WURking: a small sized autonomous robot for the Farm of the Future

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Abstract

Autonomous robots for agricultural practices will become reality soon. These mobile robots could take over regular tasks such as scouting for weeds and diseases, plant specific applications, yield and field mapping and for instance the release of info-chemicals for attracting predators of pests. This paper presents WURking, a small sized sub-canopy autonomous robot that can be used for a wide range of tasks on the farm of the future. WURking was designed for navigating within row crops like corn. It consists of a mobile platform with three independently driven steerable wheels. The robot carries ultrasound sensors and a gyroscope used for navigation between the crop rows, end of row detection and headland turning. A camera is mounted to detect objects like weeds. High level control of this robot was implemented using the visual programming language LabView. A data fusion technique is used to extract the position and orientation of the robot relative to the crop rows, from the redundant set of sensor data. Feedback linearization of the non-linear system dynamics yielded a simple linear controller structure which was fed by state estimates generated by a Kalman filter using the raw ultrasound sensor data. The headland turning was based on a proportional controller using data from the gyroscope. This paper contains a description of the robot as well as results of a performance test performed in 2008. This test revealed that the robot was able to navigate through the corn field with a maximum offset of ±10 cm from the centre of the rows and an maximum orientation error of ±0.15 rad.

Keywords: robot, crop scouting, performance, navigation

Introduction

Autonomous robots for agricultural practices will become reality soon. These mobile robots could take over regular tasks such as scouting for weeds and diseases, plant specific applications, yield and field mapping and for instance the release of info-chemicals for attracting predators of pests. Some examples are robots for plant scale husbandry (Tillet *et al.*, 1997), weed control (Astrand and Baerveldt, 2002), mapping in-field variability (Godwin and Miller, 2003) or detection of volunteer potatoes (Evert *et al.*, 2006).

In 2003, in Wageningen, the Netherlands the Field Robot Event (FRE) was initiated as an international design competition in Agricultural Engineering (Van Straten, 2004; Müller *et al.*, 2006; Van Henten *et al.*, 2007). Essentially, the objectives of the FRE are twofold. First of all, it gives a high-tech flavour to the Agricultural Engineering curriculum and can be used as a PR instrument to attract students for a career in Agricultural Engineering so as to counter the stagnating student numbers. Secondly, the FRE aims at stimulating the design of small robots for actual use in agricultural practice. Small sized light weight robots fit into the small scale farming approach of precision farming. They induce less soil compaction and offer the opportunity of a more weather independent access to the fields. And due to their small size, safety issues will be less critical under autonomous operation than with large machines. Given the current and ever growing size of today's farm machinery, deployment of small scale machines would mean a paradigm shift in agriculture. For the 2006 FRE at Hohenheim University, Stuttgart, Germany, the Farm Technology Group and the Systems and Control Group of Wageningen University decided to build a robot. The objectives were twofold: (1) to participate in the Field Robot Event, (2) to have a universal platform to be used for further research and education on small sized robots for agricultural applications. The developed robot participated in the Field Robot Event contests of 2006, 2007 and 2008. In the present paper, this robot is described in some detail. In addition, methodology and results of a performance test of the robot in a corn field are presented and discussed.

Materials and methods

The field robot

WURking is a small sized sub-canopy robot built to traverse row crops like corn (Figure 1). The platform consists of an aluminium frame, a cover to protect the electronics, a battery pack, several sensors and three independent wheel units. Two wheel units are placed in the front and one wheel unit in the rear of the frame. Each wheel unit is able to steer left (+135^o) and right (-135^o). The robot is equipped with six ultrasonic and two infrared sensors for row detection. A camera is attached to the robot for detection of objects like golf balls, lines and flags during various elements of the competition. This camera might be used for weed detection as well. A gyroscope is used to determine the orientation change of the robot.

The wheelbase is 500 mm and the track width between the front wheels is 320 mm. The total width of the platform is 400 mm and the total length is 700 mm. The clearance of the platform is 120 mm. The weight of the platform including battery pack is 39 kg.

The wheel units (see Figure 1 right) were designed in cooperation with the Kverneland Group Mechatronics BV in Nieuw Vennep, the Netherlands. The wheel drive is powered by a single 150 W motor at 24 volts (Maxon Precision Motors, brushed DC motor, model RE40). The maximal torque delivered is 181 Nm at 7,580 rpm. This motor is connected to a planetary gear head with a reduction of 15:1 and a maximum efficiency of 83% (Maxon Precion Motors, model GP52C). The

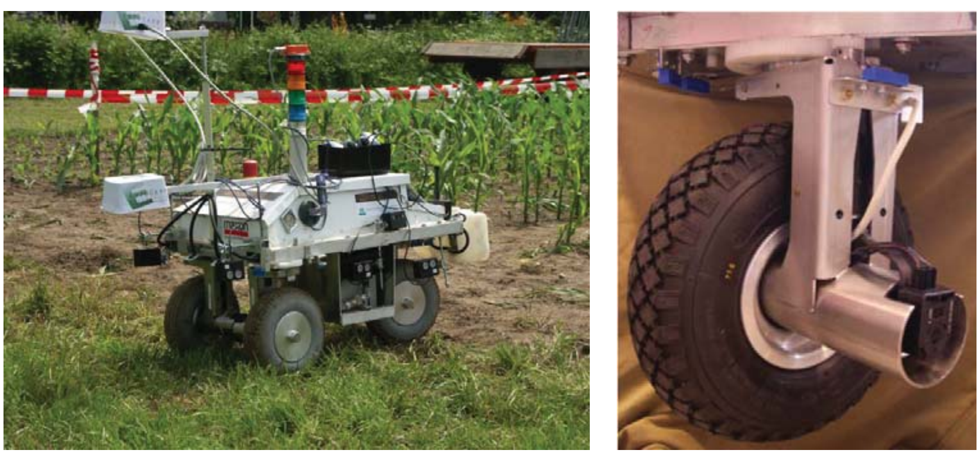

Figure 1. The WURking robot (left) and one of the wheel units (right).

drive motor is equipped with an encoder to measure the speed in counts per turn (Maxon Precision Motors, encoder, model HEDS 5540). Steering is realised by a 20 W motor at 24 volts (Maxon Precision Motors, DC motor, model RE25) connected to a planetary gear head with a reduction of 66:1 and a maximum efficiency of 70% (Maxon Precision Motors, model GP32C). The wheel units are equipped with conventional tube tyres (Ø 250 mm, 80 mm). The tyres were inflated to approximately 3 bar for optimal traction. The maximum steering velocity of the unit is approximately 115 deg/s. The weight of the wheel unit including the motors is 4.1 kg.

Each wheel unit is controlled by a Motion Mind DC motor controller. Each controller is capable of controlling two brushed motors, in this case one motor for driving and one for steering.

The platform is equipped with a battery pack containing three batteries located in between the wheel units to realize a low centre of gravitation. Two 12V, 7Ah batteries are used to power the driving and steering motors. Additionally there is one 12V, 12 Ah battery to power the PC platform, controllers and the sensors. The total weight of this battery pack is 10 kg. This battery pack is mounted on the platform in such a way that it can be easily exchanged with a spare battery pack for continuous operation.

The platform carries a wide range of sensors. Six Devantech SRF08 ultrasonic sensors are mounted, three at each side. These sensors measure the distance from the robot to the crop row. The range of the ultrasonic sensors is from 3 cm to 6 m and the sound frequency is 40 kHz. The ultrasonic sensors are connected to the I^2C bus of a BasicATOM microcontroller. Besides the ultrasound sensors, the robot has two Sharp GP2D12 infrared sensors also used to measure the distance between the robot and the crop rows.

The camera is a Unibrain Fire-i firewire camera with a ¼' CCD (659×494 pixels) and a pixel size of 5.6 µm in both horizontal and vertical direction. The frame rate is up to 30 frames per second (uncompressed VGA picture).

The robot is also equipped with a XSens MT9-B gyroscope with a 3D compass, 3D accelerometer and 3D gyro's and yields by integration very precise values for yaw, roll, and pitch. The angular resolution is 0.05º, the static accuracy is <1º, and the dynamic accuracy is 3º RMS (XSens, 2006).

For data acquisition and control, the robot contains two computer platforms, a BasicATOM40 and a VIA EPIA SP13000 PC. Part of the data acquisition is realised with the BasicATOM40 microcontroller with inputs from the two infrared sensors and the six ultrasonic sensors. The microcontroller processes the raw sensor signals and creates a message with the calibrated values which is send to high level control program.

For high level control, the VIA EPIA SP13000 PC is used as a low power compact motherboard with built in CPU, graphics, audio and network. The PC has 512 MB RAM and a 40GB hard disk with a Windows XP operating system supplemented with a WiFi connection for remote control and monitoring purposes.

The high level control of the robot is realised by a LabVIEW program and involving several processes that run independently from each other. Each process is represented by a VI (Virtual Instrument) including several sub VI's that realise a specific task. There are VI's for initialisation, motor control, the kinematic vehicle model, camera control, communication with the BasicATOM, communication with the gyroscope, and sensor fusion. A state machine controls the activation and de-activation of processes and the VI's exchange data with each other via global variables. A schematic diagram of the different components of WURking is shown in Figure 2.

One VI was designed to compute the position and orientation of the robot relative to the row using six ultrasonic sensor measurements. The VI basically employed a linear regression technique in combination with information about the row width and robot dimensions. For end of row detection, it provided a signal when one or several sensor measurements are inconsistent with these dimensions.

Navigation and control design issues were addressed in an advanced model-based design using a kinematic mathematical model of the three-wheel vehicle (see Figure 3). The kinematic model is a dynamic state-space model that is integrated using standard numerical integration as shown by

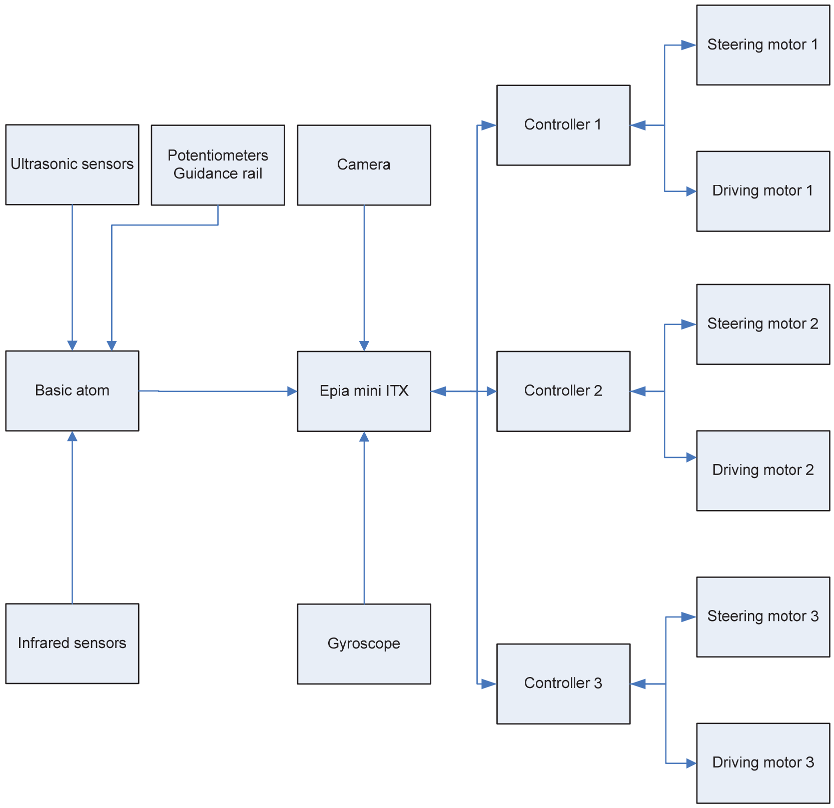

Figure 2. Schematic diagram of the different components of WURking.

Campion *et al.* (1996). In this way the next state, that is the next position and orientation of the robot, is calculated using the current control inputs being the wheel velocities and wheel angles. A so-called Kalman filter combines these computations with on-line measurements obtained from the ultrasonic sensors to estimate on-line the future state, which is the next position and orientation of the robot relative to the row. These estimates together with the state-space model are used to compute on-line the next control values, which are the next values of the wheel angles and velocities. The computation is performed by applying a feedback linearization scheme (Kwatny and Blankenship, 2000). Application of this scheme reduces the controller design to a simple linear controller design that is performed by means of pole placement. The state estimates, generated by the Kalman filter, can also be used for higher level decision making such as what to do if the end of the row is reached. Turning by means of feedback linearization was unsuccessful due to the total absence of feedback from the ultrasonic sensors. Therefore, a very simple proportional controller was used for turning at the headland. It used the X-sense absolute angle measurement for feedback and benefited from the fact that setting the three robot wheels at appropriate angles allows the robot to fully turn around its midpoint. The output of the proportional controller was clipped to limit the angular velocity of the robot. Filtering the last pair of measurements taken from the X-sense while traversing the previous row provided a good estimate of the orientation of the end of the previous row. Relative to this orientation, the robot turned into the next row using the clipped proportional controller. The turn was performed in three stages. First, a 90^o turn was made and next, the wheels were set straight to drive straight over a fixed distance coinciding with the row distance. This distance was measured

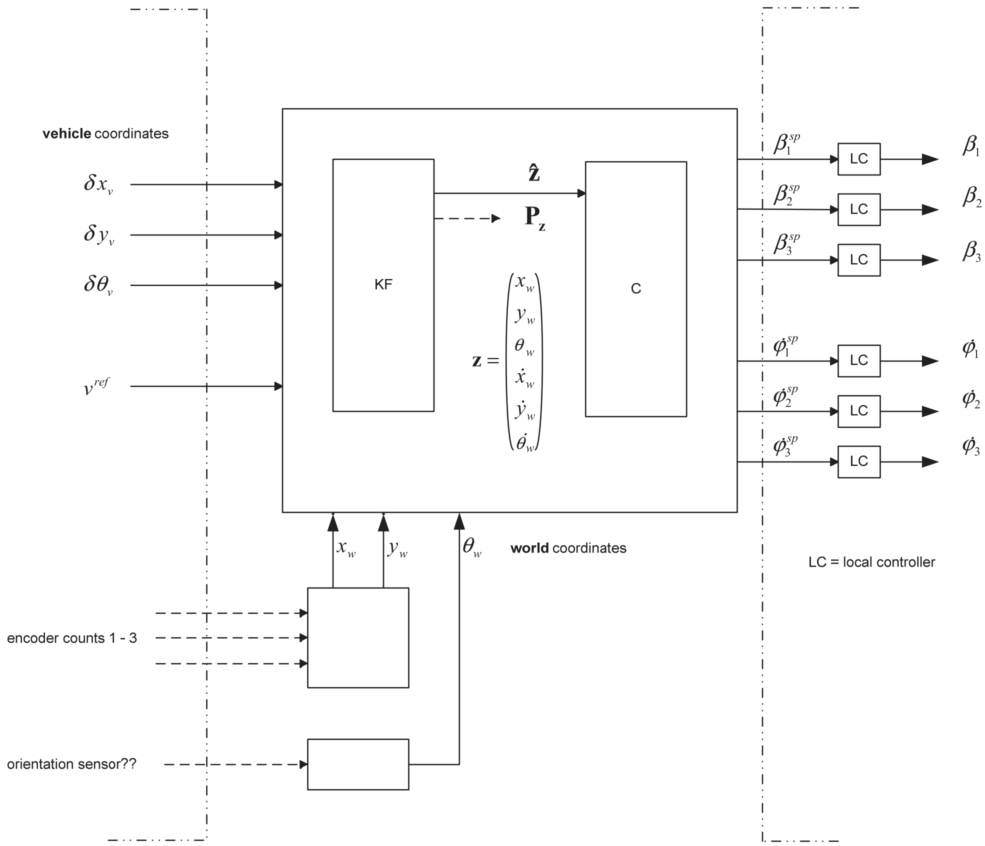

Figure 3. Controller structure of WURking.

by the wheel rotations and regulated also by a clipped proportional controller. Then a 90º turn was made again. The end of row detection was performed using the VI (Virtual Instrument) build around the six ultrasonic sensors. The VI provided a signal that indicates whether measurements occur that are incompatible with driving through the row. If this signal was received for a certain amount of time, this indicated the end of row.

The performance tests

In 2008, the performance of the WURking robot was evaluated. In spring 2008, a corn field was prepared by sowing with an interval of two weeks yielding four fields with different growth stages of corn as shown in Figure 4 (left). To measure the accuracy of the robot in terms of position and orientation between the rows, a measurement rig was designed as also shown in Figure 4 (right). Using the T-shaped mould, the foot print of the robot was followed with intervals of 25 cm over a total distance of 30 m. The mould was mounted on a slider and could rotate to allow measurement of position and orientation of the robot from the centre between the two rows. During experiments, data were recorded both by the WURking robot as well as afterwards with this measurement device. Before the performance test, the soil surface was flattened out.

Figure 4. The field for the 2008 performance test (left) and the measurement device to measure position and orientation accuracy of the robot (right).

Results

Field tests indicated that traversing straight and curved rows by means of feedback linearization performed satisfactorily since no plants were damaged while the driving speed was below a maximum of 0.75 m/sec. Accuracy of the robot in terms of position and orientation between the two rows is illustrated in Figures 5 and 6. Figure 5 first of all shows an adequate match between measurements performed with the ultrasound sensors on board the robot and the independent measurements performed with the measurement frame. Secondly, the measurements reveal an average positive offset of the robot from the centre between the rows. Maximum position errors lie between -7.5 and +10 cm based on ultrasound measurements and 0 and +7.5cm based on measurements with the measurement rig. Earlier experiments had revealed that roughly 75% of the headland turns were successful, meaning that no plants were damaged and no human interference was necessary.
Despite some fluctuations, the orientation measurement of both the robot and the measurement rig relative to the centre line between the crop rows reveal a consistent orientation offset of the frame of +0.05 rad. This is possible because the robot consists of 3 independently steerable wheels which allow the straight line motions with a continuous offset in the frame axes. Based on the measurement rig, the orientation of the robot frame varied between 0.025 and 0.075 rad. The gyro showed similar results (not in the figure): fluctuations between -0.10 and +0.15 rad were measured.

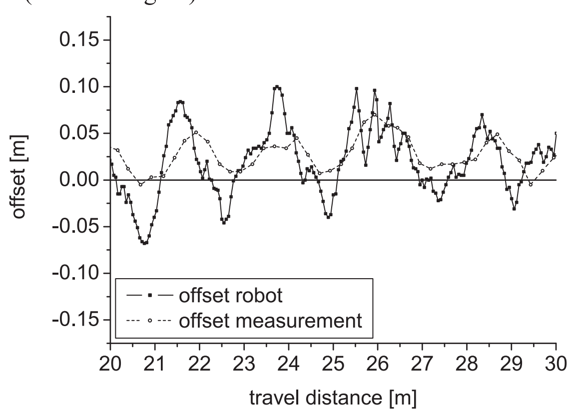

Figure 5. Position accuracy of the WURking robot, measured with the ultrasonic sensors of the robot and the measurement device.

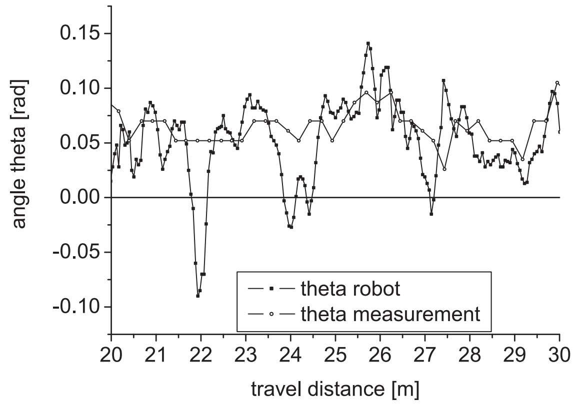

Figure 6. Orientation accuracy of the WURking robot, measured with the ultrasonic sensors of the robot and the measurement device.

Conclusions and directions for future research

In this paper, the WURking fieldrobot was described and methodology and results of a performance test were presented. The performance test revealed a success rate of 75% of the headland turns. Also, the performance test revealed that the robot was able to navigate through the corn field with a maximum offset of ±10 cm from the centre line of the two rows and an maximum orientation error of ±0.15 rad. Further experimentation is needed to verify the robustness and performance of this robot platform.

The measurement device had the advantage that it produced an independent measurement of the robot performance. However, such instrument can only be used if the soil is prepared properly. There is a need to develop a generally accepted way to evaluate robot performance. It is suggested to introduce a standard protocol for this purpose because only then can performance comparisons between robots be made.

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