Development of an Autonomous Vehicle for Weed and Crop Registration

Pedersen, Tom Søndergård; Nielsen, Kirsten Mølgaard; Andersen, Palle; Bak, Thomas; Nielsen, Jens Frederik D.

Publication date:
2002

Document Version
Også kaldet Forlagets PDF

Citation for published version (APA):
Pedersen, T. S., Nielsen, K. M., Andersen, P., Bak, T., & Nielsen, J. F. D. (2002). Development of an Autonomous Vehicle for Weed and Crop Registration. .

Development of an Autonomous Vehicle for Weed and Crop Registration.

T. S. Pedersen, K. M. Nielsen, P. Andersen, T. Bak, J. D. Nielsen*
Department of Control Engineering, Aalborg University, DK 9220 Aalborg, Denmark
email: tom, kmn, pa, tb, jdn@control.auc.dk

Introduction

The extension of information technology and computers on farming tools results in new possibilities for crop/weed handling. In this paper a system using an autonomous field robot (vehicle) able to make images in the field is described.

In the recent farming has come to rely on intensive use of chemicals for crop protection. A way to reduce the consumption of chemicals is to use precision techniques for placing chemicals where they have an optimal effect with minimal quantity. An important part of this is to locate the weed for automatic selective spraying. A camera placed on a sprayer may be a solution but at present the image analysis technology does not have the capability for online analysis. An alternative way is to construct a weed map prior to the spraying. In order to avoid damage to the soil a light weight vehicle carrying a camera is an obvious choice. To minimize damage to the crop the free height of the vehicle being developed in this work has been set to 0.5 m. The size and weight of the vehicle implies a power consumption of max 1.5 kW making electrical motors suitable for propulsion and steering. To make the operation affordable the vehicle should be unmanned requiring a high degree of autonomy.

The vehicle is part of an autonomous information system for crop and weed registration in fields which is developed at Aalborg University and The Danish Institute of Agricultural Science. The system consists of the vehicle and a stationary base station as well as a wireless communication system between the two. The base station is the main interface to the farmer. Based on farmer information a route plan for data collection is created in the base station and send to the vehicle. The vehicle collects field data using two cameras one determinates the total weed pressure and one determinates individual species. The weed data are transmitted to the base station where weed maps are calculated. The route plan is based on a grid calculated from a priori weed spatial density knowledge. The route plan consists of a set of field coordinates; at each coordinate vehicle operations are defined.

This work is funded by The Danish Ministry of Food, Agriculture and Fisheries and carried out by The Danish Institute of Agricultural Science, Research Centre Bygholm and Aalborg University in corporation with Sauer Danfoss A/S, Dronningborg A/S, Hardi International A/S and Eco-Dan. The University is responsible for the construction of the electronic part and the guidance system of the vehicle and the Agricultural Institute is responsible for the mechanical part, the image processing and the route planning.

This paper focuses on the control, guidance and navigation system. A prototype platform with the dimensions of approximately 1x1x1 meters for testing the control and navigation part is described. Based on the prototype test results a new platform is under construction.

Technical specifications of the vehicle

The technical specifications were established in cooperation with The Danish Institute of Agricultural Science, Research Centre Bygholm. The specifications to the first prototype vehicle were precision, capacity, communication, autonomy and mechanical construction.

Precision: First the vehicle must be able to follow a pre-described path in a field. The path is described by a number of way points (x,y coordinates) where each point is classified e.g. as a point where a picture has to be taken. The path the prototype has to follow was specified consisting of straight lines and circles se figure 5. The path following gives two types of position precision, namely the image collection position precision, demanding an exactness of 0.1 m and a maneuver precision of 0.1 m in the crop rows and 0.5 m in turning maneuvers. It may be noticed that the precision specifications gives demands as well on the control system of the vehicle as on the navigation system (position estimation system).

Capacity: Making images in an 8m*8m grid on the field will with a mean velocity of 3 km/h give a capacity of approx. 2.5 hectare/hour which is taken as a realistic capacity. Because the vehicle has to stop in each picture coordinate this demands a maximum velocity of approximately 6 km/h.

Communication: A wireless communication between the vehicle and the base station is needed for transmitting pictures from the vehicle to the base station and for transmitting route plan data from the base station to the vehicle. This connection must able to send within a 1 km range. The transmitting capacity must be sufficient to transmit pictures taken for each 8 m or 7th second, e.g. 5 Mpix requires 1.7 Mb/s. Autonomy: The mapping of the field must be carried out automatic and with a minimum of manpower to increase the working capacity in precision farming.

Mechanical construction: The vehicle must be maneuverable in all sort of fields, and lightweight to avoid tractosis and to minimize energy consumption. The aim of the first prototype was to gain experience in fields of positioning, maneuverability, data-communication and control system architecture.

Figure 1: Prototype vehicle

The prototype vehicle electrical layout

In the prototype layout the base station is a PC. The onboard computer is a PC/104 with a six port RS232 module and a PC card R/W module. The latter module is equipped with an Aironet 340 wireless ethernet PC card that makes it possible to communicate with the vehicle from the work station PC via a Aironet 340 Access Point. Due to different sampling rates some communication lines connects direct to the RS232 ports and others via a RS485 bus.

A digital compass (HMR3000 Honeywell), fiber optic gyro (RD2100 KVH E-core 2000 series), and GPS receiver (Legacy-E Topcon) uses RS232 ports. An ICP-CON RS485/232

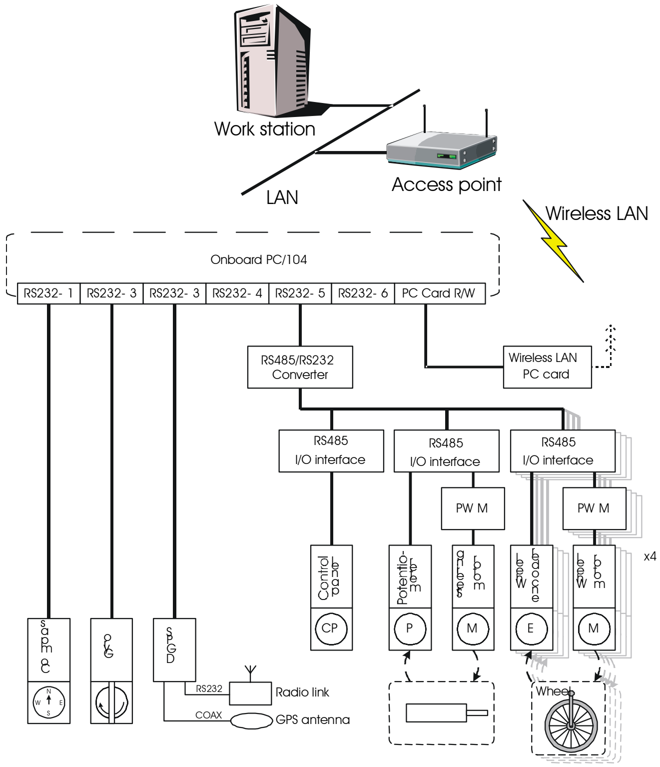

Figure 2: Electrical layout of the vehicle

converter is connected to one of the three remaining RS232 ports. Six RS485 I/O cards make the interface to the rest of the sensors and actuators. Four are connected to each of the PWM wheel motor controllers and the wheel encoders. One is used to control the steering motor and measure the steering angle from a potentiometer. One is connected to a control panel. The control panel enables manual control of velocity and steering angle of the vehicle. Two 12V accumulators/-batteries makes power supply for onboard computer, sensors, and actuators. For the implementation see (Bigum J., 2001).

Control System

The idea behind the control system architecture is to separate the vehicle tasks into well defined layers as shown in figure 3. The control system consists of four layers.

The lowest layer is the propulsion control and the steering control. These controllers use feedback from encoders and motor torque (current). The references to the controllers are wheel velocities and wheel angles. These velocities and angles are calculated according to the Ackermann steering principle. In practice the wheel velocities do not accord exact to the Ackermann calculated wheel velocities due to uneven surface and imprecise velocity measurements preventing the use of integration action in the controller. Small differences in the measured velocities will cause the integrators in the four controllers to diverge most clearly observed at stand still where the divergence of the integrators will pull the vehicle in different directions.

This behavior is of cause undesired and uses unnecessary energy; instead P-controllers are used in the propulsion.

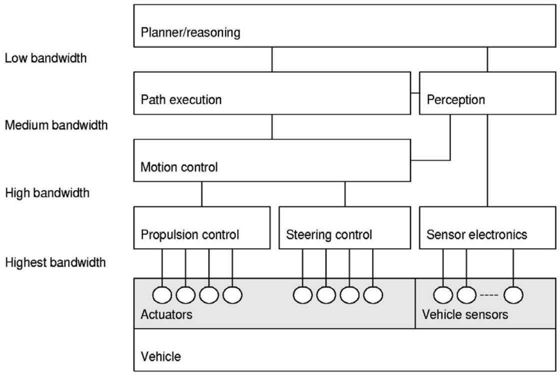

Figure 3: Control layers of the vehicle

Alternatively motor torque control could be used to avoid the above mentioned problem. PI-controllers are used for steering. The second layer is the motion control coordinating the movements of the wheel units. As reference to the motion controller the vehicle velocity and the yaw are used. From the references the motion controller calculates the four wheel velocities and the steering angles. The third layer is path execution and perception. Inputs to the path execution are desired x,y coordinates being calculated from measurements by the perception part. From these coordinates the path execution calculates the desired vehicle velocity and yaw. The perception part estimates x,y coordinates of the vehicle using GPS as the primary sensor making it possible to achieve an accuracy within few centimeters. The navigation system will be discussed in details in the next section. The upper level is a planning and reasoning system. The aim of this level is to calculate a proper trajectory for investigation of the weed pressure in the field. The field map is constructed in two steps. In a first run a fixed spatial grid is used and secondly a denser grid is used in areas with large gradients in weed pressure. Route planning for the second run is based on analysis of the registered weed densities from the first run as the weed variations are essential to precision agriculture.

Navigation

Essential to the operation of a guided vehicle in the field is precise and reliable sensing of the position and orientation (pose) of the vehicle in the field. Basis for the navigation solution is a Carrier-Phase Differential GPS (CDGPS) system that provides absolute position in Universal Transverse Mercator (UTM) coordinates with an approximate precision of 3 cm. The GPS satellite signals are, however, weak at the receiving antenna, and at an operating frequency of 1.6 GHz, they have difficulty in penetrating solid objects and foliage, leading to outages. As a consequence the navigation system combines complimentary sensor information with the GPS position estimates and consists of a GPS system providing absolute position, a gyroscope to measure the vehicle orientation change, an odometer to measure distance traveled, a compass to sense the orientation relative the magnetic field.

If the gyro and the odometers were perfectly calibrated, and the initial position and orientation of the vehicle were known, then the pose of the vehicle could be determined at any future time. However, even high quality gyros accumulate angular errors with time due to bias and scale factor errors, and the odometer scale factor changes slowly with time, tire pressure and field surface. A system based on only gyro and odometers would hence diverge from the actual position. Combined with GPS measurements the error may, however, be reset at regular intervals.

The aim of the navigation algorithm is to fuse the available sensor information into an estimate of the vehicle pose in an optimal way while providing continuous coverage. Fusion of the available sensor information has been achieved using Kalman filtering. Simply put, the algorithm estimates the system pose based on the last measurement, the previous values of the pose, and the estimated accuracy of the estimated pose and sensor data. The filter contains a weight called the Kalman gain that is calculated such that the error covariance of the state estimates is minimized. If the variable estimate has large uncertainty, but the measurement is good, then the measurement is weighted heavily. On the other hand if the variable estimate has a small uncertainty, and the measurement is bad, the measurement is lightly weighted. This structure allows us to maintain pose estimates for longer intervals without GPS measurements. An example from actual field tests is given in figure 4. The GPS measurements fall out, but a valid navigation solution is obtained based on the odometer, compass and measurements. The ellipsis indicates the covariance associated with the estimates. The covariance grows due to odometer and gyro errors but is finally restored at (10.5, 27) where the GPS becomes available again. Between GPS measurements, the larger the statistical uncertainty in the system parameters and other measurements, the more rapidly the variable estimate uncertainty increases. The present system with integration of GPS, gyro, odometers and compass allow precise absolute sensing of the pose in the field even during GPS outage. From a safety and operational point of view this is essential.

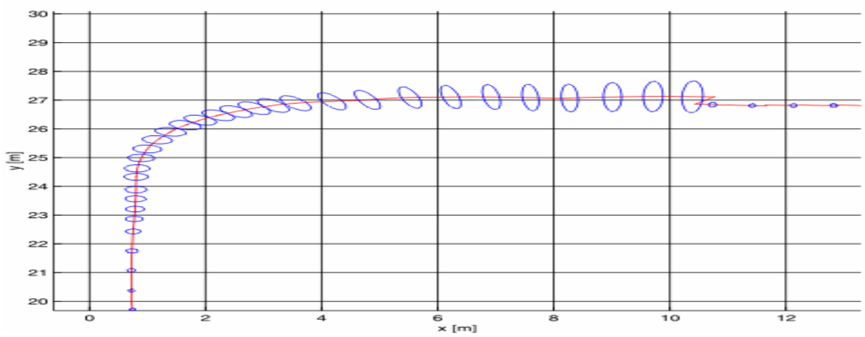

Figure 4: Navigation field tests. The GPS measurement update is omitted from point (0.7, 20), but the filter maintains an estimate to the position. The ellipse indicates the covariance of the state estimate.

The results and assessment of their significance.

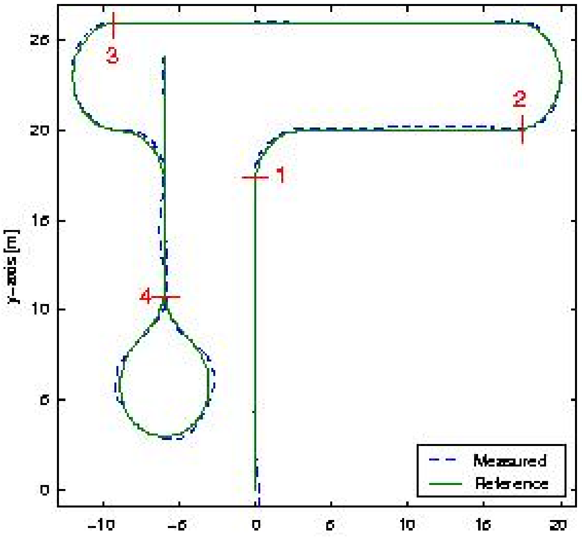

Figure 5: Measured and reference path.

Field Tests:

To evaluate the guidance and control system of the prototype vehicle a route consisting of left/right turns and straight lines as shown in figure 5 was constructed with start coordinates in (0,0) and stop coordinates in (-5,24). When moving on straight lines minor errors appear. These errors are mainly caused by the steering dynamic due to a slow linear steering motor. To overcome the steering dynamic problem only small velocities were used but nevertheless the problems are pronounced in turning maneuvers especially in the left/right/left turn shown as 4 in figure 5.

As seen the vehicle is started in coordinate (0.5,0) in order to examine how fast the vehicle will trace the correct trajectory. Due to the slow steering it takes about 10 seconds to trace the reference path. The error (not shown) is less than 0.12 m until point 1 in the figure. From point 1 to point 2 of the path there is a maximum error of 0.20 m. It may be noticed that the velocity of the vehicle is not constant. As expected the position error is largest in the left/right/left turn where an error of 0.30 m appears. As seen the specification of an accuracy of 0.50 m in turning maneuvers is fulfilled whereas the exactness of 0.10 m following a straight line is not completely obtained. This lack of accuracy mainly occurs due to the slow response of the steering motor, an issue that has to be taking into account in the design of the next generation.

A new prototype vehicle for data acquisition:

Based on the field test results a new data prototype vehicle is under construction. To get a better maneuverability e.g. the possibility of a abrupt change of direction the next prototype will be constructed with four wheel drive and four wheel steering (eight DC motors in total). To obtain modularity four similar wheel units each consisting of 2 motor and sensors for measuring the wheel angle, the wheel speed and the momentum will be used in the new vehicle. The new vehicle is shown in figure 6. The control system has not been fully implemented in the first proto type, but because the overall design structure shows satisfactory results the structure will be retained. The two lower layers in the structure has to be changed according to the four wheel steering; here non-linear control theory (Thuilot, 1996) will be used. In the path execution and perception layer a number of problems remain to be solved in the navigation. Accuracy must be maintained during the frequent GPS outage. This may be achieved by better modeling of the deterministic error sources on the gyro, odometers and compass. A more fundamental problem is that it is not practical to guide the vehicle between crop rows on an absolute coordinate. A row guidance sensor, however allow sensing of the position relative to the crop rows. Work is, however, on the way to develop a localization system that incorporates the GPS information with the crop row guidance measurements in order to allow autonomous operation and precise localization of the vehicle in the row crop while minimizing the damage to the crop. To secure an easy integration with other automated agricultural equipment standardization of the data communication system by use of a general field-bus is an issue for the new vehicle. CAN is at present the dominating standard for agricultural vehicles, and will be used for the wheel units communication to the main steering computer as well as for the other measuring units. The payload must be integrated in the next vehicle. On board the cameras for registration of the over all weed pressure and for registration of weed types will be installed.

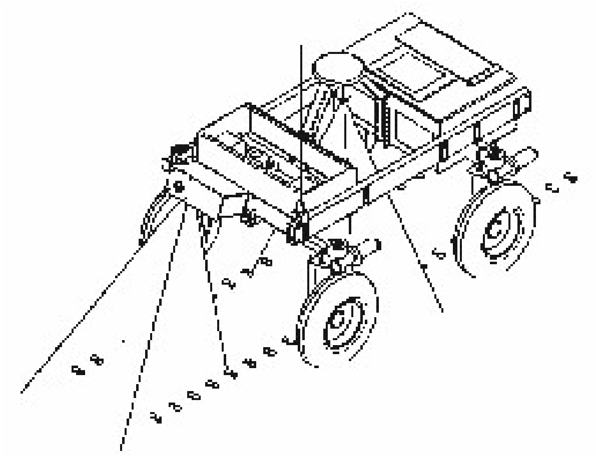

Figure 6: The new data acquisition vehicle

Conclusions

A prototype vehicle has been developed and the control system has been tested using a path consisting of turns and straight lines. The vehicle was able to follow the path with an error less than 0.3 m in turning maneuvers and 0.2 m following straight lines. Based on the test results a new vehicle is under construction. One of the main problems of the prototype platform is the maneuverability in the turns. To overcome this problem the new vehicle is designed with four wheel steering and four wheel drive. Velocity steering of the wheels is problematic in the case of roughness in the field instead momentum steering will be implemented. To obtain modularity four similar wheel units are constructed each containing a steering and a driving motor as well as a computer for motor control and supervision communicating with the PC-104 main computer. To adopt agricultural standards the on-board communication system will be implemented using a CAN bus. The navigation accuracy will be improved by implementation of an Eco Dan row camera to be fused into the navigation system.

References

Baerdemaeker, J.D., Munack A., Ramon H., Speckmann H.: Mechatronic Systems, Communication, and Control in Precision Agriculture, IEEE Control System Magazine 2001.

Bigum J., Hvilsted D., Lange M.: Positionering og orientering af autonomt landbrugskøretøj , Aalborg University, Master's thesis 2001.

Biltoft J., Nielsen J.,Thomsen P.: Autonom robot til markanalyse, Aalborg University, Master's thesis 2001.

Campion G., Bastin G., D'Andrea-Novel B.: Structural Properties and Classification of Kinematic and Dynamic Models of Wheeled Mobile Robots, IEEE Transactions on Robotics and Automation, 1996 , vol. 12 , 1.

Petriu E.M., Ionescu D. et. al: Multisensor System For Mobile Robot Navigation, IEEE Instrumentation and Measurement, 1996, Brussels, Belgium.

Thuilot B., d'Andrea-Novel B., Micaelli A.: Modeling and Feedback Control of Mobile Robots Equipped with Several Steering Wheels, IEEE Transactions on Robotics and Automation, 1996, vol. 12, 3.