Safety aspects for automatic guidance of agricultural machines and low-cost solutions

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ABSTRACT: Automatic steering devices for farm machinery and tractors have the task to relieve the driver from the physical and mental stress of monotonous steering work. Simultaneously, they are intended to help exploit machines and tractors closer to their full performance and improve the quality of work. However, it is not possible to rule out malfunctions or breakdowns of sensors, gaps in guidance lines, obstacles in the field such as ditches or pylons, temporary hazards like the sudden appearance of animals in front of a moving machine or a temporary lack of concentration of the operator. Most of these problems may be prevented by a safety system for automatically steered agricultural machinery developed at the Department of Agricultural Engineering of the Martin-Luther-University in Halle. The function of the components of the safety system and preliminary results obtained in field experiments are introduced and discussed.

Keywords: automatic steering; DGPS; GIS, safety system

For many years, the development of automatic steering devices for farm machines and tractors has been a research object both in industry and institutions of higher education.

To highlight the broad spectrum of activities, some recent studies are reviewed. Regarding their use in agriculture, investigations can be divided into two groups. The first comprises automatic steering devices with sensor systems for guidance during field passage along existing guidance rows. The underlying physical principles are based on simple electro-mechanical sensors, ultrasonic sensors and lasers up to high-resolution digital camera systems. Selected examples are: sensor sampling of plant rows in sugar beet, maize or potato crops (Gerrish et al. 1997; Toda et al. 1999; commercial leaflet Sauer/Danfoss 2000), of swaths or traffic aisles (Noguchi et al. 1997; Pudszuhn 1999), crop edges in cereal fields (Diekhans 2000) or plough furrows (Klee et al. 1998). An indispensible precondition for using such systems in practice is the existence of an uninterrupted guidance row for pulse-controlled or non-contacting sampling. In the field, however, this seems to be problematical for at least some of the contours mentioned (i.e. crop edges or plant rows).

The second group of automatic steering devices makes use of the advantages of GPS techniques which have attained great importance since the introduction of precision farming, or were even the precondition for it. The following examples are to demonstrate the development trend in vehicle guidance by means of DGPS in recent years. The technical approach comprised pseudo-range correction DGPS (Cho, Lee 2000) up to real time kinematic-DGPS (van Zuydam et al. 1999; Stoll, Kutzbach 2000; Bell 2000). However, in field operations reception failures or shading effects can never be fully excluded, and therefore automatic steering by help of GPS is often coupled with terrestrial support systems, for example infrared tracking and microwave velocity sensors (Schwenke, Auernhammer 1999), laser optics (Sogaard 1999) or inertial navigation (Freimann, Sterlemann 2000).

Malfunctions or breakdowns of the sensors and gaps in the guidance lines or tillage edges cannot be ruled out. Natural obstacles in the field such as ditches, boulders or pylons cannot be recognized by the available automatic guidance systems. Neither can field margins be identified. Thus, hazardous situations may occur, particularly while driving through tall crops, e.g. during fertilizer spreading or spraying in grain crops or rye harvesting. Under these circumstances, the driver has difficulties observing obstacles at ground level such as ditches.

The main advantage of automatic steering control is that more attention can be paid to the actual field operation, if permanent manual steering operations became superfluous. For example, while automatically driving along a straw swath, the farmer can watch the work of a rear-attached straw baler more attentively. This important feature of automatic steering is only of benefit if there are warning signals when obstacles or field margins are encountered. Furthermore, long field operations may weaken the driver's concentration and endanger the safety of work.

This paper presents a "safety system for farm machinery", which works independently of the driver and improves the safety and reliability of automatic steering systems to the benefit of man and machine (Pickel et al. 2000).

MATERIALS AND METHODS

Objectives and components of the safety system

A safety system for automatically steered farm machinery and tractors is expected to manage at least the following tasks:

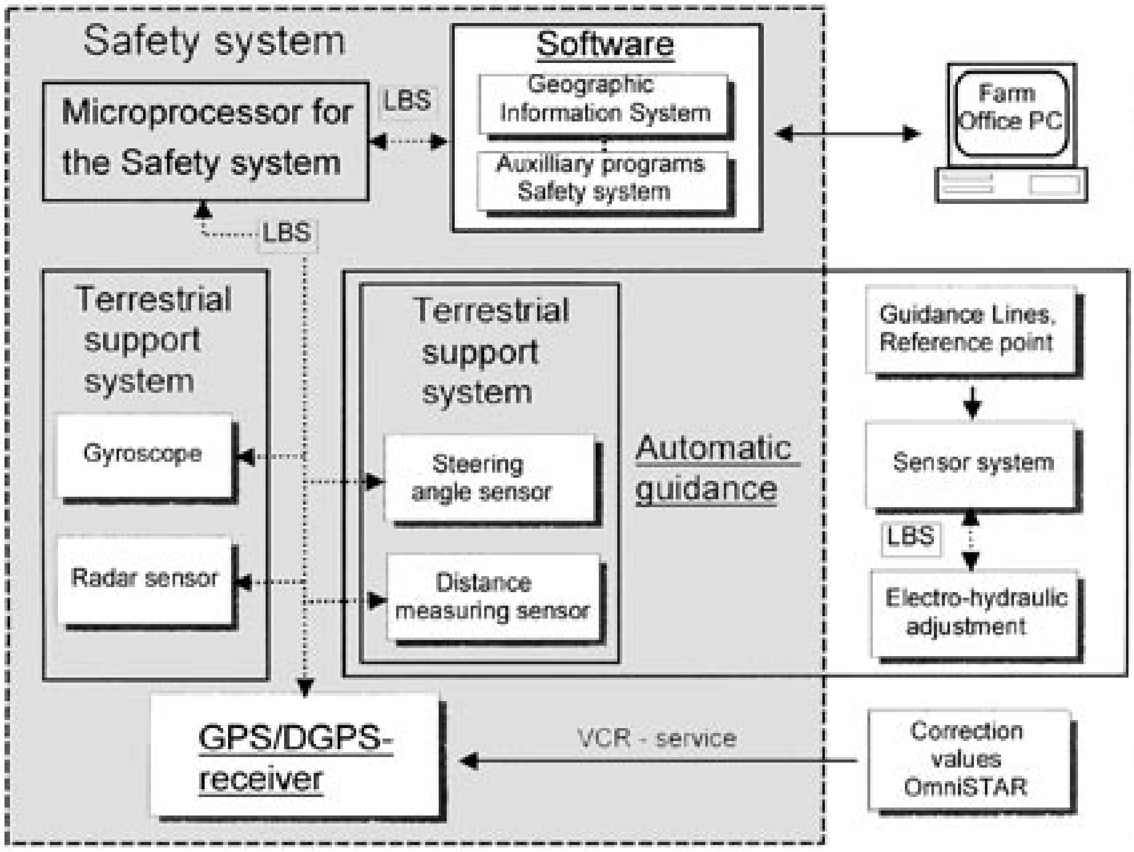

Fig. 1. Structure of the safety system

– early recognition of critical situations such as violating a predetermined minimum distance to obstacles or field margins;
– release of suitable warning signals to the driver in case of critical situations;
– warning and signalling of malfunctions or breakdowns of the automatic steering control;
– the bridging of gaps in guidance lines.

An important precondition for accomplishing this is the early recognition of approaching field margins, natural obstacles and self-defined no-go areas. The safety system is expected to provide optical and/or acoustic signals in order to warn the driver before a critical situation arises. For the example of an automatically guided tractor, possibilities and technical appliances for the due signalling of approaching obstacles or field edges to the driver are described.

The safety system is composed of several modules. Besides the automatic guidance, it includes a GPS/DGPS-receiver, an on-board computer with display and control panel, a radar sensor for distance measuring and a piezoelectric vibration gyroscope for measuring the angular velocity of the machinery. The on-board computer also contains the GIS modules required for the safety system.

The exact design of the automatic guidance control unit depends on the type of machinery, but it can be grouped into two main parts. One comprises the sensing system for sampling of contours (guidance line of any type), the other the electro-hydraulic components which adjust the steering wheels of the machinery automatically or by hand. Two processing units manage the data flow between the sensing system and the steering adjustment module using the LBS standard (a modified CAN-bus protocol). The bus structure allows the integration of other sensing systems into the automatic guidance control, which is necessary to establish a safety system. For the safety system data from the steering angle sensor and the transmission sensor (inductive distance sensor) are used additionally to determine the direction of travel, travelled distance and driving speed.

Fig. 1 shows the current state of development of the total safety system.

Data flows in the safety system

The data flow from the sensing systems for the automatic guidance control, from the gyroscope/radar, steering angle sensor/distance measuring sensor and the GPS/DGPS-receiver are recorded and subsequently used to calculate the travel course of a farm machine. A display enables the operator to follow the process. At the same time, safety-relevant data about obstacles and field margins saved in the Geographic Information System (GIS) are checked. The continuous comparing of machine position and safety-relevant information in the

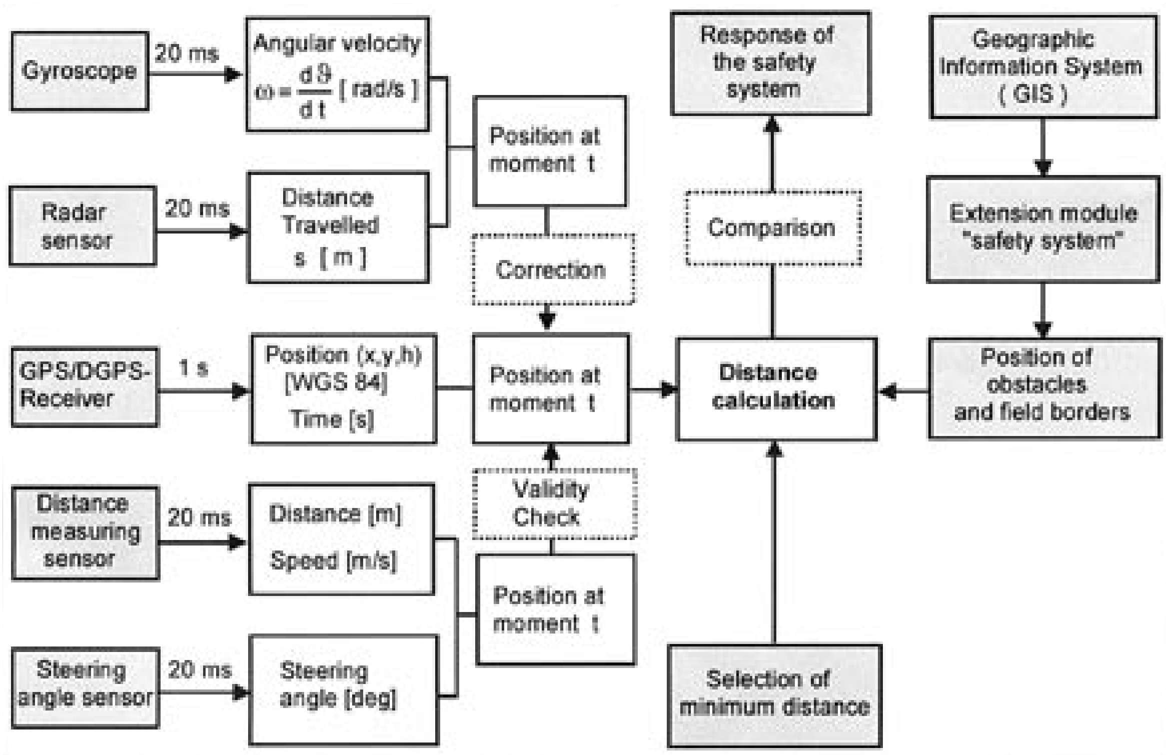

Fig. 2. Data flow in the safety system

GIS yields the distances to registered obstacles and field margins. Using the terminal, the operator can determine a minimum critical distance (e.g. 10 m), whose violation activates a signal by the safety system. In the present version, an acoustic signal is released.

Fig. 2 gives an overview of the data flows in the safety system.

Distance measurement to obstacles and field margins

For a geo-referenced field where position and size of obstacles were mapped or added post processing (Fig. 3a), a grid-map can be created in the GIS which takes into account the working widths of the farm machinery (Fig. 3b). This grid map is defined by use of a grid-map describing file (*.RAS).

It contains the following information:
- Coordinates of the upper left corner of the grid;
- Side lengths of the grid-map towards *x* and *y*;
- Number of the grid plots;
- Number of grid plots towards *x* and *y*;
- Angle of the grid pattern/degree of latitude.

Grid-mapping is possible during the preparation of field operations, e.g. for fertilizer spreading or spraying. The grid plots are numbered consecutively from top to bottom starting with the leftmost column. The vectors for field and work margins were defined anti-clockwise (mathematically positive) and those for obstacles clockwise. This allows an express determination of the tractor position relative to obstacles or field margins, because only the distance to vectors in front of obstacles is measured but not the distance to vectors whose direction turns off the travel direction of the tractor.

While generating data for the safety system, each grid section is checked for vectors crossing or touching it. The file describing the grid (*.RAS) contains the required information about the number of contiguous vector groups and at which position in the grid-to-vector-connection file (*.RVB) their description begins.

The data sets in the (*.RVB) file indicate the position in the vector description file (*.VEK) where the first vector is referred to and how many vectors of the vector group have to be considered. The vector file contains the vectors of field margins and obstacles. These vectors are stored separately as point coordinates with the same origin as the grid map (upper left corner).

Fig. 3c shows an example:
- *.RAS: 9; Pos. 176; No. 2 Grid plot No. 9 contains 2 elements whose description begins at Pos. 176 of the grid-to-vector connection file (*.RVB). These 2 data files at Pos. 176 (and 177) refer to the vectors of the obstacle in grid-plot 9.
- *.RVB: 176; Pos. 256; No. 3 Position 176 of (*.RVB) informs that the vector description file (*.VEK) at Position 256 describes the 1st point of the 1st vector of altogether 3 obstacle vectors.
- *.VEK: 256; X.......; Y......... Position 256 of the *.VEK indicates the X, Y-coordinates of the 1st point of the obstacle vector in WGS 84-format.

All three files are integrated into the module "grid-oriented no-go area management" which is part of the GIS

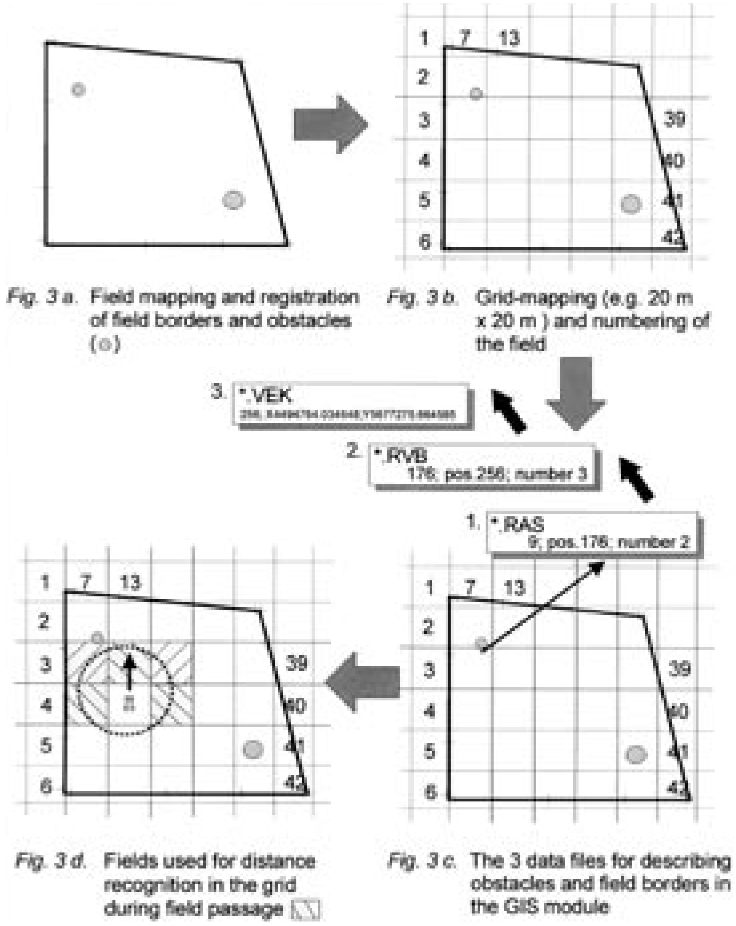

Fig. 3. Text in the Fig. a–d

"KarDüPlan" the company AGROCAD (KARDÜPLAN 1999). However, all files can also be integrated into other GIS software capable of supporting the necessary interfaces (e.g. Motorola Binary Format or DXF).

When an automatically steered farm machine with integrated GPS-supported safety system traverses a field, the following program steps are executed consecutively:
– determination of relevant grid sections with vectors of obstacles and/or field margin pointing in the direction of travel, in front and behind the traffic lane;
– calculation of distances to these vectors;
– release of a warning signal in case of approaching danger, i.e. when a predetermined safety distance is violated.

For distance calculations, the grid section of the current position, those adjacent to the right and left and the three sections ahead of these three in the direction of travel are considered. These sections are checked for vectors indicating field margins or obstacles. The position of each vector is recorded. To avoid double calculations, checkups are made prior to recording (Fig. 3d).

RESULTS AND DISCUSSION

Checking algorithms during field passage

Since 1999, a tractor with automatic guidance has been used to test the hard- and software components of the developed safety system for the reliability and efficiency of the sensing equipment, the accuracy of positioning, direction of travel and distance to obstacles or field margins and the reproducibility of the obtained results during actual field passages.

The following comments are to outline the application of automatic steering in a tractor/field sprayer combination operating in a cereal field with a tactile sensing system for sampling the wheel tracks as guidance lines. A mechanical sensor samples the course of the tracks running ahead and an analog steering angle sensor converts the information into electric control signals for adjusting the direction of travel. The necessary adjustment of the front axle is implemented by the electro-hydraulic actuator of the tractor.

Especially in dense crop stands, great physical and mental stress may arise for the operator from steering his tractor or machine across the field manually. This can be largely alleviated by automatic guidance, which allows the driver to concentrate on the actual field work, in this case the correct spraying of the crop. However, potential hazards such as obstacles or field margins are not noticed by automatic guidance control unless it includes a safety system as described above.

As long as a guidance line is uninterrupted, the sensing equipment of the automatic steering system is used to control the path of travel. In addition, the combination of gyroscope/radar and DGPS record the travelled course. The algorithm for distance calculations is activated after each 1 m distance travelled. The safety system then determines the actual position in the grid at time t_0 using sensor data from the gyroscope/radar, the automatic steering and the GPS/DGPS. While the course calculations using the inertial gyroscope/radar sensors furnish new information every 20 ms, DGPS values are for the time being transmitted only once a second.

A recurrent adjustment of the position and travel path based on data from the gyroscope/radar is indispensable ("re-calibration"). It is performed every second on the basis of a moving regression of 10 DGPS values each time. In field trials this turned out to be sufficient. The adjustment produced also values of the angle by which the gyroscope/radar track deviates from the DGPS track. These deviations are averaged over 50 values and used to correct the baseline of gyroscope and radar sensors (offset correction).

Assuming a driving speed of 10 km/h, the travel path calculation with the gyroscope/radar data is corrected every 2.7 m and the adjustment of the baseline takes place each 140 m. The same procedure can be used for correcting adjusting data from the steering angle sensor and the distance measuring sensor. The corrected position values are then used to determine the machine distance to obstacles or field margins.

However, this requires the continuous functioning of both sets of instruments, which cannot always be guaranteed in practice. For example, signal failures in the GPS- or DGPS-receiver due to external disturbances, e.g. shading effects near forest edges, must be reckoned with. Neither can failures or breakdowns of the automatic steering or gaps in the guidance lines be excluded. Therefore, it is necessary for the safety system to be able to cope with malfunctions, breakdowns etc. of any component.

A temporary malfunction or a breakdown of the automatic steering is communicated to the machine operator by the safety system via the display unit and can be overcome without endangering man and machine by switching to manual steering. Warning signals when predetermined critical distances to obstacles or field boundaries are violated will not be affected because they are activated by the gyroscope/radar and the navigation system.

Signal failure in the GPS/DGPS-receiver

More critical for the safety system is the situation when no DGPS data are arriving. Therefore, simulations were carried out in the field with real data to investigate how long the gyroscope/radar sensing system can keep a farm machine on course when the desired travel path is straight ahead. For simulating a DGPS-breakdown, travel distances of 500 m without DGPS signals were assumed. The most important results obtained in our field trials are presented in Fig. 4.

The travel path based on gyroscope/radar and DGPS were recorded during automatic steering along four tracks of more than 1,000 m length each.

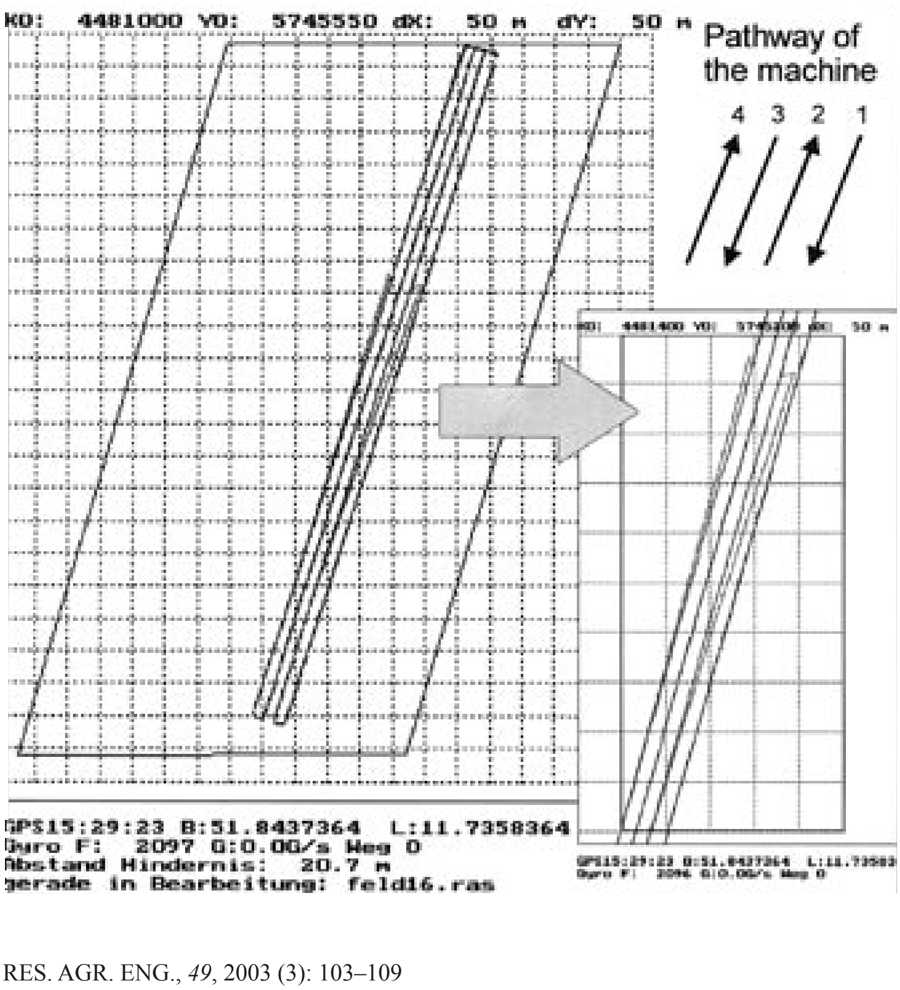

Fig. 4. Results from field experiments with simulated failures of DGPS signals

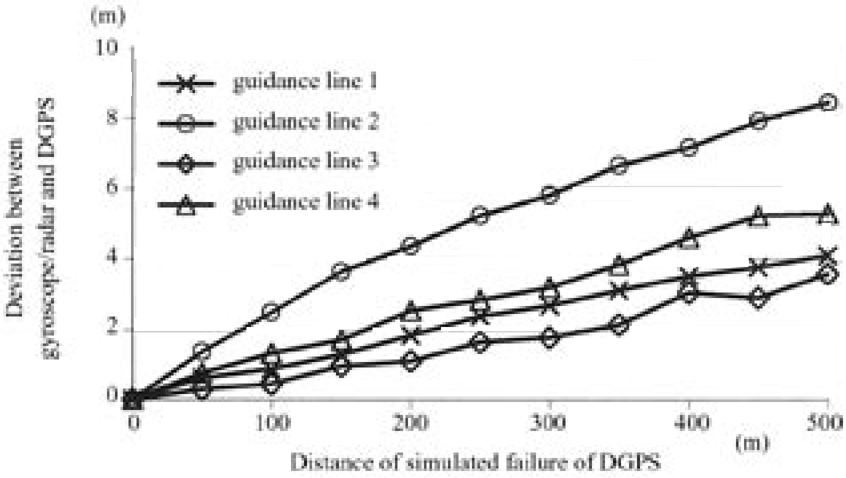

Fig. 5. Dependence of deviation between gyroscope/radar and DGPS on the distance

In case of simulated DGPS-failure the differences ranked between three (guidance line 3) and nine metres (guidance line 2) (Fig. 5).

A total of 21 field experiments were carried out with simulated breakdowns of the DGPS signal. The result of these investigations showed that the gyroscope/radar system can bridge DGPS failures for several hundred meters. At a travel speed of 10 km/h, the current state of development allows bridging a DGPS failure for 36 seconds (1 m average deviation, 2 m maximum deviation) without compromising the basic functions of the described safety system.

CONCLUSION

Automatic steering equipment in farm machinery and tractors can accomplish more safety-related operations if the DGPS positioning service is used simultaneously. Currently practicable applications include acoustic and/or optical warning signals when the moving machine violates a selected minimum distance to obstacles, field margins or work boundaries. Predetermining and checking the course of travel with three independent on-line sensing systems (automatic guidance, gyroscope/radar and DGPS) can help compensate the simultaneous breakdown of up to two of these systems for several hundred metres of travel without compromising the basic functions of the safety system. This allows malfunctions and breakdowns of the automatic guidance equipment and interrupted guidance lines to be bridged, at least for a limited time.

The GPS-assisted safety system for automatic steering offers numerous opportunities for improvement, for example for machines operating close to forests. Here, shading may cause failures of the GPS-navigation system. To reduce such risks, additional data about lines of travel or field edges can be stored in the GIS and then be used to synchronize the lines of travel similar to route planning in passenger cars. These GIS maps will be the basis for an accurate control of the travel path. The advantage would be the ability to bridge GPS-navigation failures over a longer period with terrestrial components of the safety system.

Another useful improvement would be to extend the current optical and/or acoustic warning signals to allow direct intervention into the engine or transmission of a farm machine. This would further improve the safety of man and machine by electronically blocking or disconnecting operations.

More ecologically oriented developments consider partial field management in precision farming. By defining no-go areas, where certain operations are to be avoided, the existing components of the safety system can be used to implement an easy and cheap control of field sprayers, fertilizer or liquid manure spreaders. Defining lines of travel and no-go areas (margins, protected zones) and comparing them on-line to GPS and vehicle sensor data may prevent the uncontrolled entry of pollutants into ground and surface water. At the same time, field operations and the travel path can be completely documented.

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Bezpečnostní aspekty automatického řízení zemědělských strojů a nízkonákladová řešení

ABSTRAKT: Automatická řídící zařízení pro zemědělskou mechanizaci a traktory mají za úkol uvolnit řidiče z fyzického a duševního napětí, pramenícího z monotonní řídící činnosti. Současně jsou tato zařízení zamýšlena jako pomoc lepšího využití strojů a traktorů z hlediska jejich výkonnosti a zlepšení kvality práce. Avšak není možné vyloučit nesprávnou činnost nebo poruchy čidel, mezery ve vodící čáře, překážky na poli, jako jsou příkopy nebo stožáry, momentální nebezpečí, jako je náhlé objevení se zvířat před jedoucím strojem nebo momentální ztráta koncentrace řidiče. Mnoha těmto problémům může být zabráněno bezpečnostním systémem pro automaticky řízenou zemědělskou mechanizaci, vyvinutou odborníky z katedry zemědělské techniky Univerzity Martina Luthera v Halle. Jsou uvedeny a prodiskutovány funkce komponentů bezpečnostního systému a předešlé výsledky získané při polních pokusech.

Klíčová slova: automatické řízení; DGPS; GIS; bezpečnostní systém

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