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# AGRICULTURAL VEHICLES WITH AUTOMATIC NAVIGATION

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**ABSTRACT**

Automatic control of ground vehicles has been a research objective for many years. Such control has many potential applications, including development of smart roads that automatically pilot vehicles to the destinations their users select; control of construction vehicles that build roads automatically; and control of vehicles operating in hazardous environments. Satellite-based controllers also might allow farmers to do things that are impossible or impractical manually, such as enabling a single driver to operate a convoy of several tractors at the same time. A spiral pattern would allow a farmer to plow a large field continuously, without wasting time making U-turns at the end of each set of rows, but it is very difficult for drivers to do. Automatic guidance of agricultural vehicles like tractors in the mechanized farming practice has taken the attention of Agricultural engineers. For this to be truly practical on the farm, it should be economical, simple to operate, and entirely contained on the vehicle. Steering automation has been implemented successfully on agricultural vehicles on the basis of analogue-type components, i.e. sensors, controllers, and actuator elements. The paper describes the different features of automatic navigated vehicles and summarizes the success stories in developing countries.



## INTRODUCTION

In an agricultural field, the routes followed by an implement are determined by field size and shape, working width of the implement, terrain conditions, and the requirements of the crops. The position of these routes in the field is sometimes important, e.g. to position the crop rows of the current year between the positions of previous rows, or when successive machine operations within 1 year need to follow the same route, e.g. ridging over the position of seed potatoes (to prevent off-centre potato nests, which result in green potatoes) or hoeing between crop rows. Adjacent passes of machine operations also demand the best possible fit, to prevent positive or negative overlap. The accurate steering of an implement over the field requires a high rate of concentration from the driver is demanding. That is why steering aids, to lighten the duty of the driver, have been developed over many years. These aids often refer to the crop row or to markings in the field that are specially made for this purpose. However, reference to the position of the previous year crop is hardly ever possible (Muhr and Auernhammer, 1992). Differential and phase carrier GPS make it possible to determine the position in the field very accurately with respect to field unbound references (satellites). A position fix with an average error of typically 1–2 cm at a rate of 5–20 Hz is possible nowadays by manufacturer specifications, so using this technique for on-line steering of the implement is an obvious application. Computation of the steering correction, however, is limited in time because of the high refreshing rate of the positioning sensor used here (typically 5 Hz). This demands smart algorithms and reference data in order to be fast enough for controlling the steering of the implement, or of the vehicle itself. Route planning software is available from commercial companies for use in automobile, aviation, marine and geodetic survey. Off-line planning, with user-friendly graphics, make these programs very attractive. However, they are currently far too slow for supporting on-line steering purposes.

### *Major components of an Automatic Guided Vehicle*

### *Global Positioning Systems (GPS)*

The satellite positioning through Global Positioning System (GPS) is a burgeoning technology, which provides unequalled accuracy and flexibility of positioning for navigation, surveying and GIS data capture. Its development makes high accuracy spatial data easier to obtain in less time. It has a tremendous amount of application in GIS data collection, surveying and mapping. It uses satellite and computers to compute positions anywhere on earth. As a result, numerous observations and measurements can be taken at specific position and GIS can be used to create field maps based on GPS data to record and assess the impact of farm management decisions. The technology is a set of 24 satellites in high altitude orbit above the earth developed for pinpointing objects on the surface of the earth. These satellites

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continuously transmit radio signals that are picked up and deciphered by special receivers. A GPS receiver requires at least four satellites to determine its position on earth. However the raw GPS signal is not sufficiently accurate to determine position within a field. An additional signal from a known position (reference) is needed to provide the necessary accuracy, which can come from a land-based reference signal or another satellite.

***DGPS***

'Do the right thing, in the right place and in right time' – This is where GPS comes into picture. In addition, the accuracy, which is the important factor in PF, demands for DGPS (Differential Global Positioning System). GPS makes use of a series of military satellites that identify the location of farm equipment within a meter of an actual site in the field. The value of knowing a precise location within inches is that: (1) Locations of soil samples and the laboratory results can be compared to a soil map, (2) Fertilizer and pesticides can be prescribed to fit soil properties (clay and organic matter content) and soil conditions (relief and drainage), (3) Tillage adjustments can be made as one finds various conditions across the field, and (4) One can monitor and record yield data as one goes across the field. The Global Positioning System (GPS) technology provides accurate positioning system necessary for field implementation of variable rate technology (VRT). The Internet makes possible the development of a mechanism for effective farm management using remote sensing. An automatic guidance system can position a moving vehicle within 30 cm or less using high-precision DGPS. It may replace conventional equipment markers for spraying or seeding and may serve as a valuable field-scouting tool (Goddard, 1997).

***Agricultural vehicles***

A lot of research and development with autonomous vehicles for use in agriculture has been conducted the last decades. The primary agricultural activities addressed have been harvesting, mowing and applications of pesticides. Stanford University (O'Connor *et al.*, 1996) developed a system for agricultural equipment that follows a preplanned path. A four-antenna system with Differential GPS (DGPS) provided a heading accuracy of 0.1 degrees and offset accuracy of 2.5 cm. A row-following system for harvesting in cauliflower fields was also developed. (Marchant *et al.,* 1997). At Carnegie-Mellon Robotics Institute an autonomous vehicle for cutting forage using vision-based perception on the cut and uncut regions of crop was developed (Ollis *et al.*, 1996, Ollis *et al.,* 1997). The developed system used DGPS combined with wheel encoders and gyro data to compute estimates of both position and attitude. The vision sensing included functions for vehicle guidance (row-following), "end-of-row" detection, correction of illumination due to shadows and obstacle detection. An adaptive Fisher discriminate classifier was used to segment the images in cut/uncut regions by pixel wise classification based on RGB values. The obstacle detection was implemented with similar techniques where each pixel was classified as "normal" or "abnormal" relative to a training image. The probabilities for a pixel belonging to the probability distributions constructed from the training image were used to decide if the pixel belongs to an obstacle or not. Regions with a large number of such pixels were identified as obstacles. Three onboard computers were used, one for image analysis, one for control and one for task management. A pure pursuit algorithm is used for the path-tracking task. The accuracy of the GPS position estimate was constantly monitored. If it fell below a certain threshold (typically 20cm), the vehicle was halted and resumed operation when the readings were good again. The length of this break varied between 30 and 120 seconds but did on the other hand not happen very often (Pilarski *et al.*, 1999).

Computer vision is combined with fuzzy logic, genetic algorithms and neural networks in a system for "smart spraying" for weed control and detecting crop growth has been developed (Noguchi *et al.*, 1998).

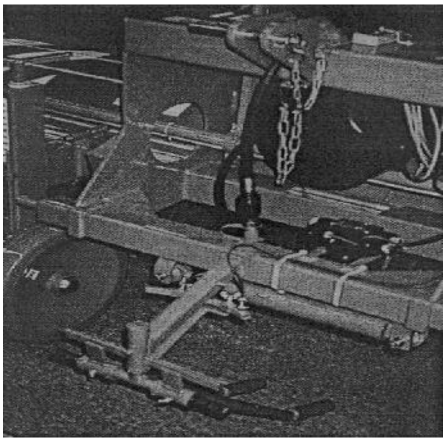

**Fig. 1:** Automatic side guiding equipment for a rotavator (Wulf, 1997)

Various manufacturers offer automatic side guiding systems for implements. The Kuratorium fur Technik und Bauwesen in der Landwirtschaft (KTBL) in Dethlingen, Germany, tested three row crop rotavators manufactured by Grimme, Germany, and Amac and Rumptstad, the Netherlands, equipped with an automatic steering device, available also for ridge weeder or ridge drill (Wulf, 1997). Fig. 1 shows one of the sensors used to trace the course of the ridge. Wheel tracers were also tested. These tracers simply operate a hydraulic valve, which compensates deviations caused by driver error by side shifting the implement.

In a project involving fusion of computer vision, Kinematic GPS and a fiber optic gyroscope (FOG) is used to guide an agricultural vehicle following crop rows. The reason to use Sensor fusion is to combine the good sides of the different sensor types while avoiding the bad sides. GPS is said to be affected by reflections from trees and obstructions, computer vision is affected by soil color and changing light levels while the FOG is subject to drifting errors. By combining the three sensor types, a better performing system was achieved. The development project for an Autonomous Christmas Christmas Tree Weeder has been initiated with a feasibility report (Have *et al.,* 2002). The aim is to develop a light Christmas tree weeder, that is "superior to the present heavy ineffective, costly and environmental detrimental equipment, and can make mechanical weed control competitive to chemical control".

In a status report on autonomous guidance of agricultural vehicles, Reid (1998) concludes that while all of these ideas might appear very strange to the average farmer, there are few scientific or technological barriers. Economics and ingenuity will determine which occur first.

Since 1978, an automatic guidance system for agricultural purposes has been available with the Claas autopilot. Originally manufactured for choppers, the modified version for tractors (shown in Fig. 2) consists essentially of three parts: The hydraulic system, the sensor system and the controller unit. The hydraulic system components are the steering valve (3), the hydraulic ram in the steering circuit (5) and the 7:2 valve (2) to switch off the standard steering equipment. The sensor system is the wheel angle sensor (11) and the mechanical sensors, which are mounted at the front of the tractor (not shown in Fig. 2). They, plugged into the connector (12), provide the third part of the system, the controller unit (6), with a voltage proportional to the excursion, i.e. the path deviation. The controller compares this voltage with the potential of the wheel angle sensor and uses the difference as output voltage to change the steering angle via the hydraulic valve.

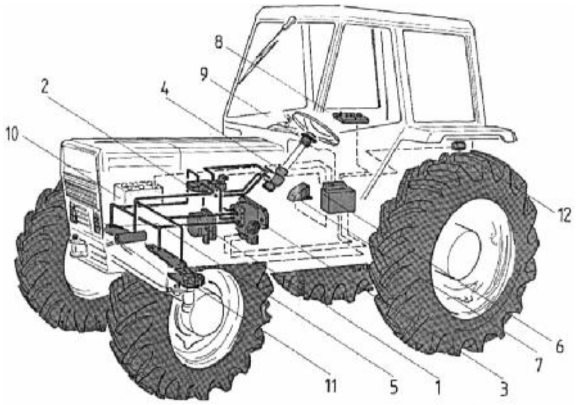


**Fig. 2:** The Claas autopilot (Keicher and Seufert, 2000)

The Claas autopilot is a perfected, reliable automatic guidance system for many kinds of agricultural vehicles. Since its introduction its acceptance was constantly increasing. According to information from Diekhans (1999), Claas sells about 90% of their choppers and 15% of their combine harvesters equipped with the automatic steering system, and about as many of their autopilots licensed in other manufacturers vehicles. That means, with about 2500 sold systems a year, it is the most common, if not the only, guidance system for agricultural vehicles purchasable in Europe. In corn, grain or sugar beet harvesting this requirement is met, but tasks like weeding or spraying require non-contact object detection.

### *Current Research Areas*

Automatic guidance of agricultural tractors has been studied over the past several decades. The potential benefits of automated agricultural tractors include increased productivity, increased application accuracy, and enhanced operation safety (Reid *et al.*, 2000). Various guidance technologies, including mechanical guidance, machine-vision guidance, radio navigation, and ultrasonic guidance, had been investigated (Reid *et al.*, 2000; Guo *et al.*, 2003).

Most previous work on tractor dynamics considered the tractor alone in attempts to investigate its ride characteristics. However, there are few agricultural operations in which implements are not used. In recent years, several studies were conducted to include the effect of rear-mounted implements on tractor ride vibration (Bukta *et al.*, 1998; Bukta, 1998; Collins, 1991; Crolla, 1976; Sakai, 2000; Sakai and Aihra, 1994), but the results are still unsatisfactory in predicting the motion of the tractor-implement system. Bukta et al.,(2002) investigated the role of the free play of the three-point hitch linkage system as a source of nonlinearity in tractor-implement systems. University of Illinois researchers have successfully developed and demonstrated a prototyped autonomous tractor that can perform autonomous planting and field cultivation (Zhang, 1999).

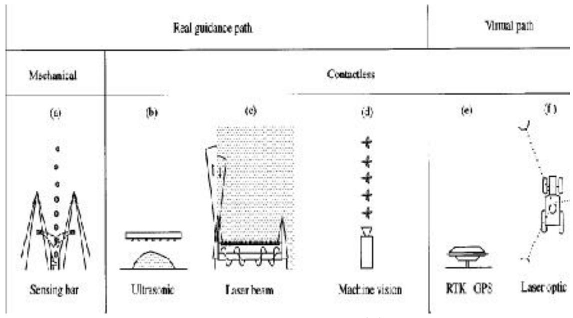


**Fig. 3:** Automatic steering systems of farm machines: (a) mechanical sensing bars; (b) ultrasonic sensors; (c) laser beam reaction; (d) machine vision; (e) real-time kinematic global positioning system and ( f ) laser optic navigation

A real-time kinematic (RTK) GPS and a Fiber Optic Gyroscope were used to provide tractor position, speed, and heading. In addition to the steering control, engine throttle, transmission speed, and 3-point hitch position were automatically controlled via a Controlled Area Network (CAN) bus based on field locations.

Both the desired tractor path and the desired tractor functions (e.g., travel speed, hitch position) were developed off-line and then loaded into the navigation computer before the field operation started. Han and Zhang (2001) gave a map-based methodology used for the implementation of autonomous field operations of agricultural tractors. In mechanical inter-row farming operations, especially during curve rows, accurate lateral control of the tractor-implement unit is required, since row space is only 76 cm (30 in). Lateral control of tractor- implement often requires estimates of tire side-slip angle and lateral velocity, which are difficult to measure directly. Several studies were conducted to estimate cornering stiffness for vehicles steering on the road. Sienel (1997) demonstrated how the cornering stiffness could be estimated by measuring dynamic vehicle parameters like lateral accelerations and yaw rate. Kitahama and Sakai (2000) presented a method for measurement method of the normalized equivalent cornering stiffness that dominated a vehicle's steering responses. Bevly *et al.*, (2001) used integrated Inertial Navigation System (INS) sensors with GPS velocity measurements for estimating tire cornering stiffness. Fig.3 shows the automated steering system of a typical farm machine.

The objective of this study was to use a dynamic model of tractor system to support navigation system design for an automatically guided agricultural tractor. This dynamic model consists of a bicycle model of the tractor. This paper showed how to estimate the cornering stiffness of the system, and how to use the estimated results for tractor navigation application.

### *Follow the carrot*

One simple approach is known as follow the carrot (Fig4). The name comes from the idea of holding a carrot in front of an animal to lure it into moving along the path. The carrot point is defined as the point on the path that is a look-ahead-distance away from them.

The orientation error of the vehicle is defined as the angle between the current vehicle orientation and the line from the vehicle to the carrot point. The vehicle steering angle is then controlled such that the orientation error is kept as small as possible. A zero orientation error means that the vehicle is pointed at the carrot point. Several problems have been observed in practice. The vehicle cuts corners and there is also a tendency to oscillate about the path. Other methods have therefore been developed.

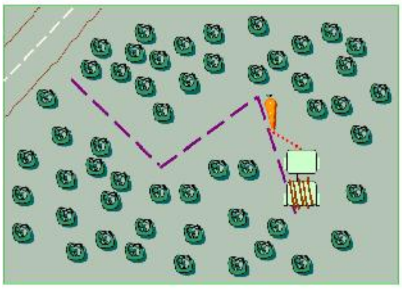

**Fig.4:** AGV following a path by waypoints. Path tracking by "following the carrot"., a method causing the AGV to take shortcuts in sharp turns

***Obstacle detection***

The main task for the perception is obstacle detection, which is essential for a safe autonomous vehicle. Detecting obstacles implies an active perception of the environment. Typical sensors for this kind of task include cameras, millimeter wave radar, and laser rangefinders (Simmons *et al.*, 1996). Laser rangefinders have the great advantage of providing accurate depth information that has to be computed from calibrated stereo images if using cameras for the same task. Radar has the advantage of working better in rain, mist and snow, and also sees beyond light vegetation such as bushes. In (Pilarski *et al.*, 1999, Ollis, 1997) images are used to identify crop lines for automated harvester. Individual pixels are classified as either cut or uncut and lines in the images are computed by regression based on these classified points. Similar techniques are used in (Byrne *et al.*, 1998] to identify trees in images, such that the diameter of the trees can be determined. Ultra-sonic sensors are also common sensors for obstacle detection. While the spatial resolution is rather low (a wide sensitivity cone) they are useful for determining the existence/non existence of obstacles in front of the vehicle. Infra-red detectors can be used to detect human presence by detection of heat radiating from the human body.

***Obstacle avoidance***

Obstacle avoidance is crucial for safe autonomous operation, and is considered to be the difficult part in this kind of construction of systems that operate in the vicinity of humans (Stentz, 2001). Several well-known methods for obstacle detection have been proposed. Potential fields (Khatib, 1985, Krotkov *et al.,* 1995) is the classical approach where the desired heading of the vehicle is computed as the vector sum of repulsive and attractive forces associated with objects in the environment of the vehicle. The method was later combined with the concept of certainty grids (Moravec, 1985), a mapping technique for sensor data accumulation and data fusion. The resulting method was named Virtual Force Field VFF [Borenstein *et al.*, 1989). Vector field histograms VFH (Borenstein *et al.*, 1991] is an improvement using polar histograms with inverted distance information. Openings in the histograms indicate open areas for the robot to travel through. The robot velocity is chosen proportional to the obstacles. VFH overcomes the problems with local minima and instability associated with potential fields. Also, it recognizes the fact that a vehicle typically moves along arcs, rather than in straight lines. A further development, VHF+ [UlBo98], reduces some of the parameter tuning in VHF and also compensates explicitly for the robots width. The method is implemented and tested on the Guide Cane, which is a guidance device for the blind. When the Guide Cane encounters an obstacle, it steers around it. The VHF+ method is reported to give a more reliable and smooth trajectory than when using the unmodified VHF method.

The Curvature-Velocity Method CVM (Simmons, 1996) operates in velocity space rather than Cartesian space, and takes into account constraints in dynamics and assumes circular movements rather than linear ones. Other techniques for obstacle avoidance are Elastic bands (Quinlan *et al.*, 1993) and Nearness diagrams (Minguez *et al.*, 2000).

## CONCLUSIONS

A lot of research and development with autonomous vehicles for use in agriculture has been conducted the last decades. The primary agricultural activities addressed have been harvesting, mowing and applications of pesticides. Looking further into the future, driverless, autonomous machines will significantly alter the character of agricultural machinery.

Automatic guidance of agricultural tractors has been studied over the past several decades. The potential benefits of automated agricultural tractors include increased productivity, increased application accuracy, and enhanced operation safety. Various guidance technologies, including mechanical guidance, machine-vision guidance, radio navigation, and ultrasonic guidance, had been investigated. More research need to carry out based on the different sensors in the off-road vehicles in the actual field conditions.

## Reference


1. Muhr, T., Auernhammer H., 1992. Technische Mo¨ glichkeiten zur Ortung landwirtschaftlicher Fahrzeuge im Feld. In: Ortung und Navigation landwirtschaftlicher Fahrzeuge. VDI:MEG Kolloquium Agrartechnik, Du¨ sseldorf, pp. 49–56.
2. Goddard, T. (1997). What is precision farming. In Proceedings of the Precision Farming Conference, January 20 -21. Taber, Alberta, Canada.
3. O'Connor, M., Bell, T., Elkaim, G. & Parkinson, B. (1996). Automatic Steering of Farm Vehicles Using GPS. In Proceedings of the 3rd International Conference on Precision Agriculture, June.
4. Marchant, J. A., Hague, T. & Tillet, N. D. (1997). Row-following accuracy of an autonomous vision-guided agricultural vehicle. Computers and Electronics in Agriculture, 16(2), 165-175.
5. Ollis, L. & Stentz, A. (1996). First results in vision-based crop-line tracking. In Proceedings of the IEEE Robotics an Automation Conference, Minneapolis, MN, 951-956.
6. Ollis, L. & Stentz, A. (1997).Vision-based harvester for an automated harvester. IROS.
7. Pilarski, T., Happold, M., Pangels, H., Ollis, M., Fitzpatrick, K., and Stentz, A. (1999). The Demeter System for Automated Harvesting. In Proceedings of

the 8th International Topical Meeting on Robotics and Remote Systems, April.
8. Noguchi, N., Reid, J.F., Will, J., & Benson E. (1998). Vehicle automation system based on multi-sensor integration. ASAE Paper 983111. St. Joseph, MI. UILU-ENG-98-7021.
9. Have, H. (2002). Autonomous weeders for Christmas tree plantations - a feasibility study. Pesticides Research Nr. 59, Danish Environmental Protection Agency, Danish Ministry of the Environment.
10. Reid, J. F. (1998). Precision Guidance of Agricultural Vehicles. SME Meeting, Sapporo, Japan, UILU-ENG-7031.
11. Reid, J.F., Zhang, Q., Noguchi, N. & Dickson, M. (2000). Agricultural automatic guidance research in North America. Computers and Electronics in Agriculture, 25,155–167.
12. Bukta, A.J. (1998). Nonlinear dynamics of traveling tractor-implement system generated by free play in the linkage. Journal of Japanese Society of Agricultural Machinery, 60(4), 45–53.
13. Bukta, A.J., Sasao, A., Sakai, K. & Shibusawa, S. (1998). Nonlinear Dynamics of Tractor-implement System during Transport. ASAE International Meeting. ASAE, 981087.
14. Bukta, A.J., Sakai, K., Sasao, A., & Shibusawa, S. (2002). Free play as a source of nonlinearity in tractor-implement systems during transport. Transactions of the ASAE, 45(3), 503–508.
15. Collins, T.S. (1991). Loads in tractor linkages when transporting rear-mounted implements: Development of modeling and measurement techniques. J. Agricultural Engineering Research, 49, 165–188.
16. Crolla, D.A. (1976). Effect of cultivation implements on tractor ride vibration and implications for implement control. J Agricultural Engineering Research, 21, 247–261.
17. Sakai, K. (2000). Experimental analysis of nonlinear dynamics and chaos in bouncing tractor. J Japanese Soc. of Agricultural Machinery, 62(4), 63–70.
18. Sakai, K. & Aihra, K. (1994). Nonlinear vibrations in an agricultural implement system. Int. J. Bifurcation and Chaos, 4(2), 465–470.
19. Zhang, Q. (1999). Automated guidance control for agricultural tractor using redundant sensors. Journal of Commercial Vehicles, 108, 27–31.
20. Sienel, W. (1997). Estimation of the tire cornering stiffness and its application to active car steering. In Proceedings of the IEEE Conference on Decision and Control, 5, 4744–4749.
21. Kitahama, K. & Sakai, H. (2000). Measurement method of normalized cornering stiffness. J Japanese Soc. of Agricultural Engineering, 21(2), 213–217.
22. Bevly, D.M., Sheridan, R. & Gerdes, J.C. (2001). Integrating INS sensors with GPS velocity measurements for continuous estimation of vehicle sideslip and tire cornering stiffness. In Proceedings of the American control conference,7, 25–30.
23. Wulf, B. (1997). Automatische Seitensteuerung bei Pflegegeräten und Erntemaschinen. VDI Landtechnik 3, 130–131.
24. Byrne, J. & Singh, S. (1998). Precise Image Segmentation for Forest Inventory. CMU-RI-TR-98-14, Carnegie Mellon University.
25. Stentz, A. (2001). Robotic Technologies for Outdoor Industrial Vehicles. In Proceedings of SPIE AeroSense Orlando.
26. Khatib, O. (1985). Real-time obstacle avoidance for manipulators and mobile robots. In Proceedings IEEE International Conference on Robotics and Automation, St. Louis, pp. 500-505.
27. Krotkov, E., Hebert, M. & Simmons, R. (1995). Stereo Perception and Dead Reckoning for a Prototype Lunar Rover. Autonomous Robots, Vol. 2, No. 4, pp 313-331, 1995.
28. Moravec, H. & Elfes, E. E. (1984). High Resolution Maps from Wide Angle Sonar. In Proceedings of the 1985 IEEE International Conference on Robotics and Automation, St. Louis, March, pp 116-121.
29. Borenstein, J. & Koren. (1989). Y. Real-time Obstacle Avoidance for Fast Mobile Robots. IEEE Transactions on Systems, Man, and Cybernetics, 19(5), pp. 1179-1187.
30. Quinlan, S. & Khatib, O. (1993). Elastic Bands: Connecting Path Planning and Control. IEEE International Conference on Robotics and Automation.
31. Minguez, J. & Montano, L. (2000). Nearness Diagram Navigation (ND): A New Real-Time Collision Avoidance Approach. In Proceedings IEEE/RSJ International Conference on Intelligent Robots and Systems, Takamatsu, Japan.
32. Keicher R. & Seufert H. (2000). Automatic guidance for agricultural vehicles in Europe. Computers and Electronics in Agriculture, 25, 169–194.
33. Diekhans, N. (1999). Claas Industrietechnik product information, CIT development department.
34. Guo, L., Zhang, Q. & Feng, L. (2003). A Low-Cost Integrated Positioning System of GPS and Inertial Sensors for Autonomous Agricultural Vehicles. ASAE International Meeting, ASAE, 033112.
35. Simmons, R. (1996). The Curvature-Velocity Method for Local Obstacle Avoidance. In Proceedings International Conference on Robotics and Automation, April.

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