Cropscout II, a modular mini field robot for precision agriculture

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Abstract

In this paper a small agricultural robot named Cropscout II is described. Besides the objective to participate in the annual Field Robot Event competition Cropscout II operates as a modular test bed for autonomous robot control using sensor fusion techniques and artificial intelligence. The main challenge in this aspect is to cope with the poorly structured environment and the variation in shape, size and color of biological objects encountered in the open field. The very flexible and modular design of the system in both the electrical and mechanical way proofed to have many advantages. Unless some of the tasks to complete were solved very well the final conclusion is that it is still a big challenge to build a robot for the wide variety of different and unpredictable outdoor conditions. Future research on all aspects is essential.

Keywords

autonomous robot, field robot, navigation, agriculture, computer vision, maize, sensor fusion

1. Introduction

Cropscout II is the successor of the award winning Cropscout I (Henten *et al.* 2004), a smallscale experimental platform for research on sensors for precision agriculture. One the one hand Cropscout II was built to participate in the annual Field Robot Event competition (Straten 2004 and http://www.fieldrobot.nl) on the other hand it operates as a modular test bed for autonomous robot control. The main challenge in this aspect is to cope with the poorly structured environment and the variation in shape, size and color of biological objects encountered in the open field.

The 4th edition of the international Field Robot Event took place at the University of Hohenheim (Stuttgart) in Germany at 24th of June 2006. Inspired by the soccer FIFA World Cup held at the same time the tasks the field robots had to perform were as follows:

The line: can the robot detect a corner flag placed on the lawn and draw a straight white line towards it?

Dandelion detection: how many dandelions (simulated by yellow golf balls) can the robot count while navigating between rows? The robot will navigate through curved crop rows, spaced 75 cm. At the end of each row the robot is expected to make a turn, miss out one row, re-enter in the rows and keep going back and forth. In doing so, the robot has to count dandelions.

Speed race "all in a row": can the robot outspeed its competitors in an open race? The robot will be within a straight crop row and follow the row. The end of the row is the finish line. Collision free driving is required.

Hole detection in grass: There will be a competition field with lawn, approx. 5x5 m. The boundary is marked white – like on a soccer field. Inside, the lawn is damaged at one spot. The robot has to detect this spot. The hole will be some 10x10 cm wide and a minimum of 5 cm deep.

Freestyle: Present your own ideas. In this paper, the technicalities of Cropscout II are illustrated and the results of test-runs and of the competition are described and discussed.

2. Objectives

The objectives of the project described are as follows: The development of a robot which participates in the Field Robot Event competition and which wins the first prize. The development of a small experimental platform for research on precision agriculture (e.g. detection and control of weed and diseases). And finally the design and realization of a system which serves as a test bed for the development of autonomous robot control algorithms using sensor fusion techniques and artificial intelligence.

3. Materials and Methods

3.1. General construction of the vehicle

Cropscout II is based on a hand made wooden box containing the electronics mounted on top of a under carriage containing the motors, batteries and the tracks. After one of the gear transmissions from our custom designed under carriage broke down just some days before the contest we decided to reuse the motors and tracks from Cropscout I (Henten *et al.* 2004) which are made from a scale-model of a crawler. Sensors for navigation and orientation, including cameras are mounted around and on top of the vehicle. Two tracks, powered by electrical motors, are used as drive train. Figure 1 and Figure 2 show photographs of the robot and its components. In Figure 1 the optional spraying unit is mounted. In Figure 1 the upper box is opened to view some of the inside components.

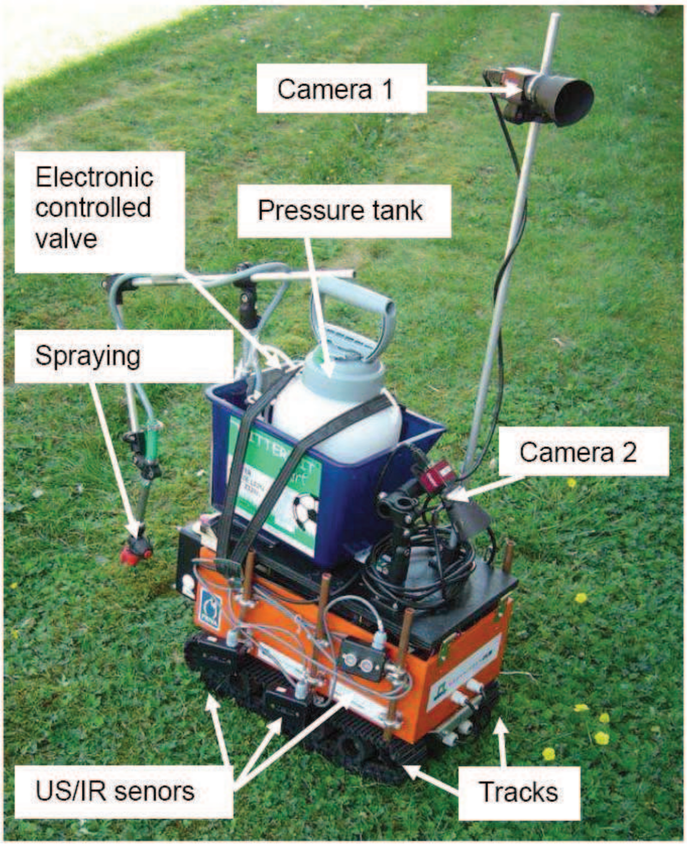

Figure 1: The components of Cropscout II (1)

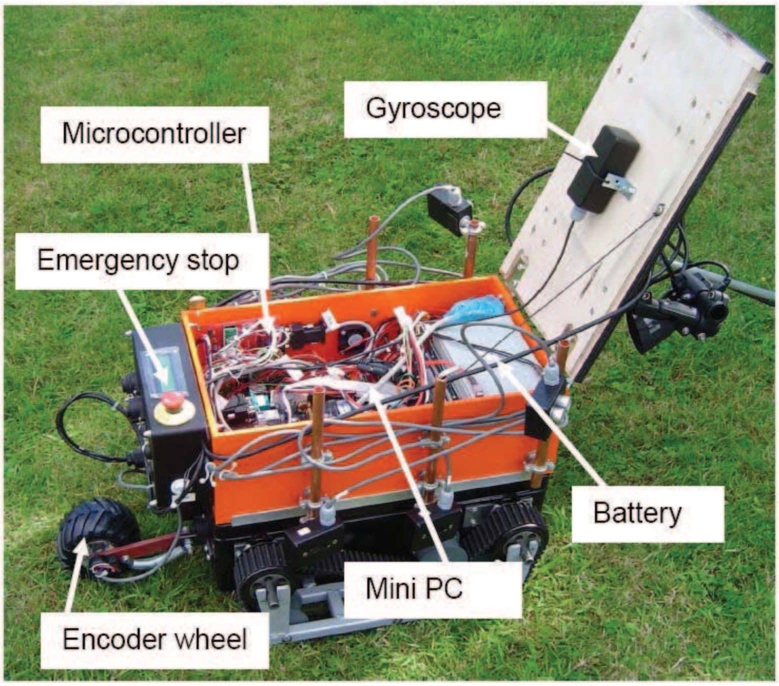

Figure 2: The components of Cropscout II (2)

Table 1 lists the mechanical dimensions of the robot and some properties of components used.

Table 1: Overview of different properties of Cropscout II

Property	Measure
Width	38 cm
Length	48 cm
Height	26 cm
Ground clearance	3 cm
Camera for corner flag detection mounted at	100 cm
Weight	15 kg
Drivetrain	2 electrical motors (Graupner BB700) with gear transmission
Conception	Track driven
Power	12 V Battery/7Ah for motors and sprayer 12 V Battery/4 Ah for electronics
Speed	mean speed approx 1.5 m/s

A 2x16 character LCD display is connected to the electronics. This user interface is used to provide information about the current state of the machine and information about the detected objects (i.e. number of golf balls found in the field). The robot is operated by a number of onoff and tip switches which can be accessed at the back side of the vehicle. The user can select an operation mode and can start, stop and reboot the system. For normal operation there is no need to attach a keyboard or monitor to the system.

3.2. Spraying unit and flash light

For the task of spraying a white line on the lawn a spraying unity was developed. This device consists out of a 5 liter plastic pressure tank, a solenoid-controlled valve, tubes and a membrane controlled minimum pressure nozzle to prevent dripping and leakage after shutting down the sprayer. The tank is filled with fluid soccer field paint and pressurized by hand. The unit can be mounted on top of the box. In place of the spraying unit also a small flash light can be mounted on the same electrical interface. The flash light was used for indicating holes and obstacles.

3.3. Sensors

The sensor concept of Cropscout II is a modular system which enables to use different kinds of sensors which can be positioned at almost any place on the vehicle. The different sensors were all mounted in the same type of housing with a standard mechanical and an electrical connector. A system consisting of several metal tubes, clamps and joints is used to position the sensors. Depending on the task, the positions can be changed quickly. The sensors used include infra-red range sensors, ultrasound range sensors, a gyroscope and two digital color cameras operating in the visible light spectrum. Sensor redundancy was implemented to increase the robustness of the system under varying outdoor conditions.

Cameras

Cropscout II is equipped with two color cameras (Allied Vision "Guppy", F-033C, 1/3" Sony Progressive Scan CCD) IEEE1394 with 6 mm lens. This very compact camera has a standard C-mount lens adapter and is able to acquire images up to a resolution of 640x480 pixels (VGA). For the tasks described in this document, an image resolution of 320x240 pixels and 160x120 pixels was used.

Infra red range sensors

Two short range infrared (IR) distance sensors (Sharp GP2D12, range between 0.10 m and 0.8 m) and two long range IR sensors (Sharp GP2Y0A02YK, range between 0.20 m and 1.80 m) can be used.

Ultrasound range sensors

Further two Devantech SRF08 ultrasound range sensors can be mounted on the robot. These sensors have 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.

Gyroscope

A gyroscope (Analog Devices ADXRS150) is used to measure changes in the yaw angle of the vehicle. The gyroscope produces a positive going output voltage for clockwise rotation about the Z-axis. By integrating the voltage readings over a defined period it is possible to determine (changes in) the heading direction of the device and thus of the robot it is attached to. This sensor is e.g. used for controlling the head-land turns.

Odometer

A free running extra wheel pulled by the vehicle was equipped with an encoder (Spectrol 120e, generating 128 pulses per revolution). This sensor is used as odometer. Figure 3 shows the used sensor positions for in row navigation and dandelion detection. On each side of the robot one ultrasonic, one long range infra red and one short range infra red distance sensor is mounted. All three sensors are rotated by some degrees so that they are pointing towards the direction of driving. Actually only one camera was used for the task of detecting the dandelions.

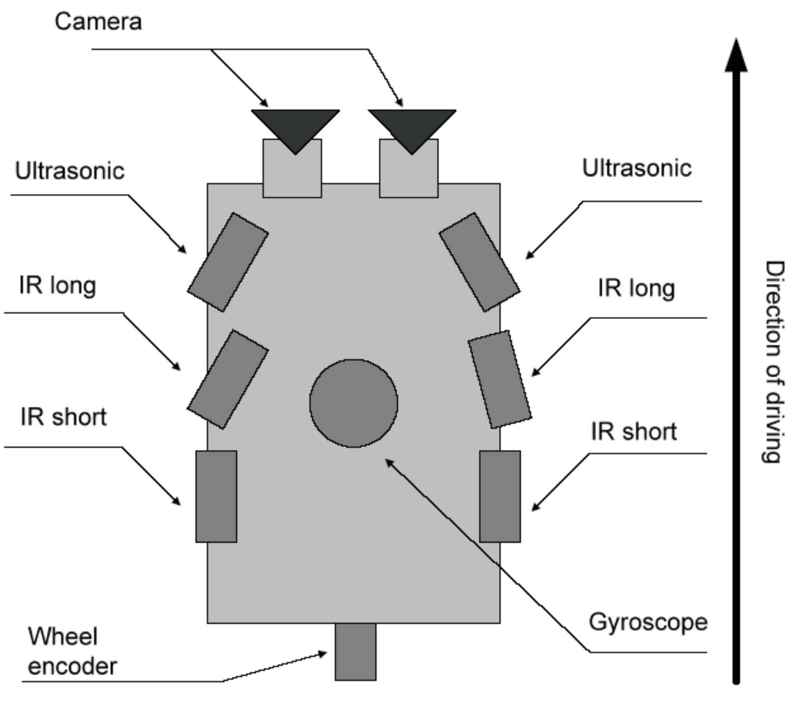

Figure 3: Sensor positions for in row navigation and dandelion detection (top view of robot)

3.4. Control hardware

The control hardware consists out of three main components:

A mini-ITX PC mainboard with VIA Epia 1.3 Ghz CPU, 512 MB RAM and hard disk (http://www.via.com.tw/en/products/mainboards/)
A Basic ATOM40 microcontroller (Basic Micro http://www.basicmicro.com/) for sampling sensors and switches; and
A Rototeq (http://www.roboteq.com/) motor controller.

Via the USB port of the mini-PC a WiFi dongle is installed to exchange data with other PCs, handheld PDAs or other robots. Figure 4 shows the main schema of the electrical design. At low-level the microcontroller is used to sample the sensor values (A/D conversion) and the state of the switches on the back panel. Also the calculation of the heading direction of the vehicle based on the gyroscope values and the control of the LCD character display is done by the microcontroller. The motor controller is used for controlling the speed of the motors. The used controller has also a number of special inputs and is therefore used for sampling the wheel encoder of the odometer and to control the actuator port (spraying unit or flash light). Via serial interfaces the microcontroller and the motor controller communicate with the mini PC. This PC is used for image acquisition and image processing and for the high-level control.

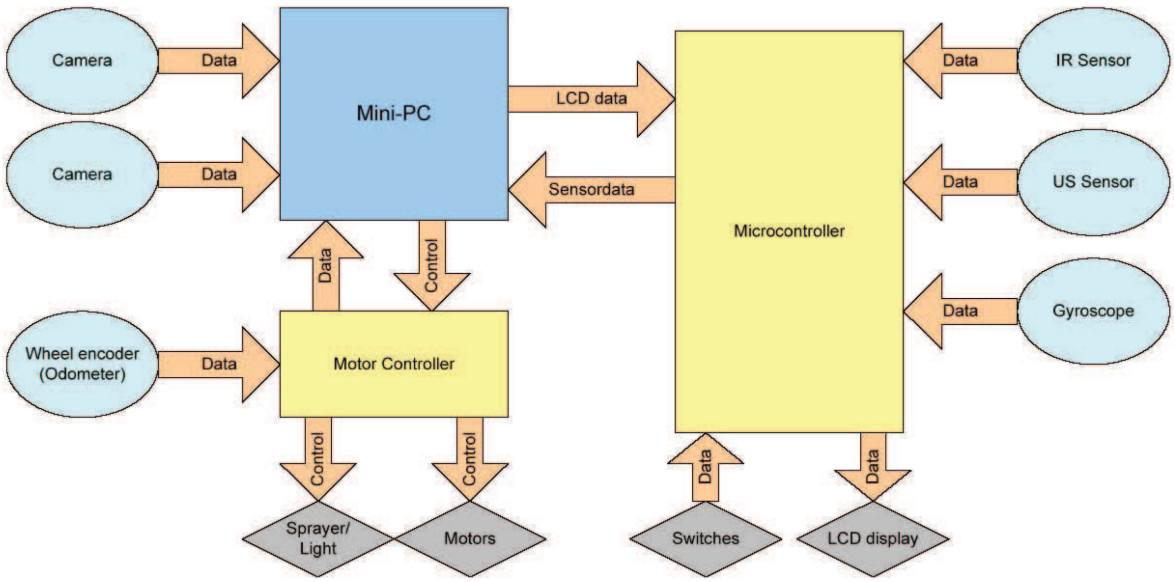

Figure 4: Main schema of the electrical design

3.5. Control software

The Mini-PC is running on the Windows XP operating system. National Instruments Labview 8.0 is used for the high level software layer and for image processing. C is used to program most of the control algorithms. Figure 5 shows a screenshot of the high level application. The ATOM microcontroller is programmed in Micro Basic 2.2. The software is running in a sequence with different steps:

Table 2: Main steps in high-level software

Step No.	Description
0	Read in configuration file and perform settings and store values in global variables
1	Perform init functions such as initialize variables and init cameras and COM ports as required
2	Main loop containing several multitasking loops. This step/loop is running until a “stop application” command is given. This main loop can handle different states or modes such as “navigate in the row” or “find corner flag” or “idle”
3	De-initialize hardware such as COM ports and IEEE1394
4	Shutdown functions such as exit Labview and shutdown/reboot PC

Once the main step is initiated several multi-tasking loops are running using a specific timing and priorities (Table 3).

Table 3: High-level multitasking loops

Timer	Task	Priority	Default timing [ms]
GUI	Update graphical user interface	Very low	100
ATOM	Read/write serial data microcontroller	High	10
Motor	Read/write serial data motor controller	High	20
Enc	Request data motor controller (e.g. wheel encoder)	High	100
Ctrl	Control intelligence loop	Very high	50
Vision	Image acquisition and processing loop	Medium	100
LED	Watchdog loop	Low	1000

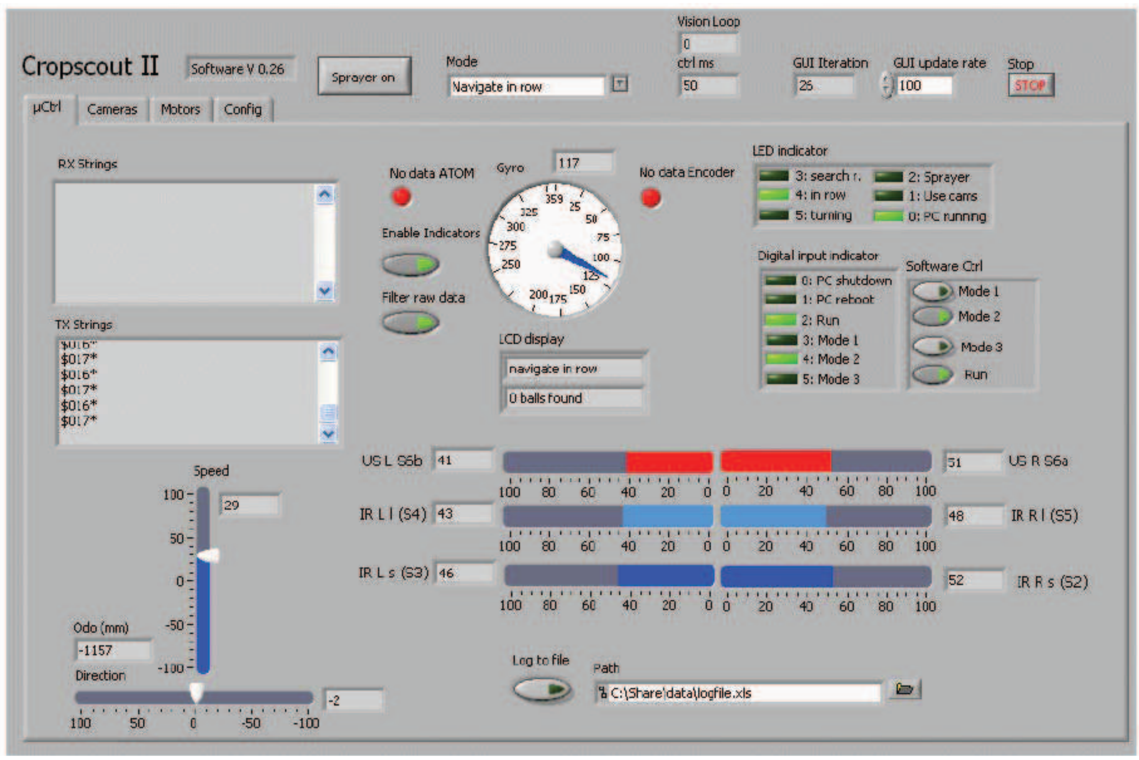

Figure 5: Screenshot of the main user interface

Strategy and control intelligence

The line

The strategy for drawing a line on the soccer field was as follows:

Search flag by computer vision while robot is running a small circle.

Once the flag is found, centre flag in front of the vehicle by steering based on the camera image.
Once centered, drive straight towards the flag while spraying the line. The straight forward drive is based on the readings of the gyroscope.
Stop when flag is reached (measure distance of approaching flag post by an ultrasonic range sensor looking straight forward).

The system can be configured to look for a specific flag color (e.g. red or yellow). To make the color detection more independent from changing light conditions the red, green, blue (RGB) color space of the image was first transformed to hue, saturation, intensity (HSI) color space. The algorithm tries to detect a post (a straight line) beneath the detected colored blob using edge detection methods. An example image is given in Figure 6 where an edge is detected (indicated by a red line) within the edge search area (green box). Only the combination edge and colored blob gives a valid flag detection result. Furthermore, the system calculates the centre deviation of the flag position in relation to the camera position. This value is used to control the motors in such a way that the flag gets centered in front of the robot.

Figure 6: Locate position of corner flag by computer vision

Navigate in row and count dandelions

The strategy for this task is as follows:

Search row.
Navigate in row based on infrared and ultrasonic sensors.
Detect and count dandelions by computer vision (color and shape parameters) while driving in the row.
At the end of the row turn headland based on gyroscope.

Much of the in row navigation code used in Cropscout I was reused for Cropscout II. Refer to Henten *et al.* (2004) for an in depth discussion about this subject. One major difference is that cameras and computer vision are not used for navigation this time. This is due to the fact that the idea of the competition field this year was to have green maize plants on a green undersown crop. This will make it very difficult if not impossible to implement an image processing algorithm which can detect the crop row. 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 on each side of the vehicle. The offset is translated to a control signal to drive the individual tracks. Once the end of the rows is reached, a turn is implemented using the gyro signal. 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 ‘navigate’ state and to the ‘turning’ state *etc.*, is fully determined by the detection of the plant rows.

For the detection and counting of the yellow golf balls (the dandelions) one camera looking ahead on the field in front of the vehicle was used. The image acquisition of the camera was triggered by the odometer in such a way that there was merely no overlap in successive images (e.g. one image per 80 cm). Each image was analyzed individually. As for the corner flag, first the RGB color image was transformed into the HSI color space. Objects of a certain size and a circular shape showing the pre-learned “dandelion color” were counted as valid object. The number of found objects was presented on the LCD display.

Speed race

For the speed race Cropscout II used the gyroscope to drive straight ahead. Before the start the robot was placed manually in the correct orientation in the row. Measured deviations in the driving direction during the run were compensated by the controlling the speed of the two tracks. Motors were set to near maximum speed.

Hole detection

The strategy for this task was as follows:

Navigate in-between white lines (based on information of the first camera).
Search holes with the second camera.
Indicate hole by flashing a light and make avoidance maneuver.

For this task both cameras were used. The task of the first camera was to look ahead some centimeters and to detect white lines on the lawn. Once a line was detected the robot is supposed to make a turn of 180 degrees based on the gyroscope in order to stay within the contest field. A line detection algorithm which could cope with incomplete and fuzzy lines was developed using color algorithms and morphological image processing operations. At the same time the second camera looked for spots which were neither green nor white (the holes).

Freestyle

For the freestyle session Cropscout II performed a spot spraying task. The strategy was as follows:

Slowly drive forward.
Search for small artificial flowers (coloured pieces of plastic).
If detected, drive robot to the flower.
Stop at flower and spray flower with water from the line spraying unit.

Navigation for this task was done by computer vision using the data of the odometer.

3.6. Contest field and weather conditions

As in the earlier editions of the event a real outdoor maize field with straight and curved rows was used for the competition this year. However, inspired by the soccer world cup some additional modifications were introduced. Some tasks should be performed on grass/lawn and some on maize rows sown on a ‘green’ bed consisting out of undersown and mowed grain.

Due to unsuitable weather conditions in spring the maize did not emerged well so that the coordinator decided to mow rows directly in undersown barley. Figure 7 show a photo of the curved rows section. One of the effects was that the remaining mown undersown crop did have a completely different color - way less green as expected. The “crop-row” was at many places also not as dense as expected, large gaps made the row detection more difficult. Also due to very dry conditions just before the competition much of the undersown crop was dried out completely.

Figure 7: Contest field with curved rows of grain

On the day of the event there was clear sky and high temperatures above 30 degrees Celsius in Hohenheim.

4. Results

4.1. The line

Navigation straight to the corner flag and drawing a white line (Figure 8) worked very well during test sessions and also during the contest. Because of the dual feature based image processing (flag and post of flag must both be detected), the detection of the flag turned out to be very reliable and was not affected by e.g. somebody wearing a red t-shirt standing behind the flag. The spraying unit operated flawlessly and a professional white line was drawn by this 10 implement. Because the implement was mounted behind the vehicle it was not possible to spray the line up to the position where the flag was plugged in the field. On the other hand this minimized the paint soiling the robot.

Figure 8: Drawing a line towards a corner flag

4.2. Navigate in row and count dandelions

At the end of the development the robot could navigate, count and turn in a satisfactory manner in the artificial test field the authors had built up indoors. Having the hot, dry and dusty outdoor conditions during the contest the performance decreased dramatically. The leaves of the grain plants of the contest field were very thin in comparison with the maize plants we expected and tested to navigate through. The IR range sensors did not give a robust signal due to lack in reflection of the infra red light. Finally they could not be used for the task of navigation. In addition to this problem the ultrasound range sensors were influenced by dust so that also this signal was unreliable. Thus the sensor fusion concept intended to use failed because most of the sensors did not give a reliable result. The overall row navigation result during the contest was less than expected.

Counting yellow balls was successfully tested indoors and outdoors. To aggravate the situation during the contest the yellow balls provided by the coordinator did have a light yellow "neon" color which turned out to show almost no color component in direct and high intensity sunlight. To stay in the given row of the field the robot had to be reset some times during the competition run. As a consequence the golf ball counter was reset at the same time so that the robot could not present the right number of balls laid out in the field.

4.3. Speed race

The robot performed very well during the contest and we ended up on the 3rd place. The robot drove very straight and stayed in the row. Only the top speed was less than the top speed of some of the competitors.

4.4. Hole detection

The contest field provided by this task was not very suitable for Cropscout II. The field was soggy and the white border line was hardly visible and turning was difficult. In addition to this, the hole detection algorithm (looking for blobs in the image which are neither green nor white) did sometimes classify shadows as holes. Due to a time consuming control algorithm the performance of the mini PC was at the edge of its possibilities causing the whole system to stall sometimes. Anyhow the whole indicating mechanism with the flash light worked perfectly.

4.5. Freestyle

The robot performed pretty well in the freestyle session. The flowers were detected by the system. However in some cases the positioning of the spraying nozzle was inaccurate. As far as we could analyze this was due to a system overload in the high level control caused by the combination of the complex image processing and the control of the vehicle. Also the high outside temperatures may have slowed down the system control.

4.6. Overall remarks

The very flexible and modular design of the system in both the electrical and mechanical way turned out to have many advantages. Such a system is very suitable as a test bed for research and can easily adapted to new tasks. The use of Windows XP as the operating system of the high level controller simplified the integration and the debugging compared to the use of a microcontroller only, as was done in Cropscout I. The mini PC could be easily integrated in and accessed over the network (both wired and wireless). Labview as graphical programming language also allowed rapid implementing of user interfaces and of a complex multitasking system. The use of the comprehensive image processing library of Labview was also favorable and time saving for the project. Drawback of the windows operating system is the lack of real time performance. Much more then expected the cycle time of time critical loops like the core control loops were affected and delayed by other tasks that caused the whole system to stall sometimes.

The used microcontroller turned out to incidentally reset itself. The reason was not found but caused unpredictable behaviors of the robot. The BASIC stamp is a low budget microcontroller which is easy to program but afterwards it would have been worth to invest in a more powerful component here.

The weight of the vehicle turned out to be almost too high to be carried and driven by the mechanics. This was also caused by the fact described above that the authors had to reuse the motors and tracks from Cropscout I. A vehicle on tracks makes the control easy; no wheels have to be steered and the traction on the field is high. In Cropscout II the setting of the track speed is implemented as an open loop control without feedback. Advisable for the future is to implement a closed loop control enabling a much better control.

5. Conclusions

The objective to develop a small experimental platform and to create a test bed for autonomous robot control algorithms was fully realized. The sensors, cameras, control hardware and software can easily be deployed and adapted for various applications.

It turned out that even for an experienced team it is still a big challenge to build a robot which can cope with the wide variety of different and unpredictable outdoor conditions. Beside these aspects most of the components used will not be able to deal with conditions encountered in agricultural practice: the system is not yet waterproof, sensors are sensitive to dust, mud and high or low temperatures. Due to the capacity of the batteries the operation time is limited to less than one hour. Future research on all aspects is essential.

Acknowledgements

Financial support by Priva, De Lier, The Netherlands (http://www.priva.nl), IMAGWageningen, Wageningen, The Netherlands and WitterWit Sport, Bekenbergen, The Netherlands (http://www.witterwit.nl/) is gratefully acknowledged.

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