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Automatic determination of headland turning from auto-steering position data for minimising the infield non-working time

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ABSTRACT

Minimising the infield non-working time that is spent when performing agricultural applications is one of the main factors that could lead to an increased efficiency of the utilised machinery. Machine developers and technology providers are striving to offer various solutions towards this direction. This study is focused on minimising the time for the necessary manoeuvres that are performed close to the boundaries of the field, i.e. headland-turning, in order to traverse all parallel tracks that will result in covering the entire field area. A 4.8 m cultivator and a 2-Track tractor equipped with an automatic steering driving system, with parallel tracking functionality, were utilised to perform seedbed preparation for a total area of 3000 ha during four consecutive years, i.e. 2014–2017. Four different drivers operated the tractor and performed different turning patterns by driving to the adjacent track (T_1), up to skipping five tracks and driving to the sixth parallel track (T_2-T_6). The T_1 was performed by an Ω-Turn while the T_2-T_6 by a U-Turn. From the recorded position information, a methodology for automatically determining the turning pattern and duration was introduced. The empirical cumulative distribution function of the turns was used to fit a known distribution and then perform Monte Carlo simulation to simulate a field with 40 turns. The headland turn, which was skipping two tracks (T_3 U-Turn), proved to require the minimum time with a value of 890 s while the maximum time was required for the Ω-Turn (T_1) with a value of 1522 s.

1. Introduction

Minimising the necessary time of performed agricultural operations had always been one of the overarching aims of the farmers and the machine developers. This need becomes even more imperative when is related to non-working time. An operation that requires substantial time is the turning that takes place at the headlands (track-to-track turn) in order to perform the in-field parallel tracks until the entire field area is covered. With the increase in automatic steering systems development, more complex steering paths can be manoeuvred including adjacent and nonadjacent pass headland turns.

The majority of the performed studies found in the literature are focused on minimising the non-working travelled distance concluding that this minimisation could also minimise the non-working time spent at the headlands for the necessary manoeuvres. Bochtis and Vougioukas (2008) used an algorithmic approach in order to find the most suitable sequence of tracks for processing. They concluded that the savings on the non-working distance can reach up to 50%. Bochtis et al. (2013) compared B-patterns with conventional fieldwork patterns by using the operation simulation. Their study showed a range of the non-working distance savings to be between 3.73% and 58.65%, and a range in the increased area capacity to be between 0.50% and 19.23%.

An optimal path planning algorithm that was offered in a study by Jin and Tang (2010) was aimed to find an optimal division of the field into sub-regions with a consequent determination of the coverage directions. It was indicated that there were no cases when an algorithm performed worse than the farmers' approaches. Even in extreme cases, it was possible to reach savings in a number of turns (up to 16%) and headland turning costs (up to 15%). Hameed et al. (2011) developed an approach for solving the problem related to field area coverage using genetic algorithms. A three-stage configuration was suggested: the first stage included a minimisation of the overlapping area; the second stage was aimed to decrease the non-working distance; and the final stage optimised the sequence of blocks.

Another important aspect is the determination of a smooth turning path taking into consideration the restrictions that arise from the steering system of the tractor. In their study, Backman et al. (2015) developed an algorithm for generating a smooth turning path for headland manoeuvring. The limited steering rate and acceleration were taken into account that made the offered algorithm to be different from

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the standard ones such as the Dubins Curve or Rees-Shepp path. A continuous-curvature path planning was offered as a method for generating turn trajectories by Sabelhaus et al. (2013). Different turning types were analysed and the presented results showed that CC-circles could be used for developing the suitable paths with fast computation performance.

Time minimisation has been also examined in a number of studies. In a study performed by Seyyedhasani and Dvorak (2018) for reducing field work time using fleet routing optimisation, a conventional human-operator routing was compared to a routing that was improved by the Tabu Search optimisation technique, in terms of the field completion time. As a result, it was proved that a reduction in completion time (by 17.3%) and a total operating time of the vehicle (by 11.5%) can be reached by the computer-optimised routings. Although in the work of Bochtis et al. (2015) the optimisation criterion was the non-working travelled distance, the authors also examined non-working time as a side effect and indicated a time reduction of 17.5–32.4%. Spekken and De Bruin (2013) tried to minimise the non-operational time of agricultural vehicles. They applied the heuristic Clarke–Wright savings algorithm (Clarke and Wright, 1964) resulting in a reduction of up to 50% in turning time.

Except the various modelling techniques, a proper analysis of acquired historical data could provide valuable information on how to perform in an optimal manner agricultural operations. With the increased adoption rate of precision farming technologies – 30% alone among German farmers as reported by Paustian and Theuvsen (2017) – the regular farmland is becoming a source of valuable data towards agricultural task optimisation. Various commercial solutions related to agricultural data collection and management are also available (365FarmNet, AgriWebb Agworld, FarmLogs and FarmWorks, just to name a few) with the number of vendors to be rapidly increasing. In many cases, the collected data are being stored in data repositories using telematics services (Paraforos et al., 2017a), something that facilitates data post-processing. As an example of time assessment of agricultural processes, Kortenbruck et al. (2017) used a combination of position information and ISO 11783 communication data from a number of four-rotor swathers, in order to extract the operation profiles of this machine under different local conditions.

The aim of the paper is to develop a methodology that automatically determines the headland-turning pattern (time and number of skipped tracks) from acquired position data, in order to minimise the headland turning time. The main objective is to find the number of skipped parallel tracks that require the minimum time. This should be achieved without using complex modelling or a high level of automation, but a thorough analysis of experimental field data. The methodology assumes that an auto-steering system with parallel tracking is available but not necessarily automatic headland turning support, i.e. the driver takes control of the steering during turning at the headlands. The contribution of the present work lies in the fact that it uses collected historical data from headland turns from different drivers that perform track-to-track turn with a different number of skipped rows.

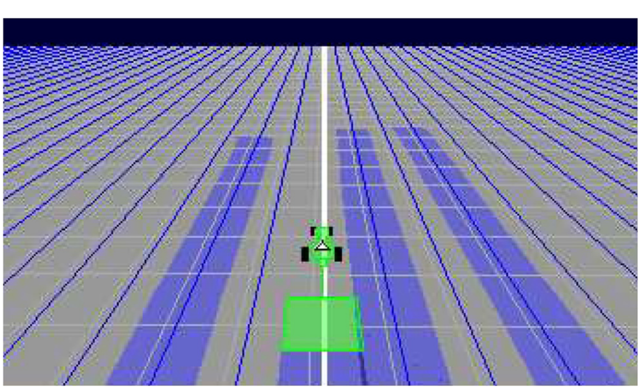

Fig. 1. Screenshot from the GS3 display indicating the currently driven track (white line); all parallel lines to the white one (blue lines), and the covered area (blue area). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Materials and methods

2.1. Instrumentation

A 2-Track 8345RT 254 kW tractor with a GreenStar™ 3 2630 (GS3) touchscreen display (John Deere, Moline, Illinois, USA) was used in this study. A Tiger LT 5 cultivator (HORSCH Maschinen GmbH, Schwandorf, Germany) with 15 tines and 32 cm tine spacing, with a total working width of 4.8 m, was pulled by the tractor to perform tillage operation. The tractor was equipped with an AutoTrac™ automatic guidance system with parallel tracking functionality. The GS3 display was connected to a StarFire™ dual-frequency GPS receiver with integrated Terrain Compensation (iTC). The receiver was receiving the John Deere-exclusive free StarFire™ 1 (SF1) differential correction signal, as well as the European Geostationary Navigation Overlay Service (EGNOS) correction signal, providing a 0.15 m pass-to-pass position accuracy.

2.2. Parallel tracking system

The tracking mode of the AutoTrac system was configured to follow a straight track using an AB line (A + B method in the GS3 display). In

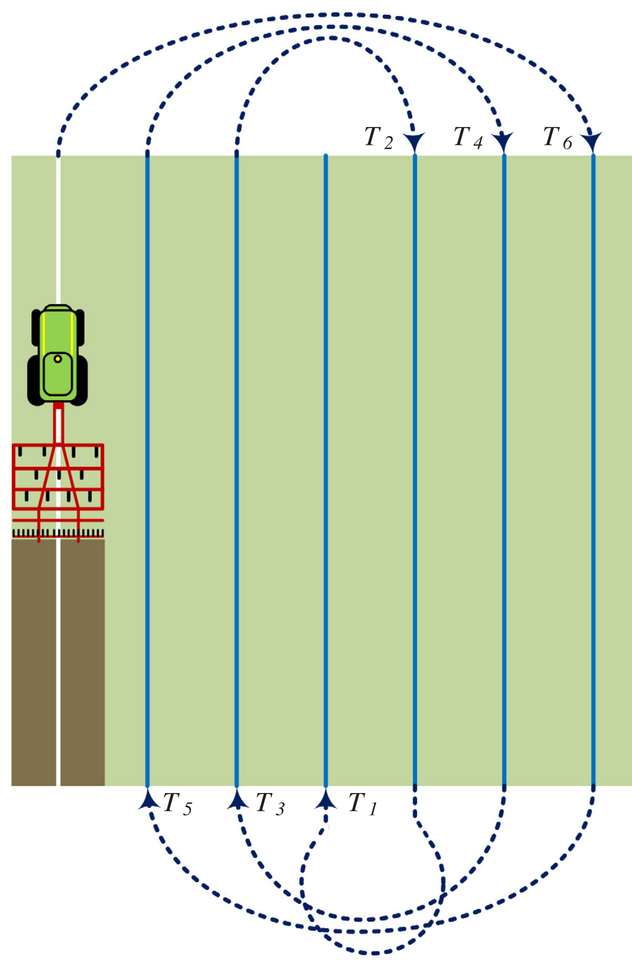

Fig. 2. Examined headland-turning types between the fieldwork tracks. For T_1 an Ω-turn was performed while for T_2-T_6 a U-turn.