Task Scheduling and Trajectory Generation of Multiple Intelligent Vehicles

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Abstract

The problem of multi-vehicle path planning can be treated as a machine scheduling or a vehicle routing problem with definite temporal, spatial and other constraints. We consider the scenario of path planning of multiple Automated Guided Vehicles (AGVs) and Automated Trucks (ATs) in a Ship-Container Terminal area*. Our main focus is on developing global and local path planning methods for each of these vehicles along with a centralized task scheduler to designate goals to each of the vehicle. The whole problem can be divided in to two folds: Firstly, it is required to produce optimal schedule (planned path lengths), for a fleet of AGVs to certain goal points to pickup/drop off containers. It is treated similar to a truck scheduling problem with special constraints to deal with dynamic and complex environment. Secondly, it involves finding collision free trajectories for each of the vehicle using gradient descent method. We aim to propose an integrated framework for solving the goal assignment and trajectory planning problem minimizing the maximum cost over all vehicle trajectories and avoiding conflicts.

Research Situation

I started my PhD program in May 2014 at the Intelligent Systems Lab under the Center for Applied Intelligent Systems Research at Halmstad University. My supervisors are Prof. Thorsteinn Rognvaldsson and Dr. Rafael Valencia. I am also being by Dr. Karl Iagnemma (Visiting Professor from MIT, Cambridge, MA). Dr. Roland Philippsen of Google Inc., USA is my research mentor. My project is funded by EU Project Cargo-ANTs FP7-605598 in collaboration with three industrial partners Volvo AB - Sweden, TNO - Netherlands and ICT Automatisering Netherlands and academic partners IRI-CSIC, Spain. The project started on September 2013 and the aim of the project is to create smart Automated Guided Vehicles (AGVs) and Automated Trucks (ATs) that can co-operate in shared workspaces for efficient and safe freight transportation in main ports and freight terminals. The project ends on August 2016. The PhD program is generally 3-4 years and I two more years to defend my thesis. There is no research proposal stage and I have been working on the project from the start of my program.

My focus of my part of the project is on multi-vehicle path planning. The objective of the work is to develop and demonstrate planning, decision, control and safety strategies for automated vehicles. My main research question is to setup a high level interaction planning which integrates with the vehicle control system. So far, a complete navigation framework has been developed in this work as shown in figure 1. It consists of a task scheduler, global path planner and a local planner. Literature review has been conducted on each of these areas to choose on the specific approach/methodology that will fit our application scenario. This will be discussed in the third section. A simple task assignment algorithm based on the classical Hungarian Assignment (Kuhn 1955), a dynamic navigation global planner based on Estar (Philippsen 2002) and a local planner based on CHOMP (Covariant Hamiltonian Optimization Algorithm for Motion Planning) by Zucker 2012 has been adapted for this framework.

The novelty of my thesis is to adapt this approach for the chosen scenario which will be discussed in the next section. With respect to this, a simple ROS navigation stack has been developed in C++. Preliminary results of the local planner have been conducted on an Automated Truck Volvo FH 60 since November 2015 and have been continuously debugged. The ROS stack has been continuously extended to adapt to complex and dynamic environments. Presently, I have been integrating mapping and vehicle control techniques with this framework by conducting real time tests as well as simulation tests in Gazebo. High level planning and task scheduler are needed to be integrated yet. Moreover, research questions on task scheduler and novelty problems faced during integration have to be addressed yet.

Content and Motivation

More than 60% of the worlds cargo has been transported using ships and there is a continuous growth in global container trade. Hence, container transport industry faces new challenges such as increasingly stringent environmental regulations as well as capacity bottlenecks at ports and hinterland connections. The Cargo-ANTs project is based on the premise that technological innovations in transsshipment technologies will play a key role in meeting these demands in an integrative and cost efficient manner especially on the truck scheduling problem in container terminals.

In this regard, there is a need of a completely autonomous system to transport containers using AGVs and ATs. Hence, in this work, apart from developing global and local planner for making an AGV/AT fully autonomous, there is a need for creating an optimal task scheduler that resembles a traditional truck scheduler used in ports. However, this scheduler is integrated with the vehicle planners in such a way that it can avoid path conflicts with other vehicles as well as produces optimal paths in terms of the path length. This is the novelty of my thesis.

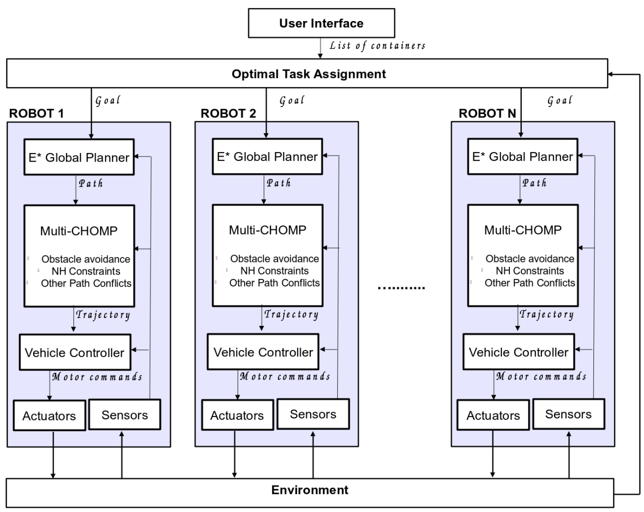

Figure 1: Navigational Framework

Related Work

The core part of the thesis is about Multi-Vehicle Path Planning. It can be dealt as a centralized planner or a decentralized planner. But, there is a tradeoff between complexity and optimality in these approaches. There are also other approaches as in swarm robotics as multi robot coordination problem but they are far from optimality. Recently, a new approach involves treating multi robot vehicle problem as task allocation problem which is a balance between centralized and decentralized approach that gives near optimal solutions. Liu and Shell (2013) used an any time assignment algorithm which was a dual to the Hungarian algorithm. Turpin et al. (2014) used an optimal goal assignment method coupled with trajectory planning for multiple quadcopters.

All of these approaches used only assignment methods especially the Hungarian or any variant of this algorithm. There is no scheduling involved that includes temporal and spatial constraints. Gombolay et al. (2009) developed a fast task sequencer in conjunction with a MILP solver to generate near-optimal task schedules. But there is no integration with trajectory planner here. Hence, this work tries to exploit the usage of a centralized task scheduler to avoid path conflicts between vehicles. Since task scheduler itself is a time complexity problem, coupling a planner with it, is a challenging problem to look on.

Problem Statement

The main research problem that will be addressed here is on exploiting the global nature of the task scheduler in avoiding local conflicts between vehicle paths by coupling it with the trajectory planner. This problem has not been discussed in the literature due to the computational complexity of the scheduler. However, if scheduler is coupled with trajectory planner, it is possible to develop near optimal solutions for multi-vehicle planning problems with less complexity.

Research Goals/Methodology

The whole of this work is a synergetic amalgamation of three different areas - optimization techniques in container terminal schedulers, multi robot task allocation and trajectory planners. Depending upon our application, a navigation framework is to be designed that could be run on real AGVs and ATs in a dynamic environment as the container terminal area. The research problem is to develop a centralized task scheduler similar to a traditional truck scheduler for container terminals with additional constraints suitable for autonomous vehicles. The second part of the research problem deals with the trajectory planner of the vehicle in optimizing the planned trajectory to adapt to the kinematic and non-holonomic constraints of the vehicle using a gradient descent method. The main research goals are:

- Development of a centralized task scheduler for autonomous vehicles.
- Development of a smooth and collision free trajectory planner.
- Integration of the scheduler with the trajectory planner to avoid conflicts.

We presently use Hungarian, variants of Hungarian and auction algorithm for task assignments in a simple environment. Hence, for task scheduler, we adapt an existing fast task sequencer (Gombolay et al. 2009) that can work for truck scheduling constraints. For obtaining smooth and collision free trajectories, a gradient descent method (CHOMP) is used. Adaptation of these algorithms for this specific application is one of the major research goals.

Dissertation Status

Literature survey has been done on three different areas - truck schedulers in container terminal areas, trajectory planners and multi-robot task allocation methods. With respect to the dissertation, adding side-slip constraints to the wheels of the vehicles has been implemented on the trajectory planner. The problem formulation of the truck scheduler with spatial and temporal constraints have been devised. Implementation of this scheduler instead of the regular task sequencer is under study. Literature study is being done on ways to couple scheduler with trajectory planner.

Expected Contributions

The expected outcome of this thesis is to find an approach that is computationally less expensive and produces near optimal solutions for multi vehicle path planning problems. Though the concept of task allocation has yielded better results in literature, we aim to replace it with task scheduler. By this, the application of this approach can be extended to more complex and dynamic environment with temporal constraints. Moreover, the global nature of the task scheduler can be used to resolve the local path conflicts between vehicles thus avoiding priority setting of vehicles.

References

Zucker, M., Ratliff, N., Dragan, A.D., Pivtoraiko, M., Klingensmith, M., Dellin, C.M., Bagnell, J.A. and Srinivasa, S.S., 2013. Chomp: Covariant hamiltonian optimization for motion planning. *The International Journal of Robotics Research*, 32(9-10), pp.1164-1193.

Turpin, M., Mohta, K., Michael, N. and Kumar, V., 2014. Goal assignment and trajectory planning for large teams of interchangeable robots. *Autonomous Robots*, 37(4), pp.401-415.

Liu, L. and Shell, D.A., 2013. An anytime assignment algorithm: From local task swapping to global optimality. *Autonomous Robots*, 35(4), pp.271-286.

Kuhn, H.W., 1955. The Hungarian method for the assignment problem. Naval research logistics quarterly, 2(12), pp.83-97.

Philippsen, R. and Siegwart, R., 2005, April. An interpolated dynamic navigation function. In Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on (pp. 3782-3789). IEEE.

Gombolay, M.C., Wilcox, R. and Shah, J.A., 2013, June. Fast Scheduling of Multi-Robot Teams with Temporospatial Constraints. In Robotics: Science and Systems.

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