

prospective.HARVEST – Optimizing Planning of Agricultural Harvest Logistic Chains

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Abstract: The research and development project “prospective.HARVEST” aims at optimizing the process chain of silo maize harvesting, based on a predictive approach using prognosis data. New methods and tools have been developed utilizing remote and in-situ (geo-) data from a variety of data sources in order to enable farmers to optimize their logistic chains. Optimizations are computed as recommendations on several layers of the harvest process, from monitoring the crop over planning the inter-field and in-field coordination of harvesters and transport vehicles up to the surveillance and dynamic replanning of the ongoing harvest execution.

Keywords: Precision Farming, Smart Farming, Planning, Maize Harvesting, Logistic Chains

1 Introduction

Every year, farmers face a series of planning and logistical challenges when harvesting silo maize. Monitoring field status, degree of ripeness and estimated yield, planning the harvest order of fields as well as coordinating harvesters and transport vehicles are just a few examples of the complex but interdependent processes that farmers need to manage. Traditionally, the management of this process is done based on individual experience and simple manual structures. However, the current trend towards large-scale agricultural crop cultivation poses new challenges to farmers, since larger amounts of cultivated fields increase the complexity of planning, monitoring, as well as cultivation. Hereby, traditional methods reach their limits leading to an inefficient use of available resources and thus to avoidable costs for farmers. Deficits, for example, have been identified by Feiffer [Fe04] in terms of coordination-related poor machine productivity (>50%), and by Duttmann et al. [Du14] in terms of high soil compaction overrun (63% on average) resulting in high costs per unit and negative side effects on the biosystem.

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Farmers are therefore seeking for a scalable approach to optimise their production processes in order to achieve cost savings and a more sustainable agriculture, thus becoming more competitive in a globalized modern market.

Nowadays, many approaches for optimizing agricultural logistic chains and in particular harvesting processes exist. However, past and current optimizations often focus on partial facets, e.g. waypath travel optimization and multiple machine coordination in- and off-field [Ga14; Ed17; SLH16]. In a holistic approach, automated decision support should be provided on several levels, starting with long-term monitoring of the harvest, via the optimization of the field sequence and up to foresighted and automated control of transport logistics. This poses new challenges to infrastructure and data management, which need to be integrated and interlinked across different levels.

The research and development project prospective.HARVEST addresses these challenges and aims to provide proactive decision support tools for farmers and dispatchers in order to improve the logistics of silage maize harvesting processes. For this purpose, a technical solution consisting of complementary services has been developed which uses modern information and communication technologies to control and monitor the complete logistics based on satellite, machine and other forms of geodata. In particular, the approach aims at maximizing the yield and the utilization of machines and other resources while minimizing machine downtimes and travel routes. The following paper summarizes some of the methodological approaches and gives an overview of the overall system architecture.

2 Multi-layered optimization of silo maize harvest

The aim of the project prospective.HARVEST is to increase the resource efficiency of harvesting processes by exemplarily focusing on silage maize. Hereby, multiple layers – each addressing different aspects of the complete harvest process – can be identified. Figure 1 illustrates the multi-layered architecture developed by the project, including the deployed components and their responsibilities.

Crop Monitoring: This layer is responsible for the continuous monitoring of crop ripeness and biomass for all fields of interest. To identify optimal harvest dates and to monitor field status, satellite data (e.g. originating from the European Copernicus programme) is being analysed and integrated with other data sources.

Capacity Planning: Once the harvest period for each field has been determined, the next step in the chain is the strategic planning of required resources for a set of cultivated fields considering their spatial distribution and suggested harvesting windows. This is dedicated to find an optimal harvest sequence based on available resources (e.g. harvesters, transport vehicles, employees) by solving inter-field travel routes and

considering further constraints such as working hours, ripeness degree, and available resources.

Daily Schedule Planning: This layer uses scheduling and optimization algorithms to create a work plan for in-field activities by predicting harvester and transport vehicle routes, processing time, and crop overloading windows. This enables farmers and contractors to better coordinate their resources and thus to increase machine productivity while reducing resource consumption.

Harvest Execution & Monitoring: This monitoring layer is responsible for tracking the harvest progress. Based on near-real time information remaining harvesting activities will be dynamically re-planned, e.g. in case of exceptional situations such as changed resource availability.

By following this multi-layered approach, prospective.HARVEST aims for an integrated optimization of the entire process chain by providing insight into all relevant aspects of the harvest process and to deliver recommendations to farmers and contractors where needed (e.g. field order according to shortest distance and target ripeness degree or recommended harvester infield route).

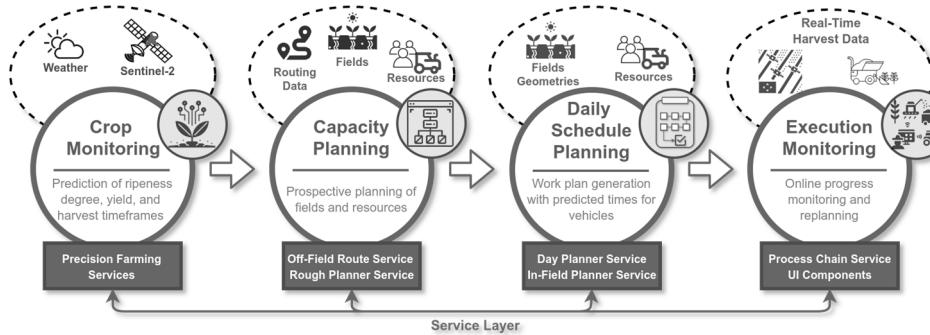


Fig. 1: The multi-layered optimization approach followed in prospective.HARVEST

3 The prospective.HARVEST Platform

prospective.HARVEST offers automated on-demand analysis and decision support tools and services for each of the phases mentioned above. They are implemented as complementary software services which are based on state-of-the-art information and communication technologies and which leverage a wide range of (spatial) data resources made available publicly (e.g. satellite data as published by the Copernicus programme) or offered by the various actors of the harvesting process (e.g. field boundaries and telemetry data) as well as third parties. The prototypical implementation forms a spatial information infrastructure and combines RESTful architectural styles based on OpenAPI

standardized interfaces as well as event-driven approaches for real-time processing and monitoring the progress of the field harvest. It offers applications for predictively planning, monitoring, and proactively controlling the individual links of the logistics chain. Amongst others, the service network comprises components for simulating off- and in-field processes, components for predicting the degree of ripeness and estimating the expected yield as well as components for managing and monitoring harvest execution and machine performance. The task of the In-Field Planner (IFP), for instance, is to generate routes for the harvest and transport vehicles aiming to optimize the machine usage and the harvesting duration for a given field. The computation of the routes is based on the geometry of the field, the static and dynamic parameters of the vehicles (incl. working widths, speed limits, bunker capacities, and current location and bunker states), the estimated biomass and dry-matter, user-defined parameters (incl. headland width and headland harvesting direction), and duration of out-of-field activities (incl. travel to and unloading at the silo). Figure 2 shows an example of the computed harvester (left) and transport vehicle routes (right) for a field. The generated routes are also used to estimate the duration of the harvesting process of each field and to plan the overall campaign. They are also presented to the drivers via a graphical user interface (GUI) while harvesting in order to suggest optimal driving routes. Moreover, the IFP offers dynamic planning, where maps of the area that has been already harvested are used together with the current states of the machines to re-plan the vehicles' routes in real-time during the harvesting process.

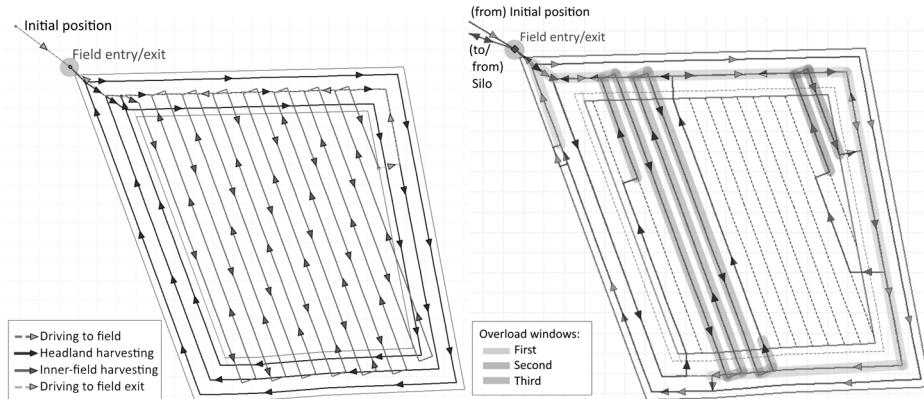


Fig. 2: *Left:* harvester route: 1. driving to the field (green); 2. harvesting the headland clockwise (blue); harvesting the inner field (magenta); 4. exiting the field (cyan)
Right: transport vehicle route highlighting three overloading windows: one in headland harvesting; two in inner field harvesting

4 Results and discussion

To evaluate the overall system, a total of three different field tests for silage maize harvesting were carried out by an agricultural holding in the area of Lower Saxony, Germany, within 2017-2020. Each year, one harvester and several transport vehicles handled approximately 15-20 fields of varying sizes and shapes by following prospective.Harvest recommendations. With each test period, the requirements with regard to testable components and expected results increased incrementally.

The evaluation of the final field test in 2019 revealed that the overall system worked stable and predominantly provided helpful planning recommendations for each step of the harvest chain. For instance, the comparison of forecasted biomass raster maps, acquired through the analysis of Sentinel-2 data, and the actual yield maps generated by the in-situ harvester Telematics system for 17 exemplar fields, reveals that the crop density is well reflected by the prognosis data. Although the pixel size of 10 meters is still too coarse to allow for fully automated high-precision harvester control, the biomass and dry matter maps and the monitored ripeness degree represent crucial information for the planning services that estimate the field's harvest duration through harvester progress simulation. Future improvements such as higher spatial resolution of remote satellite and in-situ weather data may produce even more realistic predictions.

Regarding the recommended field sequence computed by *Rough Planner* and *Off-Field Route Planner*, the field tests have shown that, from an abstract point of view, the inter-field travel route computation produces plausible spatially optimized field groups for each day of the harvest period. However, in reality, often farmers and dispatchers dynamically adjust field harvest sequences due to facts or constraints uncovered within the current logistic planning model (i.e. hands-on experience with traffic jams on certain roads at certain times). Still, the optimized field harvest order computed by the *Rough Planner* may serve as a solid starting point to plan the harvest for each day of the campaign that might be slightly adjusted to the farmers' desires.

5 Conclusion

This paper presented the conceptual approach of a multi-layered optimization for silage maize harvest. The results showed that traditional farming competence can be expanded through the systematic analysis of agriculturally relevant geodata and – based thereupon – the automated and dynamic generation of harvest plans. However, not all recommendations were in line with the farmers' own experiences. For instance, the recommended field order partially diverged from the order chosen by the farmer, based on his long standing experience. Nonetheless, even experienced farmers may benefit from the various planning and monitoring components of the system. Foremost, the satellite data based prognosis data of biomass and dry matter density as well as the InField machine logistics simulation provide helpful insight on the harvest. As the

project is still ongoing, not all aspects from the harvest periods have yet been fully evaluated.

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