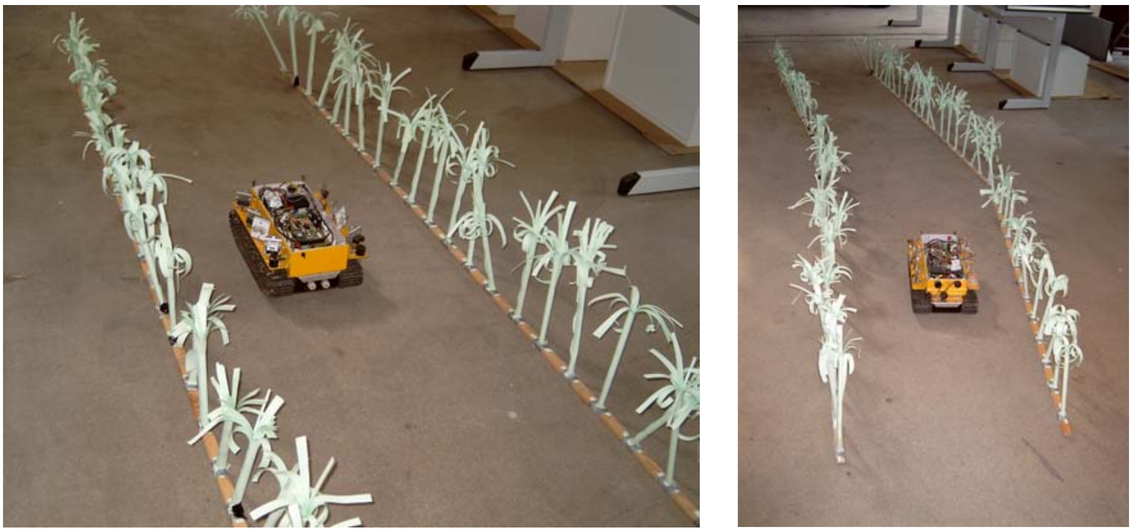


Figure 10. Cropscout between the artificial maize plants.

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.

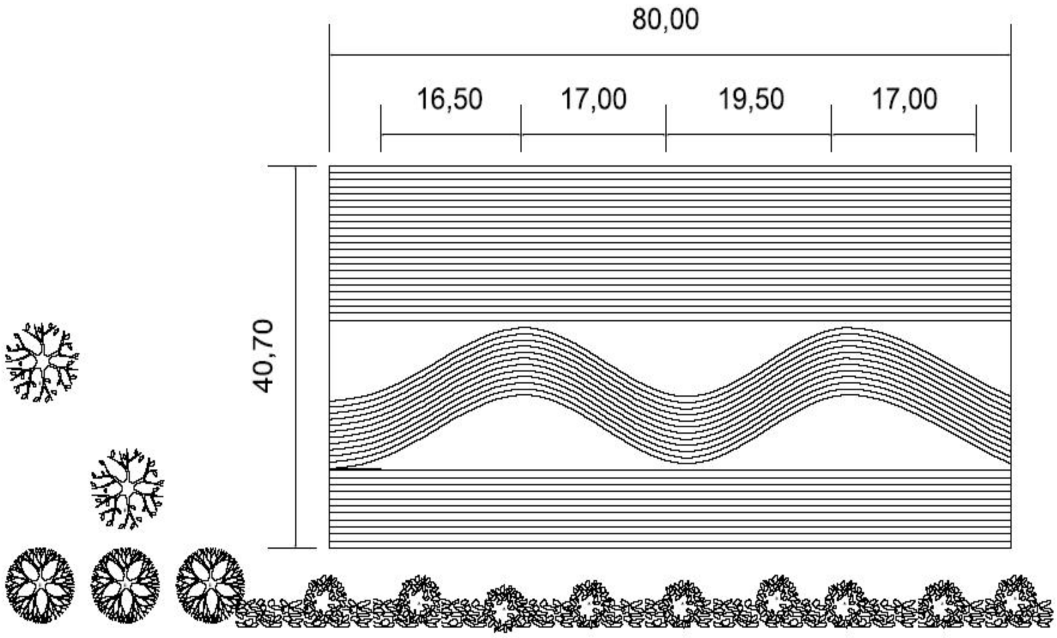
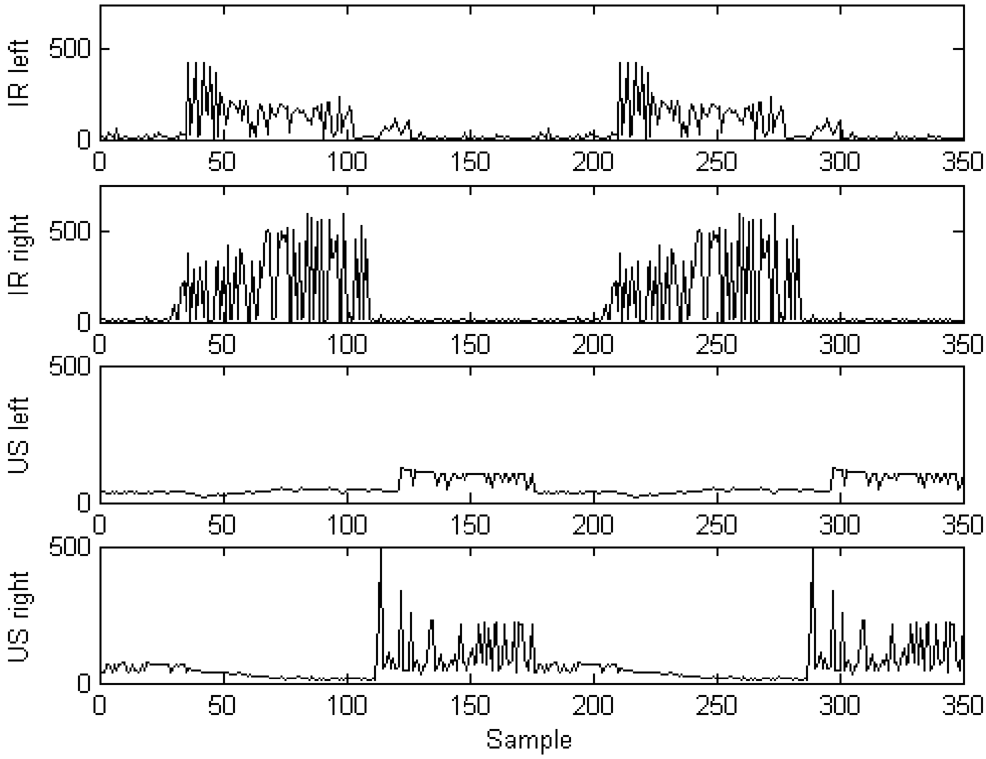


Figure 11. Straight and curved test tracks on a maize field during the 2004 Field Robot Event, Wageningen, The Netherlands (drawing by courtesy of FRE organisation 2004)

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.



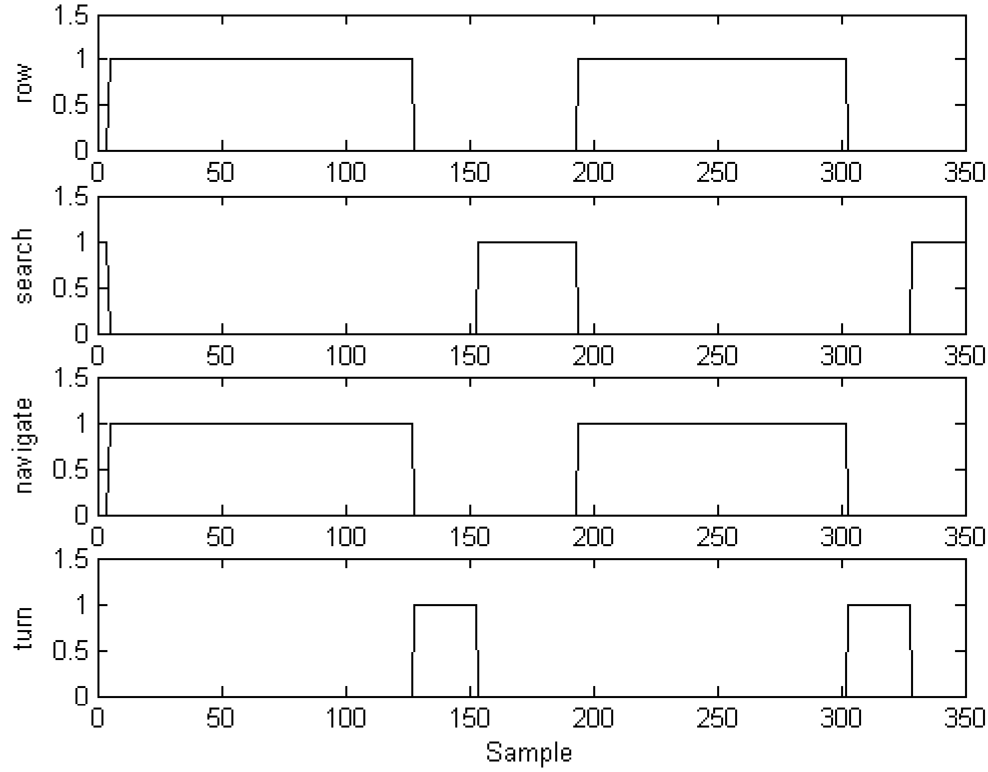


Figure 12. Test of the row detection and mode switching algorithm using data obtained on the artificial test track (the top four figures show the measured sensor data, the bottom four figures present the row detection and status of search modus, navigation modus and turn modus of the control algorithm.

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.

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