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Path-planning for autonomous swaths

The automatic steering of farm machinery along virtual guidance lines can be realised nowadays via GPS navigation systems. A possibility for calculating virtual guidance lines exists through the further processing of recorded driving line data from a machine which has used the same operating pattern (e.g. swather-silage harvester working chain). The difficulty lies in establishing the swaths in such a way that optimal harvesting can follow bearing in mind turning manoeuvres at swath ends. The planning program developed at Hohenheim calculates autonomous working and turning paths for a silage harvester equipped with GPS navigation.

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Keywords

Automatic steering, autonomous path planning, guidance along swaths

The electronically controlled guidance of farm vehicles becomes increasingly important. This is reflected not least in the current development activities in industry and research [1, 2, 3]. The structure of vehicle guidance can be classified into positional sensing, the vehicle regulator and the vehicle itself with its steering and speed controls. The location sensors serve to determine regulator difference resulting from comparison of desired situation (position, driving direction, speed) with actual situation. The vehicle's desired situation is defined by the guidance line. If vehicle guidance is reduced to regulation of steering only, basically two types of guidance line would be possible: physically existing guidance lines, e.g. edges of standing crop or plant rows, and virtual lines calculatable in a suitable system of coordinates [4].

Virtual guide lines offer the advantages of being planned in a way detached from the actual work procedure or field structure, and also able to be supplemented with additional information for vehicle guidance. They may be calculated either manually or via learn-programs. With manual calculation, the coordinates for the support points and the geometry of the guidance lines are predetermined [5, 6]. Available for such a task is a CAD software based program [3]. For learn programs, a manual reference drive is carried out. Subsequently, guidance lines for electronically controlled vehicle steering based on the course taken may be calculated [7, 8].

In the field, a farm vehicle often positions itself according to lines followed by a previous machine. Based on this known path, guidance lines for the following automatically-steered vehicle can be calculated. This method was investigated based on the example of a swather-silage harvester working chain [9] and now extended to the planning of an autonomous guidance line for following swaths.

Recording the course of the swaths

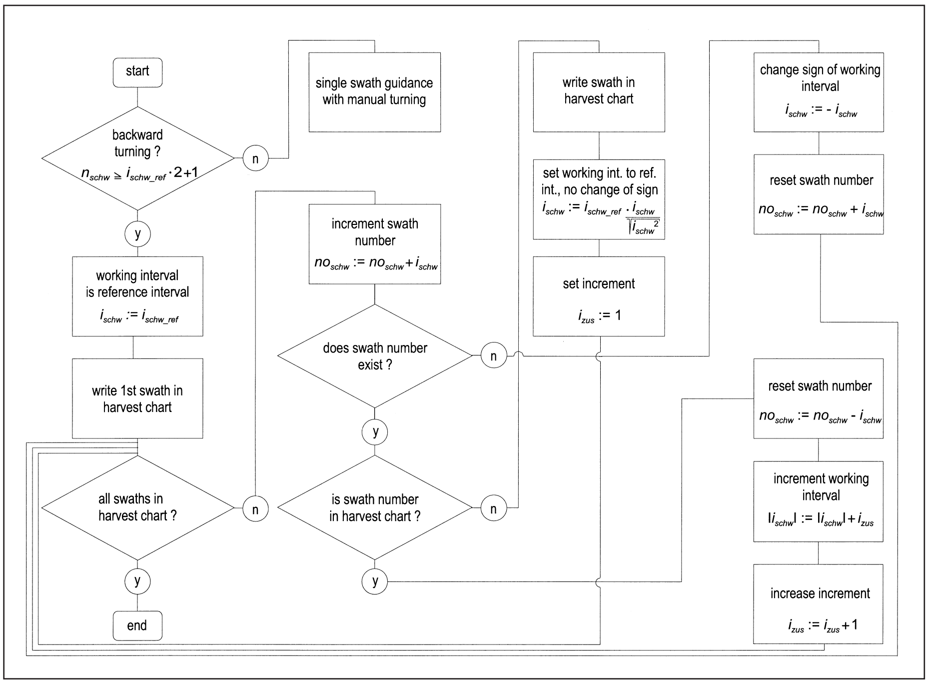
The swath courses were recorded during the swathing operation using a two-frequency DGPS offering a location precision in the region of just a few centimetres. The vehicle GPS antennae was positioned over the point where the swath was deposited. At 5 Hz frequency the path of the swath was measured and recorded in a notebook PC. Turning manoeuvres with raised swather were not taken into account. If two swaths were laid together through a forward and return bout, only the return bout was recorded.

Autonomous guidance line planning

Basic sequence

To begin the guidance line planning the recorded swath data was loaded into the plan-

Fig. 1: Determination of harvesting order



ning program. There, the data for every swath was first of all rearranged from its time-based sequence as recorded during the actual swathing to a spatial order and identified with a sequential identification number no_{schw}. No consequent role was played by the time-based order of the swathing operation. Swathing on headlands has not so far been included in calculations.

Finally, all distances d_{schw} between the swathing points were calculated and the minimum distance determined. Under consideration of the automatically-steered silage harvester's minimum turning radius r_{wende}, the reference interval i_{schw_ref} was calculated

$$i_{schw\_ref} = \text{round}\left(\frac{2 \cdot r_{wende}}{\min(d_{schw})}\right)$$

The reference interval defines the minimum distance between two swaths to be harvested consecutively. After calculating the distance, the order in which the swaths are to be harvested is determined. In that the order of the swath harvesting operation is stored in a list linked to the beginning and end of the operation, it is possible to begin the harvest process with any desired swath. The working and turning guidance lines are then automatically calculated in association with the chosen starting point.

Determining the order of swath harvest

The decision regarding harvesting order of the swaths is presented in the form of a flow diagram (*fig. 1*). To begin with, it must be checked whether there are enough swaths to allow all turning manoeuvres in foward gear. If this is not the case then only working guide lines are calculated and the turning manoeuvres carried out manually. From the list of the spatially ordered swathing, the first swath ($no_{schw} = 1$) is transferred into the new list of the harvesting sequence. The next swath no_{schw} is then calculated with the help of the working interval i_{schw} which is attributed at the beginning to the value of the reference interval i_{schw_ref}. Thus the spatially-ordered swath list is transmitted according to the work intervals in the harvest list. The work interval signal is changed when a calculated swath number lies outwith the actual swath numbers. When a calculated swath number has already been taken into the harvest list the work interval is increased by a step with regard to the total. After a swath has been successfully transferred into the harvest list, the work interval is set back onto the reference interval with regard to the total. If all swaths have been transferred onto the harvest list, then the ordering process is concluded.

Calculation of the work and turning paths

Following the calculation of the harvesting sequence, the work starting point can be defined. The preferable way is to drive the silage harvester into a swath. Based on this position the guidance line planning system seeks the appropriate point in the harvest list and calculates from this position onwards the already determined order of harvesting the swaths with all work and turning guidelines. Work guidance lines are calculated for all swaths in the form of line elements. The length of the elements is planned to allow a high driving and swath pick-up precision [9]. The work lines are linked by the turning guidelines. Every turning guideline consists of two arcs linked with a straight line. The geometry of the guide line is formed according to the end and start points as well as the delivery of the successively following work lines. The calculation takes place independently and individually for every turning manoeuvre. After all guidelines have been calculated for the complete field they can be transferred to the navigation system of the silage harvester.

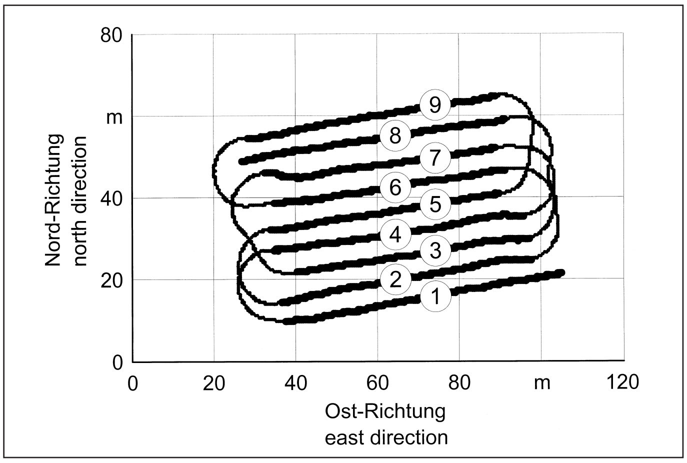


Fig. 2: Driving course of the automatically guided forage harvester; harvesting order: 8-2-5-9-6-3-7-4-1

Practical testing

The functioning of the autonomous guideline planning was successfully tested for different fields where swath order had been recorded. It has already been possible to collect first practical experience in a field trial. Nine swaths were recorded during the swathing. Based on this data, the planning program first calculated the harvest sequence as shown in fig. 1 beginning with the identification number no_{schw}=1. Finally, after the starting point had been determined (no_{schw} = 8) the work and turning guidelines were autonomously calculated. These guidelines were transferred to the navigation system of the automatically-steered silage harvester. The harvest procedure could be carried out without any manual interference regarding steering corrections. The course taken is presented in *figure 2*. The swaths, marked with their identification numbers, were harvested in the following order: 8-2-5-9-6-3-7-4-1. During harvesting, the driver could fully concentrate on the controls and the monitoring of the header and discharge control flap.

Summary and outlook

Autonomous guideline planning is a further step in the automation of agricultural field work. For the harvest of forage with a silage harvester equipped with two-frequency DGPS receiver, navigation system and steering control, a calculation method for an efficient following of the swath lines was developed. Guidelines for the individual work process and for turning manoeuvres could be calculated. The driver was thus relieved of steering work during the total harvest operation. Functionality could be successfully proved in a practical trial. In the following season further trials are to follow on larger areas of land.

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