Infield Path Planning for Autonomous Unloading Vehicles

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Abstract: In agricultural harvesting processes, the infield logistics of transporting the crop from the harvesters' tanks to a street transporter at the field border with an unloading vehicle is challenging. The harvesters have to be unloaded while driving and in time to prevent the loss of expensive process time. The path planning for the unloading vehicle has to consider the unharvested area as a dynamic obstacle and cope with additional constraints like the harvester's kinematics, dynamics and its unloading direction. We present an approach for infield path planning for autonomous unloading vehicles that tackles these problems.

1 Introduction

Today, in the agricultural process of harvesting, mobile machines cooperate to transport the crop from the field to a storage location. For large fields it is common practice to use multiple harvesters, unloading vehicles and street transporters. A harvester stores the crop in its tank until an unloading vehicle arrives next to it. The contents of the harvester's grain tank is then unloaded into the trailer of the unloading vehicle while driving in parallel. Afterward the unloading vehicle approaches the next harvester. When the unloading vehicle is fully loaded, it moves to a specified resource point at the field border to unload the grain into a street transporter. The street transporter then uses the road system to transport the grain to the silo.

The logistics chain offers optimization potential, especially when it comes to the cooperation of the machines. This paper was created within the project marion[1], in which the infield logistics is regarded, in particular the cooperation of harvesters and an autonomous unloading vehicle. It is a basic requirement of an autonomous unloading vehicle, which shuttles between harvesters and street transporters, that the computed path is smooth and feasible. Furthermore, as the execution of the harvesting process is very likely to differ from the initial plan, e.g. because of local yield deviation, path planning

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must be fast enough to be re-computed during process execution. In the remainder a novel approach for the infield path planning of an autonomous unloading vehicle is described which meets these requirements.

2 State of the Art

The general goal of path planning is to compute a feasible path from a start pose to a goal pose in a certain environment. Many path planning algorithms have been developed, of which some of them are detailed in [La91]. In the last decades, many algorithms have been tailored to be more efficient, like the probabilistic Rapidly-Exploring Random Tree search (RRT). Those fast algorithms can be used for online (re-)planning on a mobile platform. For agricultural processes like harvesting, the harvesters' paths have to cover the whole field. In [OV09, Al09] algorithms for complete and efficient coverage path planning were presented.

For path planning of the unloading vehicle, rendezvous points have to be added to the routes of the harvesters at which the unloading starts. Those rendezvous points have to be chosen in a way such that the harvesters' idle time due to a completely filled grain tank is minimized. In [BS10] the planning task for supporting agricultural machines is represented as instance of the vehicle routing problem with time windows (VRPTW). The optimization task of scheduling the best unloading locations is not part of our approach. The rendezvous points are required as start or goal pose for the path planning of the unloading vehicle.

For optimal resource utilization, a hierarchical decomposition approach for complex agricultural tasks is provided in [Bo07]. In [Je12] a path planning approach for an infield servicing vehicle is presented based on a shortest path search in a graph representation of the field. However, they do not regard the unharvested area as a dynamic obstacle but only use edges of their graph that represent harvested tracks at the start time of the unloading vehicle.

Our approach, described next, is based on a directed graph that represents the tracks and headland connections. The graph is adapted for every planning instance. For each edge time windows are added that contain times where the edge is not passable, e.g. if the represented area is not yet harvested. The shortest path in the dynamic graph is then split and used as input for path planning algorithms that consider the vehicles' kinematic constraints. Thus, the generated path can be followed by an autonomous unloading vehicle.

3 Infield Path Planning for Autonomous Unloading Vehicles

The planning task is part of the problem of spatio-temporally constrained motion planning for cooperative vehicles as described in [Sc11]. The field is divided into an area inside an inner field border that is covered by tracks and an area between inner and outer field border that is used for turning maneuvers. A variety of constraints exist for the vehicles. While harvesters have to stay on the precomputed tracks inside the inner field area, unloading vehicles may additionally cross them at low velocity. As unloading vehicles may only move across harvested area, the unharvested area has to be considered as a dynamic obstacle.

If the route of the harvesters is known and their speed and filling level can be predicted sufficiently accurately, a valid sequence of rendezvous points can be calculated. At these points the unloading of the harvesters starts. They are defined by position, orientation, velocity and time. From these points, the goal position, orientation, velocity and time for the unloading vehicle can be determined. Those points have to be connected by path planning as shown in the block diagram in figure 1.

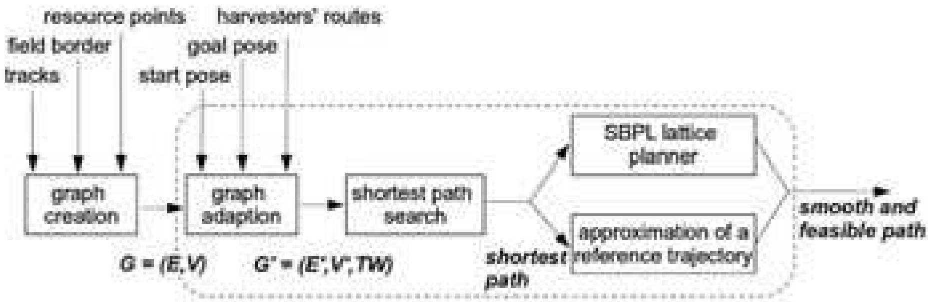

Figure 1: Block diagram of the path planning steps. First a graph is generated from the field geometry. For each planning instance, the graph is adapted using the start and goal pose and the harvesters' routes. An adapted Dijkstra algorithm returns the shortest path as sequence of nodes, which is split into parts. Those parts are refined by an approximation algorithm [Sc12] and the SBPL lattice planner [LF09], depending on the maneuvers they represent. Connecting the planned parts results in a smooth and feasible path that can be followed by the autonomous unloading vehicle.

From the tracks and resource points a directed graph $G = (E, V)$ is created. For every planning instance G is adapted. For edges e representing tracks a time window $w_{e} = [0, t_{e\ harvested}]$ is added. If start or goal pose of the unloading vehicle lies on a track, intermediate nodes are inserted and connected by new edges. This step is required to allow an unloading vehicle to follow a harvester in a certain distance on the same track instead of waiting for the harvester to leave the track. Additionally, as the unloading vehicle is allowed to cross the tracks at low velocity, nodes and edges representing orthogonal connections from start- and goal position are added. The adapted graph is then searched with a Dijkstra algorithm with time windows.

For autonomous path following the resulting shortest path in the topological graph has to be adapted accordingly to the unloading vehicle's kinematic constraints. The path is split into parts that need to be followed precisely and parts that connect them. For the different parts two path planning algorithms are used. For precise path following an approximation of a reference trajectory using motion primitives [Sc12] is employed. To connect the approximated paths the Search-Based Planning Library (SBPL) lattice planner [LF09] is used. As both algorithms build the path from a pre-computed set of motion primitives that fulfill the vehicles' kinematic constraints, the resulting path is feasible.

The parts are connected without any gaps or discontinuities, so the path is smooth, too.

The described approach provides a fast way to compute a short, smooth and feasible path for an autonomous unloading vehicle from a start pose to a goal pose on a field regarding the unharvested area as dynamic obstacle. It benefits from the implicit storage of unharvested area in the time windows of the adapted graph's edges. The approach is used as part of a planning system for optimizing the cooperation of all involved machines and thus helps optimize the whole harvesting process.

4 Conclusion and Future Work

We presented an algorithm for path planning of an autonomous unloading vehicle for an agricultural harvesting scenario. The algorithm considers the unharvested area as dynamic obstacle and allows the crossing of neighbored tracks with higher costs. We tested the described approach for various configurations in simulation. The next step will be the test of our algorithm on real machines in a harvesting scenario on a field.

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