Towards a flexible hybrid planner for machine coordination in arable farming

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Abstract: In this paper we propose a new approach to coordinate multiple machines in the grain harvesting process, based on meta-constraint reasoning. This way we obtain more flexible plans that can be adapted at execution time. As an example scenario we focus on silage maize harvesting. We argue that more sophisticated flexible planning mechanisms are needed in order to obtain flexible plans that can be adapted at runtime to changing parameters such as yield per area.

Keywords: Automated Planning, Autonomous Harvesting, Hybrid Reasoning.

1 Introduction

Robotics and artificial intelligence technologies are gaining importance in agricultural processes. One major example is the automation of the grain harvesting process with multiple cooperating machines. While at least one combine harvester is harvesting the field, unloading vehicles have to take over the crop and transfer it to a dedicated deposit point. To optimize the harvesting process, a planning system has to coordinate the machines by generating appropriate plans consisting of paths for the available machines. The resulting plans can be provided to the drivers of the machines via an assistance system or even be executed fully autonomously.

The planning system needs to take several interconnected requirements into account. For example, unloading vehicles must not drive on unharvested areas of the field, the machines' maximum capacity must never be exceeded, and valid solutions need to include the paths of the unloading vehicle to and from the deposit point. In general, the plans have to be feasible with respect to temporal, spatial, kinematic and resource requirements, which vary, depending on the specific types of harvesting process. For example, combine harvesters for wheat have a bunker, whereas maize harvesters most often do not, and therefore constantly require an unloading vehicle driving next to it.

Current approaches use domain specific planners that make simplifying assumptions or integrate the requirements of specific machine types into their internal representations. [Sc13] describes an approach for wheat harvesting that employs a graph-based representation of the field and generates feasible routes for the machines with A* search.

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A similar approach for beet harvesting is presented in [Ul16]. These kind of planners makes assumptions about the specific types of machines that are used, e.g., that the combine harvester always unloads to the left side. These assumptions are modeled intrinsically in the planner’s internal graph representation. Therefore the planner would need to be changed for machines by other manufacturers that unload to the right side.

Another important aspect of the problem is the flexibility of the resulting plans. In real world applications planning cannot be seen as a one-step process. For example, the actual yield on a given area of the field generally differs from the amount expected at the time of plan generation.

A general planner for harvesting problems therefore needs to be flexible in two ways. First, it should employ a more general representation and reasoning mechanism to integrate different requirements rather than hard-wiring these requirements into the search heuristic. Second, it should generate flexible plans to be adapted at execution time. Because of these requirements, meta-constraint reasoning is well-suited for the harvesting scenario. In this paper we focus on generating flexible plans for a specific domain: silage maize harvesting. The next step will be to show how the planning system applies to other planning problems with significantly different constraints, too.

In the given scenario, the planning system has to coordinate at least one maize harvester and multiple unloading vehicles to harvest a field. The planner is given the outer field border, a reference line(s) indicating the furrows, and information about the available machines. A resulting plan has to consist of paths for each machine. These paths contain temporal and spatial information indicating the machines’ poses at different times.

2 Hybrid planning

Hybrid planning, i.e., the integration of various forms of knowledge into the planning process, is an active research topic in artificial intelligence and robotics. Among the approaches developed in that field, meta-constraint reasoning [MP14] is becoming prominent. It is based on principles of constraint-reasoning and represents the planning problem as a constraint satisfaction problem (CSP) [De03]. Meta-constraint reasoning provides an elegant mechanism to reason about different forms of knowledge by combining various specialized constraint networks. For example, the temporal and spatial aspects of a problem can be represented and reasoned upon in dedicated low level temporal and spatial constraint networks, and combined in a common constraint network. Furthermore, additional requirements can be imposed on the common constraint network, so-called *meta-constraints*. An example for such a meta-constraint is resource feasibility, as described in [COS02]. This way we obtain a *meta-CSP*, i.e., a constraint satisfaction problem at a higher abstraction level.

Planning is done by identifying conflicts of the high-level requirements and resolving them by posting additional constraints in the low level. After adding new constraints, consistency in the specialized low level constraint networks is checked and all high-level requirements are re-checked. This way the solution gets more restricted incrementally. If a conflict cannot be resolved, the planner backtracks. For details see [MP14]. The approach has been applied to other domains such as drill planning in pit mines [MAP15].

In the work reported here, we modify and extend the work by [Sc13] by replacing its graph-based infield machine coordination planner with a new planner that is based on meta-constraint reasoning. For a field with a given outer border, first the inner field border is generated by shifting the outer border by a given headland width. In a second step, harvesting tracks are created by shifting a reference line throughout the inner field by the harvester's working width. This set of tracks is the input for our planning system. Details of these geometric preprocessing steps can be found at [Sc14].

The overall coordination problem is divided into several sub-problems, which are strongly interconnected; thus they cannot be solved independently. Instead, the solution of the overall problem is searched in the joint search space of these sub-problems by employing the meta-CSP approach. The sub-problems are represented as high-level requirements, i.e., meta-constraints in a common constraint network. This constraint network consists of variables with temporal, spatial and symbolic parts. These variables are used to represent the tracks and additional areas as well as activities of the different machines. Temporal variables are defined as flexible temporal intervals $I = [I_s, I_e]$, with intervals $I_s = [l_s, u_s]$ and $I_e = [l_e, u_e]$, where $l_{s/e}, u_{s/e} \in \mathbb{N}$, denoting lower and upper bounds for start and end times. The spatial part consists of points, line strings or polygons.

For silage maize harvesting we identified different sub-problems. The *track strategy sub-problem* decides in which order the tracks will be harvested and connects their temporal variables. To this end, it also creates new variables representing an estimation of the areas which the harvester will occupy while driving from one track to another. The tracks and turn areas are connected with temporal constraints. This way we maintain the time intervals in which the tracks will be harvested.

The *overload coverage sub-problem* ensures that an unloading vehicle is driving next to the harvester at any time. It creates unloading activities that are assigned to vehicles and connects these activities with temporal constraints. Moreover, it adds constraints making sure that an unloading activity respects a minimum and maximum capacity. This is based on a yield map that estimates the amount of crop that is harvested on parts of the field.

These two meta-constraints can be used to generate a basic feasible plan that respects the unloading vehicles' capacities based on the yield map. The information given by the spatial and temporal variables is already sufficient to coordinate the machines: the end times of the unload activities provide intervals in which the vehicle's capacity will be exceeded and another overloading vehicle must take over. If no further requirements are given, this flexible (interval based) plan suffices as a general plan, which will then be instantiated with fixed times and adapted during plan execution. These expansions require solving the *resource sub-problem.* The corresponding meta-constraint constantly assures that an unloading vehicle's maximum capacity is not exceeded, based on the yield map and the common constraint network.

The solution can be further refined with additional meta-constraints that we plan to include as future work. The distances of the unloading vehicles' paths to and from their deposit points should be estimated and maintained by temporal constraints. Furthermore, the machines' paths could be refined by a motion planner, as done in [Sc13].

3 Summary and outlook

In this paper we proposed to apply meta-constraint reasoning for the coordination of multiple machines in maize harvesting. The resulting planner employs a hybrid constraint-based representation on which multiple high-level reasoners can operate. This way flexible plans can be obtained that can be refined at execution time. Furthermore, the modularity of the planning approach allows to adapt or add high-level requirements. This work has been done within the project SOILAssist[3]. In this scope we will incorporate the minimization of soil compaction risks as an additional optimization criterion in the future. Next, the planning system needs to be tested on real machines. Furthermore, we shall adapt the planner to wheat harvesting, as demonstrated by [Sc13, Sc14].

References

[COS02] Cesta, A.; Oddi, A., Smith, S. F.: A Constraint-based Method for Project Scheduling with Time Windows. In Journal of Heuristics. 8(1):109-136, 2002.

[De03] Dechter, R.: Constraint Processing, Morgan Kaufmann, 2003.

[MP14] Mansouri, M.; Pecora, F.: More knowledge on the table: Planning with space time and resources for robots. In Proc. IEEE Int. Conf. Robotics and Automation (ICRA), pp. 647-654, 2014.

[MAP15] Mansouri, M.; Andreasson, H.; Pecora, F.: Hybrid Reasoning for multi-robot drill planning in open-pit mines. In IROS 2015 Workshop on On-line descision-making in multi-robot coordination, 2015

[Sc13] Scheuren, S.; et al.: Spatio-temporally Constrained Planning for Cooperative Vehicles in a Harvesting Scenario. In KI – Künstliche Intelligenz, 27(4):341-346, 2013.

[Sc14] Scheuren, S.: Prozessoptimierte Planung für kooperative mobile Roboter. Dissertation, Universität Osnabrück, 2014.

[Ul16] Ullrich, A; et al.: Development of a Framework for Navigation Planning in Agricultural Field Processing Using the Beet Harvest as an Example. In Proc. GIL 2016 (this volume), 2016.

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