A DGPS-Based Safety System for Agricultural Machinery

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When DGPS technology for the localization and navigation of vehicles became available, investigations were initiated at the Institute of Agricultural Engineering and Land Improvement of the Martin-Luther University Halle-Wittenberg in order to extend automatic tractor steering which had been developed as of the beginning of the nineties to comprise safety-relevant tasks.
The goal of the first development step is the timely recognition of given field boundaries, natural obstacles, and freely chosen blocked areas, which are noticed in time during the field ride due to the combination of automatic steering with a Differential Global Positioning System (DGPS) and can warn the driver by triggering optical and/or acoustic signals before a critical position is reached.
The intended hard- and software-based connection of these two different technical systems in a „safety system for agricultural machinery", which has a modular design and works independently of the driver, is to make a contribution towards improved ergonomic process design and to create the necessary prerequisites for greater process security.

Keywords
Automatic steering, DGPS, GIS, safety system

Introduction

The necessary precondition for the use of most automatic steering systems available on the market is that appropriate guidelines on the field such as plant rows, straw- and food swaths, vehicle tracks, or cultivation boundaries in the form of grain- or maize stand edges are recognized by sensors during field rides [1] - [5]. Nevertheless, malfunctions or breakdowns of these sensors and gaps in the guidelines or the crop stand edges cannot be excluded. For technical reasons, natural obstacles such as ditches, boulders, electricity pylons, or field boundaries cannot be recognized by the automatic steering system and may therefore lead to critical situations. Through the combination of automatic steering equipment with the available Global Positioning System (GPS) in a safety system for mobile agricultural machinery that works independently of the driver, some of the dangers listed in **figure 1** can be eliminated or lessened, and hence the safety and functionality of the steering systems can be increased in the interest of both humans and machines.

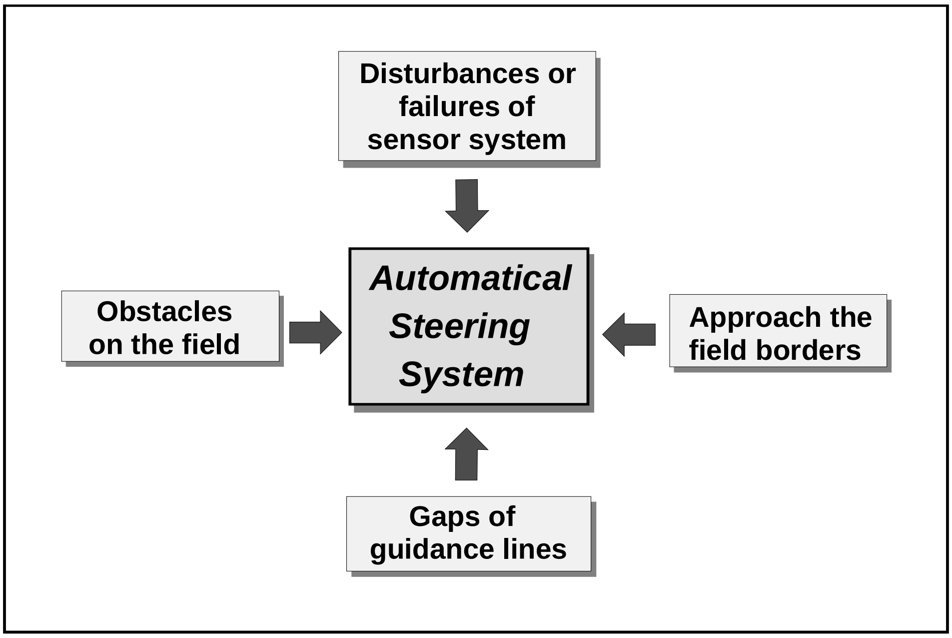

Figure 1: Possible critical moments for automatic steering

Tasks of the Safety System

For the reasons mentioned above, a safety system for automatically steered agricultural machines and tractors should be able to cover at least the following task areas:

- Signalizing of malfunctions or the breakdown of the automatic steering
- Control-technological bridging of gaps in the guidelines
- Timely recognition of critical situations, such as the falling below of a chosen minimum distance to obstacles or field boundaries
- Triggering of suitable warning signals for the driver

The goal of the first development step is the timely recognition of given field boundaries, natural obstacles, and freely chosen blocked areas, which can warn the driver by triggering optical and/or acoustic signals during the field ride before a critical position is reached.

Components of the System

With financial support from the German Society for the Advancement of Scientific Research (DFG), solutions for a safety system have been developed at the Institute of Agricultural Engineering and Land Improvement of the Martin-Luther University Halle-Wittenberg in recent years using a tractor as an example. This system is primarily supposed to meet the task of timely recognition of field boundaries and obstacles [6].

This safety system (**figure 2**) features a modular design and, in addition to the actual automatic steering system (coupling level 3), it consists of a GPS/DGPS receiver (coupling level 2), an on-board computer with a display- and operating part, a Geographic Information System (GIS), a radar sensor for distance measurement, and a gyroscope for the establishment of the angular velocity of agricultural machinery (both sensors combined in coupling level 1) [7].

The Global Positioning System enables the position and the driving direction of the tractor to be determined on-line on the field. With the reception of corrective data services, such as ALF (long wave), RASANT (VHF), or geostationary satellites (such as the providers OmniSTAR or LandStar), the achievable accuracy is meanwhile in the metre range and below, even with the natural fluctuations in the reception quality, which always exist. This was confirmed by examinations of different systems and manufacturers, which were conducted by the authors this year in January and also covered a longer period (24 hour test).

For the tasks of a safety system, this metre-range accuracy must be considered sufficient.

The process computer with appropriate input- and output interfaces and the possibility to show the field ride visually form the core of the system. With the aid of an underlaid Geographic Information System (GIS), which has been extended to comprise a program component required for the safety system, the data flows of the sensor systems for automatic steering, integral path determination (gyroscope, radar), and the GPS/DGPS receiver can be combined in a „Grid-Oriented (Blocked) Area Management System“. In recent years, the foundations which are necessary for these specific modules of the safety system to be integrated into commercial Geographic Information Systems have been created in cooperation with the Saxonian software house AGROCAD in Kleinbarbau [8].

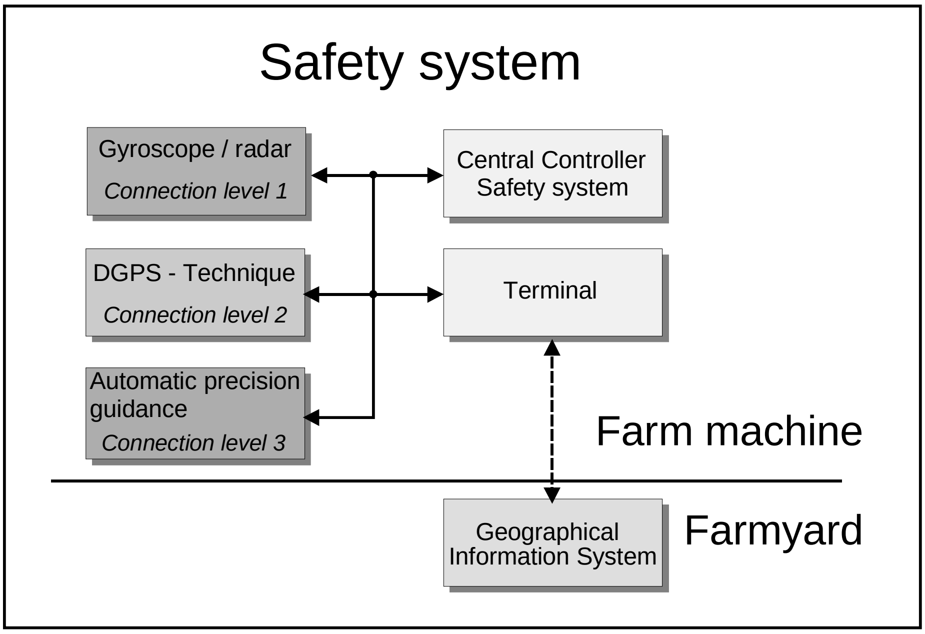

Figure 2: Components of the safety system for agricultural machinery

How Does the System Work?

Field mapping and the geo-referenced transfer of the maps to a Geographic Information System (GIS) form the basis for the application of such a safety system. Safety-relevant information can either be collected during initial mapping, or it can be determined at any time through „post processing“ at the PC. Almost all available GIS have functions which enable lines or areas to be drawn in and geo-referenced.

The current position of the agricultural machine is determined by software modules which combine the position data from the GPS/DGPS with the values from the radar sensor and the gyroscope and compare them with the given safety-relevant coordinates in the GIS. The result is the calculation of distances to obstacles or field boundaries. Using the terminal, the user can set a minimum distance (e.g. 10 metres) for the safety system to be activated if the distance falls below this minimum. In the currently realized application case, the driver is given an acoustic warning signal.

Figure 3 shows a diagram of the process described above. The functional principle of individual parts of the program and the results provided by them, first in simulation trials and then also in practice-relevant field tests, will be briefly discussed below.

Determination of the Position on the Field

The physically measurable parameters for the safety system are:

- path, clock rate 20 ms
- angular velocity, clock rate 20 ms

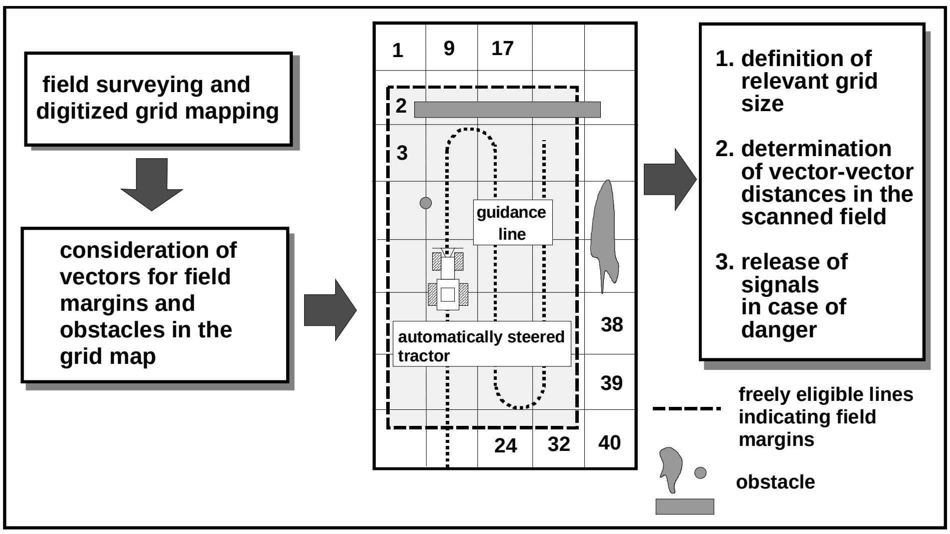

Figure 3: Principle of data processing for the safety system

- position in x-y direction, clock rate 3 s
- steering angle, clock rate 20 ms

While the vehicle is standing, the zero point of the gyroscope is calibrated. The first position measured with DGPS also provides the first common point of the gyroscope/radar and DGPS levels. It is the starting point for the course line of the gyroscope/radar level which is to be calculated. As long as the machine is standing, the following DGPS measurements are used for the improvement of the starting point through mean value formation. When the field ride begins, it is possible to determine the direction. Depending on the accuracy of the DGPS position data, the coupling level gyroscope/radar is oriented after a distance of 5 to 10 metres in sufficient accordance with the receivable DGPS values.
Further necessary algorithms are the continuous corrections of the position and the direction at this level. They are the consequence of the possible zero point drift of the calibration curve of the gyroscope, calibration- and systematic errors of the radar sensor, and path calculation errors.
For the position and the direction of the gyroscope/radar level in relation to the DGPS measuring points to be corrected continually, the distance of several DGPS measuring points from the calculated course line must be analyzed. This can be done using Hesse´s normal form because it enables the direction to be determined in the entire angle range between 0° and 360° and allows regression without reference to an axis (**figure 4**):

$$x * \cos\varphi + y * \sin\varphi - p = 0 \qquad (1)$$

The distance *d* and the position of a point relative to the driving direction can thus be determined very easily with

$$d = x_1 * \cos\varphi + y_1 * \sin\varphi - p \qquad (2)$$

The distance *d* of the DGPS measuring point P_1 perpendicular to the calculated course line of the gyroscope position P_0 is determined directionally depending on the driving direction, i.e. if the point P_f is on the left of P_1, d < 0. If it is situated on the right, d > 0.
The distance *a* is the distance of the foot P_f of *d* to the position P_0. Hesse´s normal form also enables *a* to be determined directionally. The distance a > 0 occurs if P_1 is situated in the driving direction in front of P_0 and vice versa.

Distance Calculations to Obstacles and the Field´s Edge

By agreement, the grids are numbered such that every field gets a number. With the aid of this number, the vectors for field edges and obstacles within a mapped field can be accessed using a grid-vector connecting file.
By definition, the field´s edges are given a positive orientation in the grid (counter-clockwise), while obstacle boundaries get a negative orientation.
Within the additional „Grid-Oriented (Blocked) Area Management“ module, the following program components must be worked off in the order listed below (figure 3):

- determination of relevant fields with obstacle- or field edge vectors in the driving direction
- establishment of the distance to these vectors
- signal formation in case of danger, i.e. if the distance falls below a given (set) safety distance

As shown in Figure 3, the numbered fields of the grid on the right and the left side of the current field and the fields in the driving direction in front of the tractor position as well as those on the right and the left side of these fields are employed for distance calculation. Whether these fields contain vectors for field boundaries or obstacles is then checked. The position of the individual vectors is recorded in a list. Before, the list is checked for an entry of this vector so that no distance calculation is carried out twice.
In the vector file, the vectors for the field´s edge and the obstacles are marked separately as point data in the system of coordinates.
For each vector, the variables φ and p of Hesse´s normal form and the distance L between the points are calculated (**figure 5**). If the distance between the current position and the vector is positive, the vector is ignored because one passes the back side of the obstacle or drives from outside towards the field´s edge.
In this case, examinations are carried out to establish whether the foot P_f of the ver-

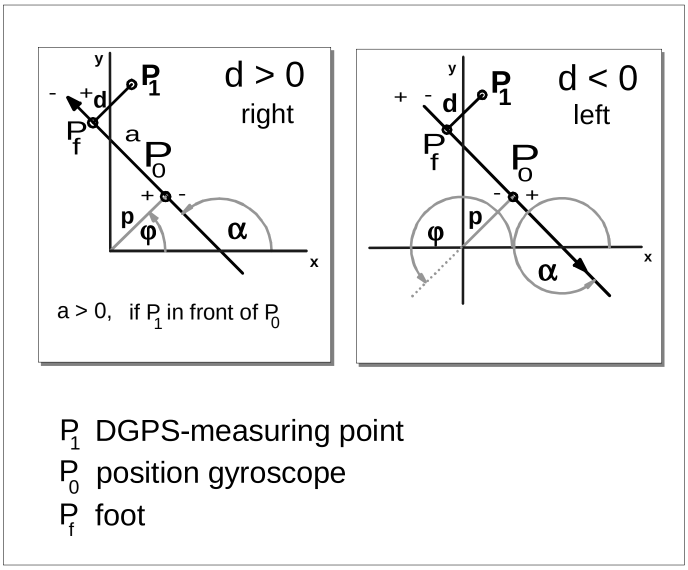

Figure 4: Determination of the direction with Hesse´s normal form

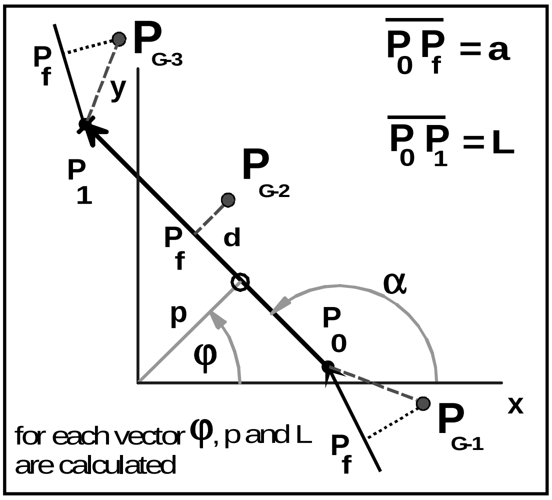

Figure 5: Calculation of the distance to obstacles and to the field´s edge

tical for the current DGPS position (in Figure 5 the points P_{G-1} to P_{G-3}) is situated in front of the starting point, between the starting- and the final point, or behind the final point of the vector. For this purpose, the distance *a* of the foot P_f from the starting point of the vector P_0 is calculated.
If *a* is negative, P_f is in front of P_0, and the distance to P_0 must be calculated as the smallest distance to the vector.
If *a* is positive and $a <= L$, P_f is situated between the starting and the final point. No further calculations regarding the vector are necessary, and *d* is the distance to the vector. If $a > L$, the distance to P_1 must be calculated as the smallest distance to the vector.

Check of the Algorithms during Real Field Rides

Figure 6 shows a field with 3 different obstacles (black background). For a tractor with automatic steering, the calculated positions of the gyroscope/radar and DGPS levels are marked in comparison with the real distance. The established maximum deviations from the actual position are in the range below 5 metres.
If the distance between the approaching tractor and the obstacle falls below 10 metres, the safety system is supposed to react. If the guideline is uninterrupted, the sensors of the automatic steering system are used for steering. Parallel to this, the GPS/DGPS receiver and the gyroscope/radar employed for the establishment of the position determine relevant safety fields in the grid and their distance to the current tractor position. If this distance is below the set safety distance, an alarm sounds.
In the case of a simultaneous breakdown of both the automatic steering system and the satellite signal, the sensor system gyroscope/radar, which is close to the ground, allows the course to be kept. Some studies have shown that, if the gyroscope and the radar sensor are precisely calibrated, the position can be established with sufficient accuracy over up to 100 metres even without DGPS support. At a driving speed of 10 km/h, this would correspond to a total breakdown of the navigational system (or its successful bridging) lasting 36 seconds.

Future Prospects

The possibilities of a GPS based safety system for automatic steering equipment can be appropriately developed further in different directions.

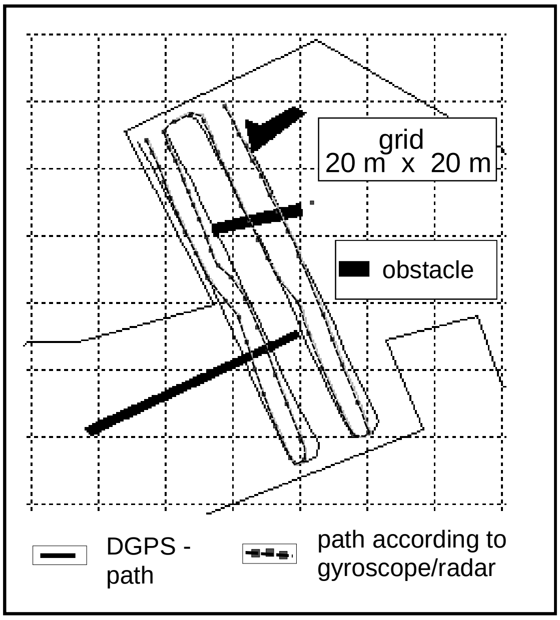

Figure 6: Representation of a field with 3 obstacles in the GIS

In addition to timely acoustic and/or optical warning of obstacles or field boundaries, these systems provide the possible perspective of extensions which include direct interference with engine- or transmission functions in order to further improve the safety of humans and machines through electronically controlled switch off functions.

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