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Measuring Method to Determine the Driving Accuracy of GPS Guided Machines

To evaluate the driving accuracy of automatically steered agricultural machines equipped with GPS navigation, a suitable reference measuring method is needed. Different measuring methods have been analysed and evaluated in a detailed study at the Institute of Agricultural Engineering of Hohenheim University. The inductive method was a compromise between accuracy and flexible applications and is common for automated guided vehicle systems. With the inductive measuring device used, the lateral offset of the GPS guided machine has an accuracy rate of ~ 5 mm. Yaw and roll movements have minimal influence.

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Keywords

Driving accuracy, GPS-guidance, inductive reference measuring method

An overall concept of an automatically guided harvester has been developed and investigated at the Institute of Agricultural Engineering at the Hohenheim University [1]. The Global Positioning System (GPS) plays an important role. Real Time Kinematic GPS (RTK GPS) receivers process the signals of the satellites and send precise positioning and motion data to the control software of the machine. The control software calculates control values based on the GPS data and the machine's guidance path and transmits them to steering and power train. With that set-up, the machine can be driven automatically without any manual interrupt in the field. In order to objectively assess and to enhance the automatic guidance system, the driving accuracy is of particular interest. In this case, driving accuracy is defined as the lateral offset to a straight or curved guidance path.

The measuring equipment should be completely decoupled from the automatic guidance system. The accuracy should be much better than the accuracy of the RTK-GPS receiver used for the automatic guidance. A lateral measurement error was set not exceeding 30 mm in a range of ± 250 mm. Herein, the proper motions around the main axles of the machine caused by drives on uneven ground should be already considered.

State of the art

Two measuring methods were described in [2] which were used to determine the driving accuracy of an automatically steered tractor on even ground. A self-tracking tachymeter was used in the first trial, which measured the distance and the angle to the surveyed object. A laser beam was reflected at a prism, which was mounted on the tractor roof in this investigation. Problems occurred because the measuring error depended on the distance between tachymeter and prism. Additionally, the high position of the prism is unfavourable for the measuring precision due to vehicle roll. As an alternative, a distance laser came into operation which was mounted under the rear axle. The distance to pylons was measured, which were placed on the track. The laser measurements represented the lateral offset to the guidance path. The number of measurements depends on the number of pylons. These results were crucial for searching further measuring methods for the own project.

Mechanical, optical, acoustic and inductive positioning methods known for automated guided vehicle systems were analysed and assessed regarding their suitability for investigations with agricultural machines [3]. The inductive measuring system was chosen as suitable alternative because it is a precise and very flexible low-cost measuring system.

Basic principles of inductive measuring methods

A single core wire is placed at the demanded guidance path. A frequency generator supplies the wire with alternating current (10 kHz). The measuring antenna is mounted under the vehicle and consists of a cross coil system with two perpendicularly arranged coils. The magnetic field induces the sum voltage U_S in the horizontal coil and the difference voltage U_D in the vertical coil. The lateral offset x can be calculated with eq. (1) or eq. (2), if a constant height of the measuring antenna is assumed. With the help of eq. (2) it can be calculated on which side of the guidance wire the cross coil system is located. The influence of the antenna height can be compensated, if both voltages are considered for the evaluation of the lateral offset (eq. 3).

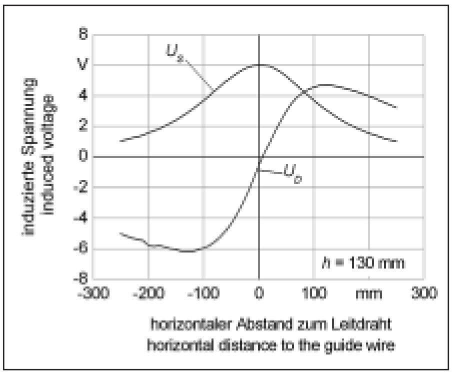

Fig. 1: Induced voltages in horizontal and vertical coil

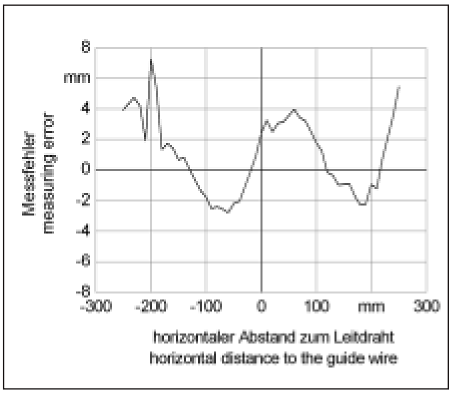

Fig. 2: Measuring error for the lateral deviation

$$U_S = \frac{K_S \cdot I \cdot h}{x^2 + h^2} \tag{1}$$

$$U_D = \frac{K_D \cdot I \cdot x}{x^2 + h^2} \tag{2}$$

$$x = \frac{U_D \cdot K_D \cdot I}{U_D^2 + \frac{K_D^2}{K_S^2} \cdot U_S^2} \tag{3}$$

The current I in the wire is controlled by the frequency generator and can be assumed to be constant. The constants K_S and K_D are coil specific parameters. Yaw influence on the measuring accuracy is negligible. Roll influence depends on the height of the measuring antenna. A suitable compromise between ground clearance and roll influence had to be found.

Measuring error of the inductive measuring method

A height of 130 mm for the measuring antenna was chosen. An error of less than 5 mm in the lateral offset determination would occur with an assumed roll angle of 2°. *Figure 1* shows the induced voltages U_S and U_D. A positive distance means a coil location to the right side of the guidance wire. The calibration function according to eq. (3) was derived with these voltages in order to calculate the lateral offset. *Figure 2* shows the measuring error of the calibration for a range of ± 250 mm. The claimed measuring error not exceeding 30 mm can be fulfilled for this range. The measuring error increases with increasing distance of the cross coil system due to low gradients of the voltages U_S and U_D. The height of the antenna can be increased if a larger range is required. However, a larger measuring error will result. As an alternative, two further cross coil systems can be placed to the right and the left side of the existing system.

Set-up of the inductive measuring device

The cross coil system was placed under the non-steered front axle of the machine (*Fig. 3*). In order to keep the minimum distance to disturbing metal parts, the cross coils system is built in a plastics housing. The measuring antenna can be exactly fixed under the machine with various adjustment facilities. The whole device can be easily detached for transport drives.

The guidance wire is a very flexible single core wire with a cross-section of 6 mm^2. The wire's PVC outer sheath is very suitable for outdoor applications. For investigations on asphalt, the guidance wire is fixed with tape on the track. On grass the wire is fixed with u-shaped metal clamps on the ground. Preliminary tests showed no influence of the metal clamps on the measurements. It is recommended to keep a distance of 10 m between the guidance wire and the return wire. After fixing the guidance wire, all characteristic points are surveyed with RTK GPS such as start and end point, vertexes and midpoints of the arcs. At least 50 GPS measurements are averaged for each survey point.

A further RTK GPS receiver is used as second measuring system in order to determine the lateral offset. The GPS antenna is placed on the cabin above the middle of the front axle of the test machine. The induced voltages and the GPS data of the additional receiver are acquired on a notebook. The measuring equipment is summarised in *Table 1*.

Conclusion

The inductive measuring method was chosen as suitable solution, in order to determine the driving accuracy of automatically guided agricultural machines. Voltages are induced in a cross coil system by a wire conducting alternating current. The cross coil system mounted under the machine is placed close to the ground. Therefore, roll influences of the machine are very small. Due to the perpendicular arrangement of the coils, variations in the height over ground can be compensated. The guidance wire represents the demanded driving course of the machine. The wire is surveyed with static GPS measurements, which are transferred to the navigation system of the machine. Various course shapes can be realised with the very flexible guidance wire. The number of reference measurements is only limited by the measuring frequency of the data acquisition.

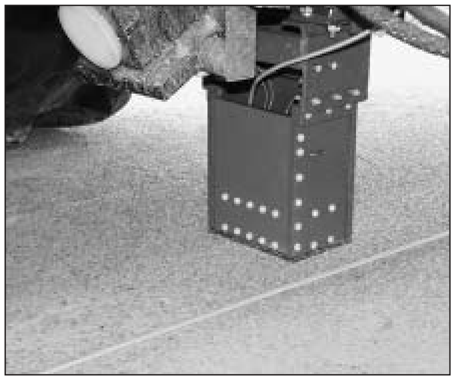

Fig. 3: Guide wire and plastics housing for coils

Gerät	Bezeichnung	Kenndaten
Messantenne	Fa. Götting HG 19330	Betriebsspannung U_B = 24 V Ausgangsspannungen U_S = -10 bis +10 V U_D = -10 bis +10 V
Frequenzgenerator	Fa. Götting HG 57400	Betriebsspannung U_B = 24 V Ausgangsfrequenz f = 10 kHz
Leitdraht	Fa. Kabelwächter Kaweflex 5115	PVC PUR Steuerschleppleitung Querschnitt 1 x 6 mm^2 Länge 220 m
GPS zur Leit- drahtvermessung	Fa. Trimble RTK-GPS 4700	Messfrequenz 5 Hz Korrekturdaten der eigenen Referenz station
GPS zur Fahrkurs- aufzeichnung	Fa. Trimble RTK-GPS 7400MSI	Messfrequenz 5 Hz Korrekturdaten der eigenen Referenz station

Table 1: Measuring equipment

Literature

[1] *Stoll, A. und H.D. Kutzbach*: Führung von Landmaschinen mit GPS. Tagungsband VDI-MEG Tagung Landtechnik, Münster, 10./11.10.2000, S. 331-336

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