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Automatic steering with DGPS

Procedural automation in an agricultural machine can make life easier for the driver. Where the steering system is fitted with a very exact dual frequency DGPS receiver, a navigation system and a hydraulic steering control, the farm machine can then automatically follow pre-determined directions. The driver can then concentrate on other tasks. The results of first driving trials with a silage harvester steered automatically along straight, stepped, angular and curved routes, on metalled and unprepared surfaces, are presented. Additionally, the influence on steering performance of different positioning of the GPS antennas was investigated.

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Farm machinery can be efficiently managed through automatic control of operational procedures, especially on large fields. The driver is thus relieved of monotonous and tiring tasks. The steering of an agricultural machine demands a high level of concentration from the operator. Exact lining-up for new bouts with broad working widths are often no longer possible. Dazzle or darkness can cause additional deterioration in working conditions. Automatic steering offers substantial relief for the driver. With it, he can direct his attention to the control and supervision of other important functions of the farm machine.

Many position sensors for automatic steering have already been investigated on agricultural vehicles (1, 2, 3). Conventional GPS receivers employ only one transmitting frequency from satellites and offer, with appropriate corrective data, a fixed reference station (DGPS system) with a precision of under a metre. In comparison, very precise receivers additionally use the second GPS transmission frequency. With this dual frequency DGPS receiver, positions with accuracy in centimetres can be calculated with up to 20 Hz. These are suitable for navigation purposes in agriculture in that positioning is independent of the fieldwork, the time of day and the extent of the working area. Up until now, these have been investigated in the form of multi-antenna DGPS (4, 5, 6) and DGPS with gyroscope (7). They represent a costly sensory technique. First driving trials with DGPS as sole sensor were carried out with a combine harvester (8).

At the Institute for Agricultural Engineering in Hohenheim a silage harvester (Claas Jaguar 820) was equipped with an automatic steering device based on a dual frequency DGPS receiver. In the following report the fitting of the automatic steering and the first results from practical trials on different predetermined routes are described.

Fitting the automatic steering

The automatic steering equipment comprises the GPS unit, the navigation system and the hydraulic steering device (*Fig. 1*).

A dual frequency GPS receiver is used for the vehicle as well as for the fixed reference station. The measurement setting represented 5 Hz. The positioning precision represents 3 cm. Under favourable conditions a precision of 1 cm was determined.

The navigation system hardware comprises a notebook PC and a parallel port adapter. The type and course of the route to be followed is fed into the navigation program by the user. Because of the momentary lateral displacement of the GPS antennae and the orientation error, the steering angle is determined according to the actual section of the route. To improve turning performance, the mid-positioning of the steering wheel is independently pre-set according to the theoretically required turning angle, assessed from the radial curveof the bend.

The positioning signals of the navigation system are transmitted to the hydraulic steering control. A proportional valve controls the oil flow in the steering cylinder and thereby the position of the steering wheel. The reporting back of the vehicle position to the GPS receiver is shown as a line in Fig. 1 because under certain conditions the connection can be lost due to poor GPS readings. The maximum steering angle is limited to ±

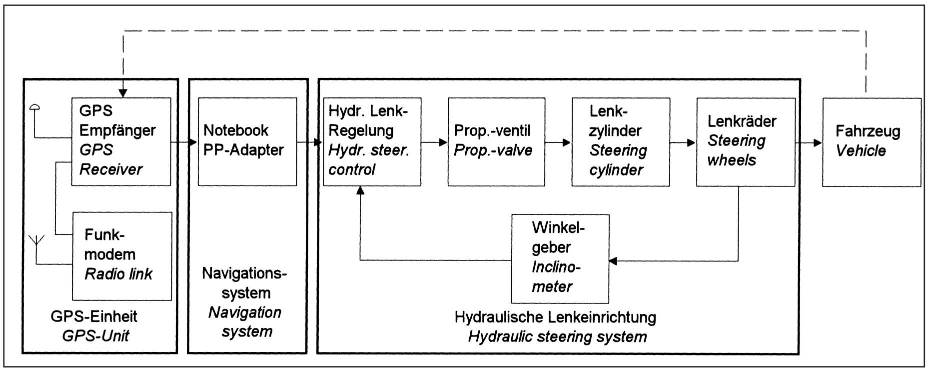

Fig. 1: Design of the automatic steering system

Table 1: Standard deviation of lateral offset and heading of driving investigations along a straight path (Results of the manual steering in parentheses)

Driving surface	1 m/s		1,25 m/s		1,5 m/s		2 m/s	
	Displace-ment (cm)	Orientation error (°)	Displace-ment (cm)	Orientation error (°)	Displace-ment (cm)	Orientation error (°)	Displace-ment (cm)	Orientation error (°)
Asphalt	2,5 (10,8)	1,3 (3,0)	3,0 (8,2)	1,5 (1,6)	2,5 (11,0)	2,4 (1,5)	6,9 (7,9)	3,2 (1,5)
Perm. pasture	2,8 (8,1)	3,4 (2,9)	3,1 (6,9)	3,2 (2,4)	2,9 (9,0)	3,2 (1,9)	6,2 (7,2)	3,0 (1,7)

Table 2: Maximal lateral offset and standard deviation of lateral offset and heading at 50 cm lateral path step with automatic steering on a meadow (drives on street in parentheses)

	1 m/s	1,25 m/s	1,5 m/s
Max. dis-placement (cm)	17,7 (10,4)	23,8 (9,9)	7,6 (12,3)
Displace ment (cm)	10,0 (7,6)	10,0 (7,8)	10,9 (9,8)
Orientation-error (°)	3,4 (2,0)	3,4 (2,2)	3,5 (3,4)

Table 3: Maximal lateral offset and standard deviation of lateral offset and heading at 10° change of path course with automatic steering on a meadow (drives on concrete in parentheses)

	1 m/s	1,25 m/s	1,5 m/s
Max. dis-placement (cm)	24,1 (23,4)	27,0 (48,4)	51,0 (29,6)
Displace-ment (cm)	5,9 (7,1)	6,6 (13,4)	11,7 (7,8)
Orientation-error (°)	4,4 (3,7)	4,1 (4,6)	4,7 (3,8)

Table 4: Maximal lateral offset and standard deviation of lateral offset and heading at 15° course change with automatic steering on a meadow (drives on concrete in parentheses)

	1 m/s	1,25 m/s	1,5 m/s
Max. dis-placement (cm)	44,3 (45,2)	50,1 (64,0)	74 (70,8)
Displace-ment (cm)	10,7 (10,6)	12,6 (16,4)	18,3 (17,7)
Orientation-error (°)	4,5 (5,6)	4,5 (4,5)	5,6 (4,4)

10.6°. A transmitter at the left rear wheel measures the actual steering angle and transmits the information back to the hydraulics control unit.

Driving investigations under various conditions

The performance of automatic steering was tested on permanent pasture on straight, stepped, angular and curved routes. In order to determine the influence of different driving surfaces on directional stability and therefore on the positioning precision of the GPS-antenna which is set at 390 cm height, additional comparison drives were carried out on metalled surfaces. All measurements are basically related to the antenna position. The GPS antenna in standard position was set 150 cm before the front axle.

Straight course

The precisely straight working line is of great importance for the majority of agricultural operations. Directional help in the form of crop borders, plant rows or tramlines are not always available or are difficult for the driver to identify. Because of this, the driving characteristics on a straight course were investigated, first with manual and then with automatic steering. Because no header was mounted on the silage harvester, the driver had no directional orientation point in front of him. The only directional aid was the edge of the road or the border of a neighbouring field which was about 50 cm to the side. The results of the driving investigations are summarised in *Fig. 1*.

On both driving surfaces and at all speeds the automatic steering showed smaller lateral deviation from the course than that of manual steering. The standard deviation of orientation error is basically greater in the automatic mode. Comparing performance on metalled and on unprepared driving surfaces, minimal differences in precision of displacement and vehicle orientation can be noted. In manually steered vehicles on permanent pasture, smaller standard deviations for displacement and angle error are measured. With automatic steering, the results for the metalled driving surface are better, with the exception of 2 m/s speeds.

Steps in the working line

In order to investigate the reaction of automatic steering to a change in conditions, a deviation, or step, in straight line travel was integrated. After 30 m of straight course, a lateral step of 50 cm was integrated into the same direction. The standard deviations from lateral displacement and angle errors over the whole working line are shown in *table 2*. Additionally the maximum lateral displacement after the change in course is given.

The results show a maximum lateral displacement of up to 23.8 cm after the course change at a speed of 1.25 m/s over an unprepared surface. After the step in the course, the working line could be further followed, in all settings, with the standard of navigation precision normal for straight-ahead driving.

Angular working line

Alongside straight working lines, minimum changes in course direction are mostly also of importance. The simplest form of a directional change is represented by a route including corners. The characteristics of the automatically steered silage harvester in directional changes from 10° and 15° were investigated. The corner position was integrated into the working line after a straight drive of 30 m. In *tables 3 and 4* the results for displacement and orientation error are presented. Additionally, the maximum displacement after the initiating of the directional change is given.

The results at a speed of 1.5 m/s indicate a maximum lateral displacement of up to 74 cm after the change in direction. On the metalled driving surface, a greater displacement was measured for speeds of 1 m/s and 1.25 m/s compared with results on unprepared driving surfaces. After the change in direction, the working line could be continued with the navigation precision standard for straight courses.

Curves

As an alternative to directional changes through angled working lines, changes in the form of arcs were investigated. In the first investigation, the average steering angle was not matched to the radius of the curve.

Following a straight approach of 10 m, a curve with a radius of 30 m was initiated in the course. There appeared an average lateral displacement of 19.5 cm as measured on the outside of the curve with a standard deviation of 10.1 cm. The standard deviation of the angle error was 5.7°. When, however, the mid-position of the steering wheel was matched to the appropriate curve radius, the average lateral displacement was reduced to 1.5 cm. The standard deviation from lateral displacement and orientation error remains approximately the same, at 9.7 cm and 6.1°.

Influence of antenna position

The influence of the GPS antenna's position was investigated on permanent pasture with a 5 m lateral step deviation from the working line and a speed of 1 m/s. The antennas were fitted at distances before the front axle at 0 cm, 75 cm, 150 cm and 175 cm. In the first trial the transmission constants for displace-

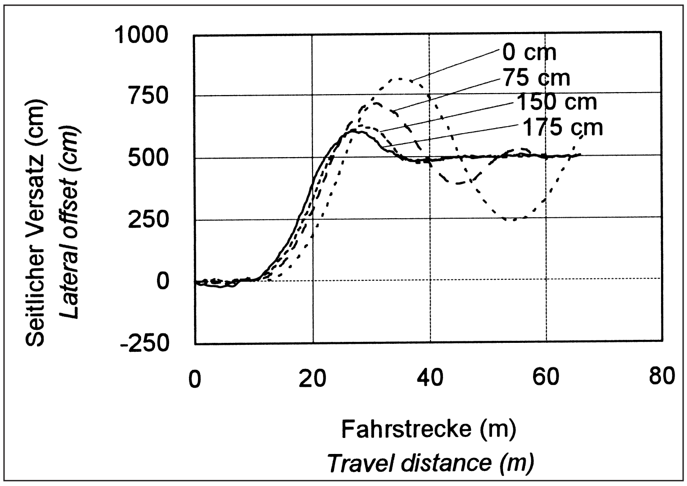

Fig. 2: Influence of the GPS-antenna, 1 m/s, 5 m path step, driveway: meadow

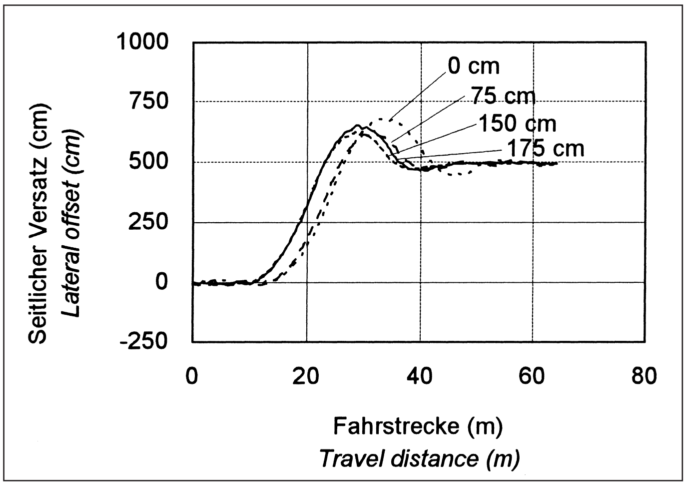

Fig. 3: Influence of the GPS-antenna with adapted parameters, 1 m/s, 5 m path step, driveway: meadow

ment and orientation error were not altered. The development of the lateral displacements for the four positions is shown in *Fig. 2*. Where the GPS antenna was mounted directly over the front axle the vehicle could not be stabilised.

The second trial was held under the same conditions except that transmission constants were matched to the altered positions of the GPS antennas (*Fig. 3*). The development of the lateral displacements is approximately the same for all four positions. The response is slower with the 0 cm and 75 cm positions compared with those further away.

Conclusion and outlook

A silage harvester was equipped with a dual frequency DGPS receiver, a navigation system and a hydraulic steering control. The reaction of the steering control was investigated in different types of working routes. For straight routes, lateral displacement of 6.9 cm on an unprepared surface at 2 m/s was measured. The navigation precision of a vehicle with a swaying directional movement was reduced through the high position of the GPS antenna. On a straight course steering was more exact with automatic steering compared with manual steering. Directional changes in working line through a 15° angle caused a short-term lateral displacement of up to 74 cm. The steering angle was adjusted according to the radius of the arc for driving in a curve. With this it was possible to reduce the lateral displacement towards the outside of the curve. In the example of a 5 m lateral step in the working line, the position of the GPS antennas showed, with the same transmission constants, a substantial influence on the steering performance. This influence could be reduced through a matching of the constants.

Here, first results from trial drives carried out since mid-March 1999 have been presented. In continuing work, the up-until-now simple concept of automatic steering must be improved with regard to influence of speed on inconsistencies of drive characteristics. In future the drive investigations should also be carried out on more difficult driving surfaces that cause greater wheelslip as well as more pronounced swaying. It then has to be discovered how an automatic steering system with a dual frequency DGPS receiver can be developed as single sensor for navigation.

Literature

[1] *Jahns, G.* and *R.E. Young*: Automatic guidance of farm vehicles. Agricultural Engineering Department Series, 1, R.E. Young (Ed) Agricultural Experiment Station, Auburn University, Alabama, 1976

[2] *Tillet, N.D.*: Automatic guidance sensors for agricultural field machines. A review. Journal of Agricultural Engineering Research 50 (1991), no. 3, pp. 167 – 187

[3] *Sevila, F.* and *P. Baylou*: The principles of robotics in agriculture and horticulture. Progress in agricultural physics and engineering. J. Matthews (Ed) CAB International (1991), pp. 119 – 147

[4] *O'Connor, M.L. et al.*: Carrier-phase DGPS for closed loop control of farm and construction vehicles. Navigation 43 (1996), no. 2, pp. 167 – 178

[5] *O'Connor, M.L. et al.*: Automatic steering of farm vehicles using GPS. 3rd International Conference on Precision Agriculture, Minneapolis, Minnesota, 1996

[6] *Elkaim, G.H. et al.*: System identification and robust control of farm vehicles using CDGPS. ION Conference, Kansas City, M.O., 1997

[7] *Nagasaka, Y. et al.*: Autonomous rice transplanting system with GPS and FOG. AgEng Conference, Oslo, 1998, AgEng-Paper No. 98-A-043

[8] *Cordesses, L. et al.*: Combine harvester control using real time kinematic GPS. 2nd European Conference on Precision Agriculture, Odense, 1999, pp. 867 – 876