AUTOTRAC - ACCURACY OF A RTK DGPS BASED AUTONOMOUS VEHICLE GUIDANCE SYSTEM UNDER FIELD CONDITIONS

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ABSTRACT

Since about two years, autonomous guidance systems for agricultural machines are commercially available and their usage in practice is increasing. The technology is generally based on the Global Positioning System (GPS) with differential correction (DGPS) or Real Time Kinematic (RTK) DGPS. Inertial guidance technology is often used for dead reckoning and roll and pitch compensation. Until now, only limited information is available on the accuracy in practical use under typical and often difficult agricultural field conditions (side slope, wheel slip).

The tested system (AGRO NAV®, GEO TEC electronics GmbH, Germany) was implemented on a standard tractor (MF 4255) and utilized RTK DGPS and an Inertial Measurement Unit (IMU) for navigation. Besides the steering, the system controlled also the engine, the clutch, the power take-off (PTO) and the whole hydraulic system (three-point linkage and remote valves).

To investigate the basic accuracy, two independent geodetic RTK DGPS rovers have been used as reference system. The measured accuracy in following a track (on a road) was about ± 25 mm with a maximum deviation of 100 mm. Field tests during winter wheat seeding showed a similar accuracy. But the downhill drift of the implement and the downhill yawing of the rear of the tractor resulted in deviations of up to 240 mm from path to path.

This system showed the great potential of RTK DGPS based auto guidance technology. Although equipped with a very efficient inertial system, limitations could be detected while working on side hill / cross slopes with three point mounted implements caused by yawing.

KEYWORDS. Automatic Guidance, Automatic Steering, Electronics, GPS, Precision Agriculture.

INTRODUCTION

Within the last ten years, the Global Positioning System (GPS) has gained more and more acceptance and usage in agricultural practice. Since the first utilization for yield mapping in the early 1990's, GPS receiver technology improved dramatically. The accuracy and reliability raised, whereas the price went down comparable to Personal Computers. This trend is mainly driven by the permanent performance growth of microcontrollers, but also by more sophisticated position calculation algorithms. A continuation of this trend seems to be sure, regarding next generation GPS satellite technology (GPS III) and the launch of the European system Galileo until 2008. The technological progress in positioning technology allowed the design of new agricultural systems,

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ranging from simple navigation aids up to fully automated field robots. The latter seems to be one of the most challenging principles for solving the problems and requirements of agricultural machinery in future.

Since about two years, autonomous guidance or steering systems for agricultural machines, especially tractors are commercially available. As machine vision systems still have unsolved difficulties (Marchant et al., 1997), the technology for autonomous navigation is generally based on Carrier Wave Smoothed Two Frequency DGPS or Real Time Kinematic (RTK) DGPS to ensure the required top level accuracy (Noguchi et al., 2001, 2002, Auernhammer et al. 1991). Most of the systems additionally use inertial guidance technology for dead reckoning and roll and pitch compensation.

For utilizing the advantages of this technology, the stable accuracy plays a major role besides of other factors like operational availability. Until now, a few investigations have been carried out under ideal conditions (Freimann, 2000) or by evaluating the write-back information of the system. Only limited information is available on the accuracy in practical use under typical and often difficult agricultural field conditions like wet soil on side slopes and different speeds.

This paper presents a reference measuring system for verifying the accuracy of such systems as well as investigations under problematic field conditions.

AGRO NAV® SYSTEM SETUP

The first commercial system for agricultural vehicles was AGRO NAV®, developed by GEO TEC electronics GmbH in Germany (Bittner, 2000). It is designed to be implemented on a broad range of tractors, whereas the adaptation complexity depends on the capabilities of the basic platform.

A schematic overview of the AGRO NAV® system setup is shown in Figure 1. A basic tool within the system is the AGRO NAV PLAN® software (Glasmacher, 2002). This software is responsible for mission planning, task management, documentation and data exchange with the mobile unit.

The navigation computer GT 2000 (Ostermeier, 2000) is a ruggedized Pentium based embedded PC with operating system. A hardware handshaked RS232 link connects a high precision RTK DGPS receiver (Ashtech Z-Eurocard) with integrated radio data link (UHF). Via two RS485 links, a specifically designed Inertial Measurement Unit (IMU) is connected. The IMU contains one high precision Fibre Optic Gyroscope (FOG) and two accelerometers for providing triaxial information. The GT 2000 processes both sources by using Kalman Filter technology and navigation algorithms. Data for documentation and task control can be interchanged by PCMCIA card or USB port. A CAN port allows the communication with and control of implements by using the standardized protocols LBS (DIN 9684) or ISOBUS (ISO 11783). The GT 2000 acts here as a Virtual Terminal (VT) to control implements.

A CAN port using a proprietary protocol connects the GT 2000 with the vehicle controller. The vehicle controller manages the whole range of actuators and several sensors in the system. The hardware platform is a 16-bit embedded controller with multiple I/O ports (ESX-STW, Infineon 167 series). It controls the steering, the engine, the brakes, the hydraulic valves and others.

However, this is not done directly, but via a special system monitoring unit. The connection between the vehicle controller and the system monitoring unit is a proprietary parallel port connection using multiple I/O's. All control and safety functions in this unit are hardware implemented. Via signal and power output ports, the proportional valve for steering, the electro-hydraulic braking system, the gearbox and the engine (throttle actuator) are controlled. Several input ports deliver information of the radar odometer, the seat pressure sensor, the emergency-stop-button or the steering angle sensor. This system design guarantees a very high safety and security level, which is often not addressed by other systems.

For testing in 2001 and 2002, this system was implemented on a standard tractor from Massey Ferguson (MF 4255). Besides the steering, also the engine, the clutch, the power take-off (PTO)

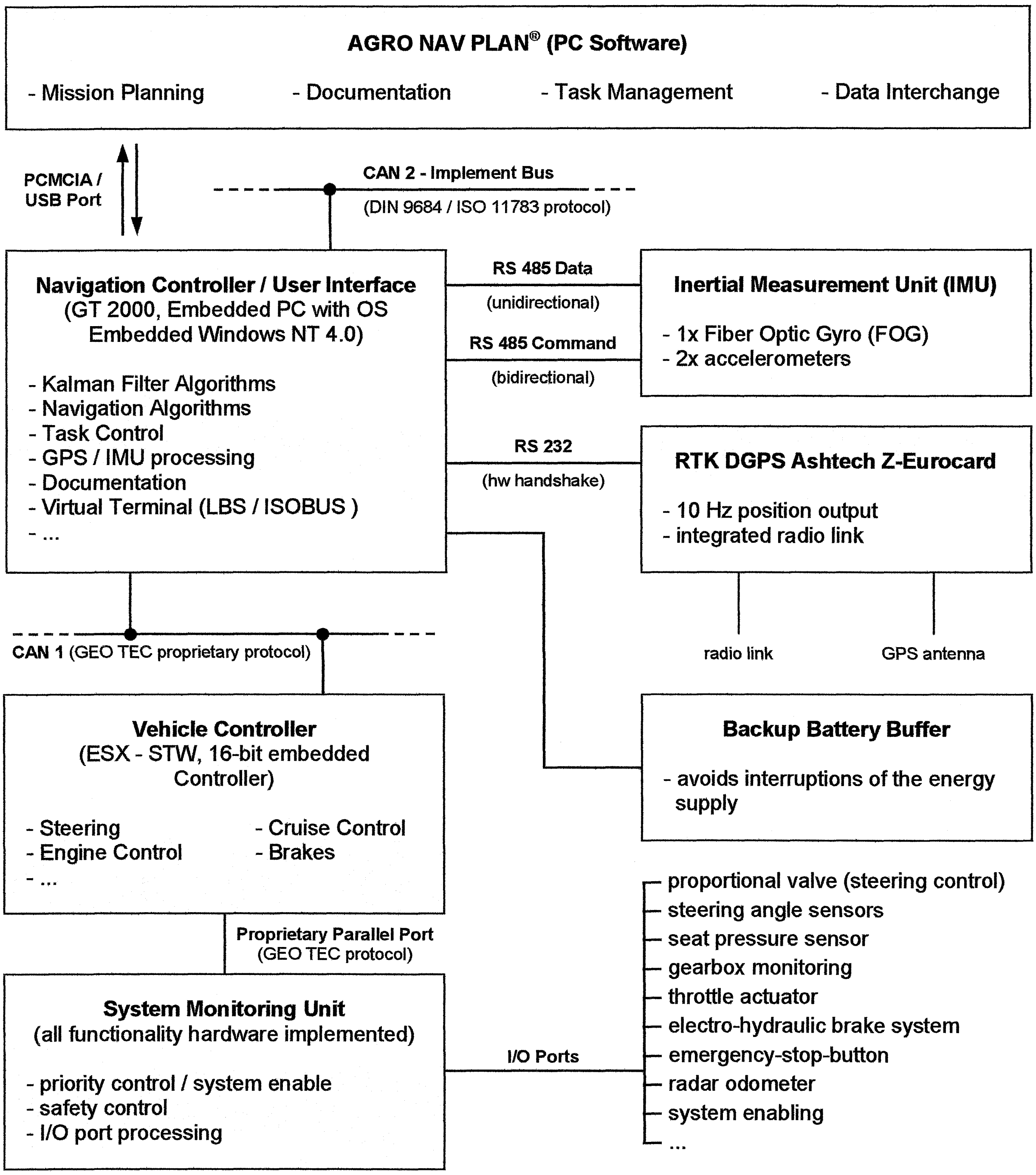

Figure 1. Schematic system setup of AGRO NAV®.

REFERENCE MEASURING SYSTEM

To investigate the accuracy of the system, a high precision reference measuring system is needed. Several prerequisites are essential to meet the requirements. The reference measuring system should be a completely independent system which does not influence the system environment. Another premise is the degree of accuracy, which should be at least three times better than the desired resolution. Furthermore, an appropriate system is needed for outdoor measurements in a rough and non-uniform environment. The reference measuring system for investigations on an oval concrete test track (Freimann, 2000) was an automatic laser tracking system (Leica TCA 1103) in combination with a laser distance sensor (sensing calibrated pylons on the track).

In general, geodetic measurement instrumentation differ considerably in measurement frequency, availability and accuracy (Stempfhuber, W. 2001). The operating principle of high-end Terrestrial Positioning Systems (TPS) is to track the movements of a reflective prism (360°) by means of an rotation angles and the distance measured by the laser Doppler frequency shift. These systems are generally very accurate (± 20 mm) but only if specific preconditions are considered. A critical problem of TPS are acute measurement angles, where the accuracy declines sensible. Another issue is the maximum measurement range which is about 200 - 300 m, depending on the laser performance of the specific system. Other problems appear in dynamic applications, especially if certain movement speeds are exceeded. For the planned tests in sloped fields, a TPS was not considered to be an ideal reference measuring system.

Another option is to use an independent geodetic RTK DPS as reference. At first sight, this seems not to be a qualified solution because of having only equal accuracy in comparison to the RTK DGPS of the test unit. However, this is not true because the reference measuring system is used for checking the accuracy of the overall system, including other sensors (IMU, radar odometer) and actuators (hydraulic valves) as well as the control algorithms. Thus, the accuracy of an independent and well calibrated geodetic RTK DGPS is adequate (Ehrl, et al. 2003).

The deployed position reference system consisted of two geodetic RTK DGPS (Leica SR530, 10 Hz, rover mode) receivers and one base station (Leica SR530, 10 Hz, base station mode) for sending correction signals to both rovers per radio link. The relative positions of the three antennas (Rover 1, Rover 2 and AGRO NAV®) on top of the tractor cabin is shown in Figure 2.

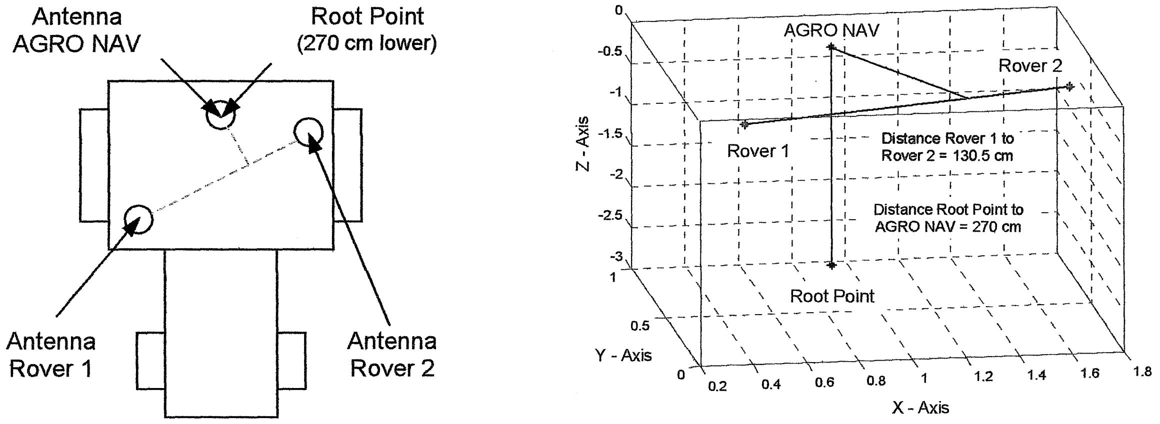

Figure 2. Antenna alignment and relative position to AGRO NAV® root point (center of rear axle).

A basic aspect is the mutual adjustment of the reference system base station and the AGRO NAV base station. This ensures consistent correction signals for the mobile units.

The accurately defined alignment of the antennas is important for data evaluation. A major advantage of having two reference positions relative to the test unit is the possibility to investigate position deviations in all three dimensions and inclinations. The standardized NMEA (National Marine Electronics Association) data strings of the reference system are output at 10 Hz rate via standard RS232 links and logged on a ruggedized PC. Additionally, the GPS and IMU output data (10 Hz) of AGRO NAV were logged on a PCMCIA card by the Navigation Controller in documentation mode. For data evaluation, a temporal synchronization of the different systems is necessary and can be done either by timestamps or via the position and the defined geometric alignment.

RESULTS

Prior to the tests on a sloped field, several measurements with different speeds on a flat tarred road have been carried out in order to verify the equipment. By means of AGRO NAV PLAN®, a job consisting of a straight line (180 m length) was planned and transferred to the Navigation Controller. The road surface has single cross grooves, a downward slope of about 4.5 percent and a sidewise slope changing between 0.5 and 3.5 percent. Several runs with speeds of 2.0, 4.0, 6.0 and 12.0 km/h (0.56, 1.11, 1.67 and 3.33 m/s) were conducted, resulting in 3240, 1620, 1080 and 540 measurement values at 10 Hz. The most significant parameter of these investigations is the so-called Cross Track Error (XTE), here defined as the horizontal distance of the root point (center of rear axle) normal to the planned position (set point). Figure 3 shows the position output of the complete system and the geometrical relationship whilst a straightforward drive. The fixed alignment of the three antennas allows to calculate a virtual position (calculated position) and therefore the XTE of the reference system (distance of calculated position normal to planned pathway). The feedback information of AGRO NAV is calculated for the center of the rear axle and already considers roll and pitch values of the IMU. The associated XTE (system output) is displayed by a dotted line.

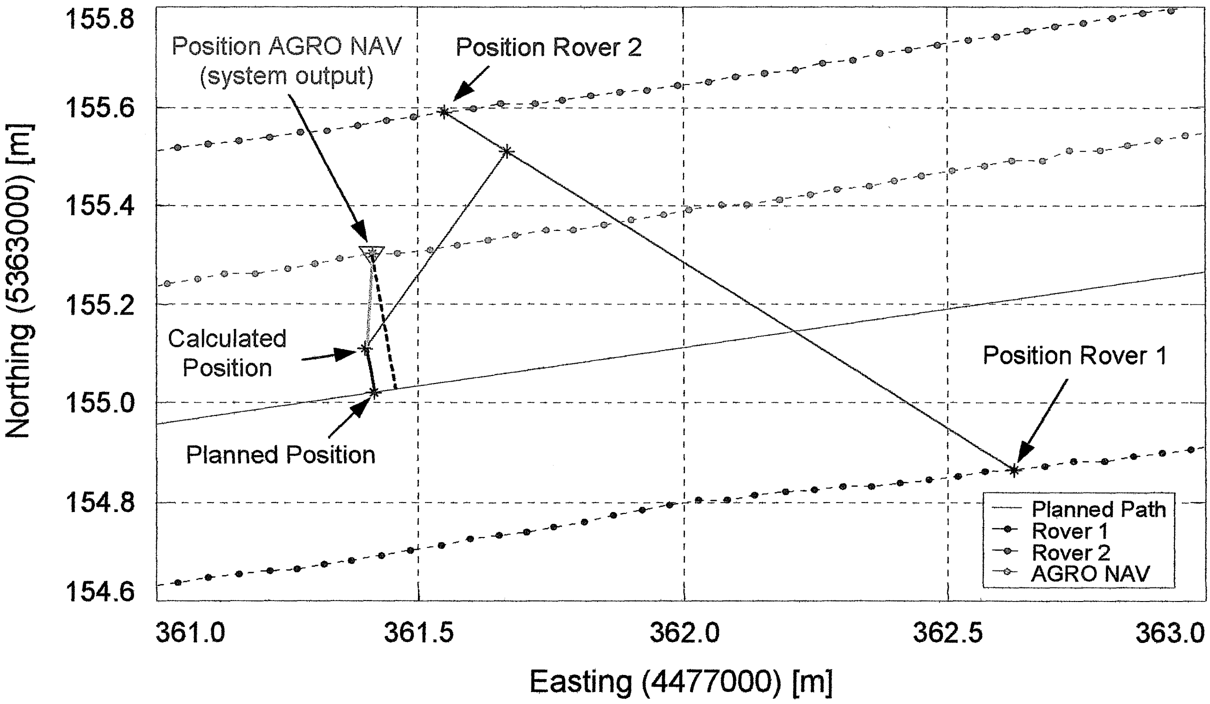

Figure 3. Spatial relationship of the planned position, the feedback position of AGRO NAV® and the positions of Rover 1 and Rover 2. The calculated position follows from the fixed geometrical alignment of the antennas.

Test measurements and data evaluations detected a constant time shift of 13.6 s among the reference system and the tested unit. According to this, the entire data output was synchronized via the geometrical alignment of the antennas.

A special reporting mode of AGRO NAV® allows to store raw data of the different sub systems. A matter of particular interest are the inclinations, output by the FOG and the accelerometers inside the IMU. The values for pitch (movements in the driving direction) and roll (lateral movements) are measured and output as inclination in degrees. Figure 4 shows the results for a straightforward drive at 2 km/h speed. The roll values are in a range between 0.5 and 4.0 degrees, reflecting the inclination variation of the tarred road. The most part of the pitch values are very small, except for several deflections with maximum values of 3.0 degrees. These peaks are caused by the mentioned cross grooves.

A consequential result for roll values was gathered by the reference system. Rover 1 and Rover 2 are spaced 1.00 m in driving direction. This distance allows to calculate roll values with an accuracy of ± 0.5 degrees, which was verified on the basis of static measurements. The result is shown in figure 5. A comparison with the roll values in figure 4 gives a very good correlation.

Figure 6 represents the XTE values of the reference system with and without roll correction. The upper line (without roll correction) shows the XTE of the calculated position to the planned position on top of the tractor cabin (see figure 3). Accounting the roll values of the reference

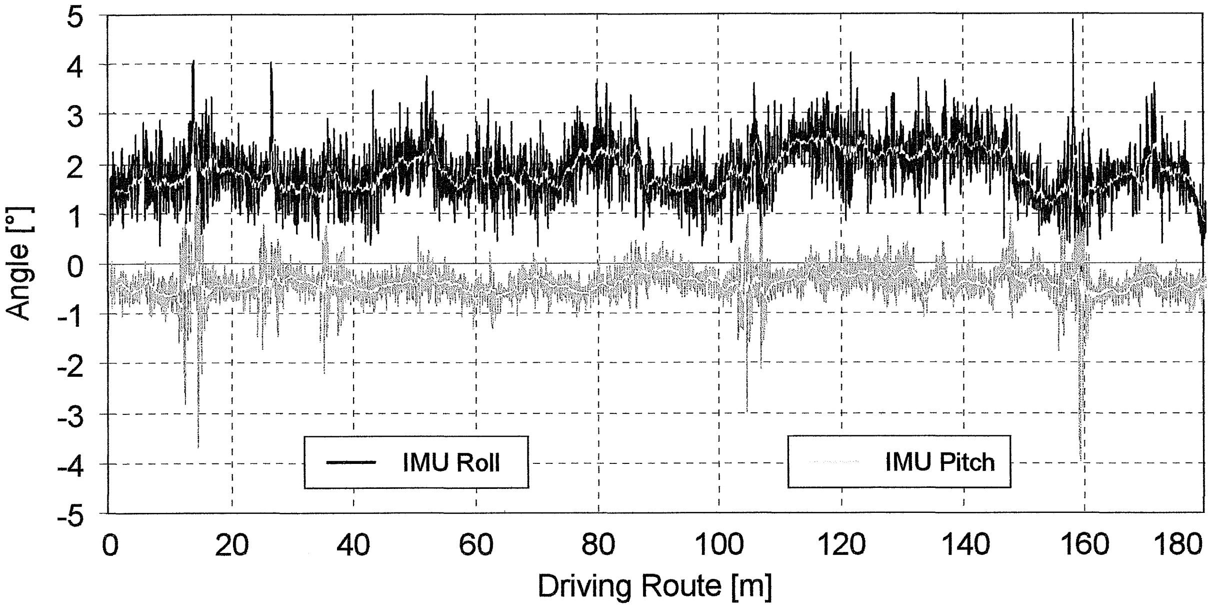

Figure 4. Inclination values for roll and pitch of the AGRO NAV® IMU at 2 km/h speed.

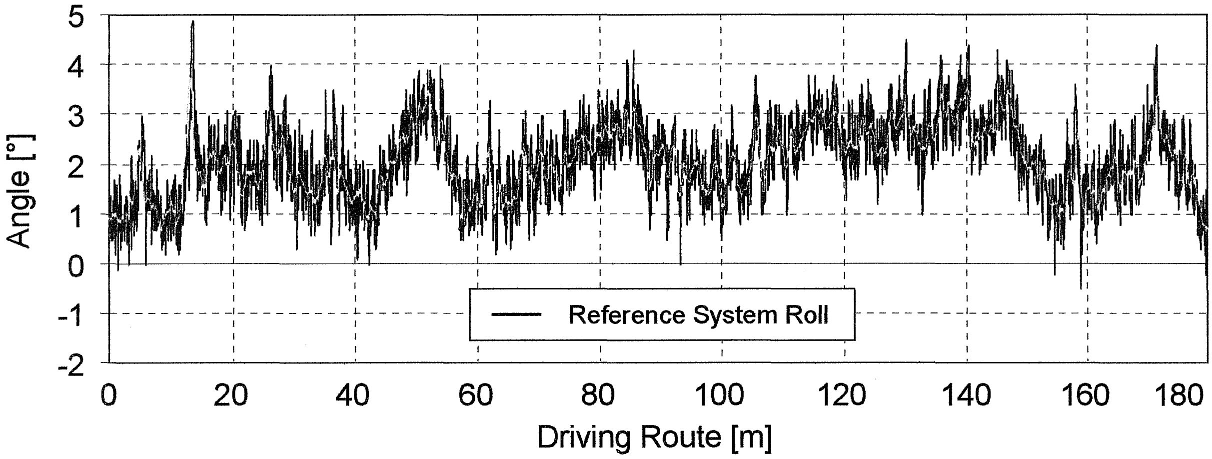

Figure 5. Calculated roll values of the reference system (Rover 1 / Rover 2) at 2 km/h speed.

Figure 6. XTE measured by the reference system with and without roll correction a 2 km/h speed.

The roll correction values of the reference system (figure 5) have an unstableness of ± 0.5 degrees resulting in an error of ± 13.5 mm at the root point (2.70 m below the calculated position). Considering this inaccuracy, the coarse line for XTE values (figure 6, lower line) is in reality more smooth and therefore more accurate. A possibility to improve the unstable roll measurements is to extend the spacing of the reference system antennas in driving direction (double spacing would halve the unstableness).

In general, the investigations comply with the outcomes of Freimann (2000) and also approve the manufacturers specifications. Results for higher speeds up to 12 km/h have shown similar results with deviations in the range of ± 130 mm.

For the field tests, a rotary harrow in combination with an air-seeder and a working width of 3.0 m were mounted on the MF 4255 tractor. The practical tests were made in autumn on wet soil at a field with side hill slopes between 0 and 14 percent (Figure 7, left). Tests during winter wheat seeding showed a similar accuracy for the tractor as on the tarred road. This is not really surprising, because the roll compensation already showed good performance on the sloped road. Wheel slip and downhill drift of the tractor have also been properly controlled by the guidance system.

However, the work result when seeding winter wheat under typical field conditions was not in the expected range of ± 100 mm. Deviations of up to 240 mm from path to path were caused by the downhill drift of the implement and downhill yawing of the rear of the tractor. Figure 7 (right) displays the deviation for 32 tracks (3.0 m working width) measured in transect 1 (left). A correlation with the inclination of transect 1 is clearly obvious.

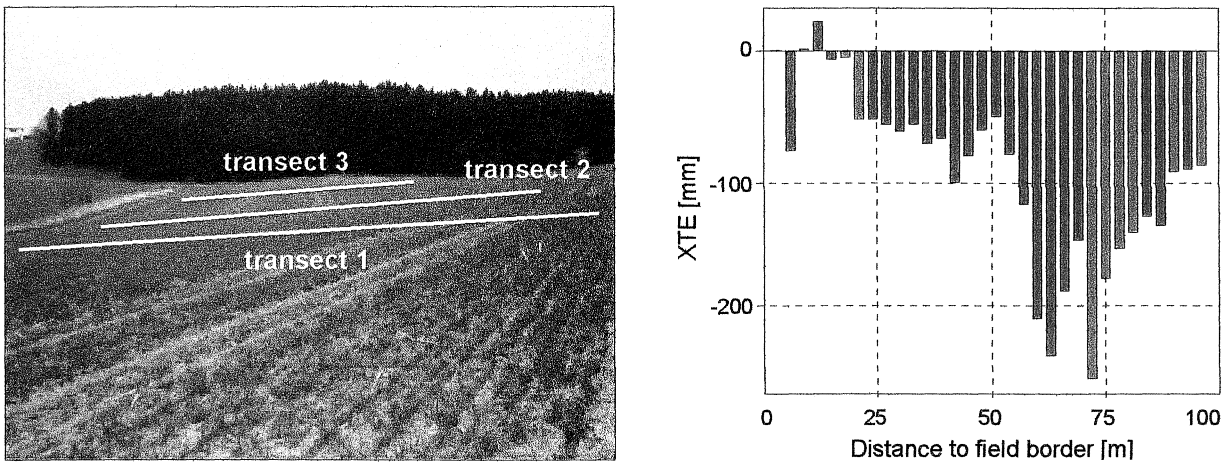

Figure 7. Transects 1-3 in winter wheat field (left). XTE of transect 1 in relation to field border (right).

A source of error can be found in the planning software. When doing this investigations, AGRO NAV PLAN® was not prepared to plan jobs in three-dimensions, but only in the x-y plane. Hence, is was not possible to create a job which considers the sloped contour of the field.

A closer look on the linkage of the tractor and the implement shows the possibility of a relative motion. This has only a small influence on flat fields, but a very significant one on sloped fields. To prevent this negative impact, a rigid connection between the tractor and the implement must be created. For others, like trailed implements, the actual technological setup offers no solution.

One possibility for solving this problem is to mount the antenna on top of the implement, rather than on the tractor cabin. Another option is to sense the position of the implement relative to the tractor with appropriate sensors or an additional GPS receiver. For applications where high precision is required like planting, seeding or hoeing of root crops, it is very important to have a system which addresses this problem. However, it must be observed, that none of the systems on

CONCLUSION

The successful introduction of autonomous steering or guidance systems for standard tractors must be accounted as a first step towards completely independent field robots. No matter if the big sized machines of today, even bigger ones or just small vehicles will be successful in future, the trend of increasing automation is clearly visible. For the whole range of this technology, the accuracy and therefore the quality of work is the most important factor for being successful in practice.

The first commercially available system for agricultural vehicles was AGRO NAV® using RTK DGPS and a high precision IMU for navigation. The aim of these investigations was to evaluate the systems accuracy under typical agricultural conditions. For this, a highly accurate reference measuring system with two geodetic RTK DGPS receivers and a specific geometrical alignment was introduced. Results of measurements on a tarred road with a variable inclination between 0.5 and 4.0 degrees have been in the expected range of ± 100 mm. Other investigations on a wet field with side hill slopes were conducted with a standard tractor and a rear mounted combination of a rotary harrow and an air seeder. Limitations caused by downhill yawing of the three point mounted implements have been detected at the side hill slopes. A possible solution for this problem would be a second antenna position on the implement or sensing the position of the implement relative to the tractor with appropriate sensors.

Besides of the mentioned problems, the tested system showed the great potential of RTK DGPS based auto guidance technology for agricultural vehicles.

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