Planning for Communication Between Cooperative Mars Rovers

Andreas F. Wehowsky, John Stedl & Brian C. Williams

Artificial Intelligence Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

http://www.ai.mit.edu

The Problem: Imagine having networks of autonomous cooperating vehicles explore the surface of a distant planet in the mission of collecting science data, communicating and sending data back to Earth. A criteria for a successful mission is to have a robust autonomous system on board every vehicle that facilitates efficient distributed mission and activity planning coupled with path planning, execution of a plan and a reactive planning capability. In addition it is required for cooperating vehicles to be able to communicate with each other to exchange planning information and science data, and send the science data to the ground control at certain time points, when radio links between vehicles are available. Due to the nature of possible unstable data links or reachability between vehicles, the vehicles need to be able to plan for when to communicate.

Motivation: These networks of vehicles may be a heterogenous set of rovers and blimbs exploring Mars. In our research group we have a rover test bed with several rovers, which we will use for testing and demonstration. The creation of robotic network cannot be supported by the current programming practice alone. Recent mission failures, such as the Mars Climate Orbiter and Polar Landers, highlight the challenge of creating highly capable vehicles within realistic budget limits.

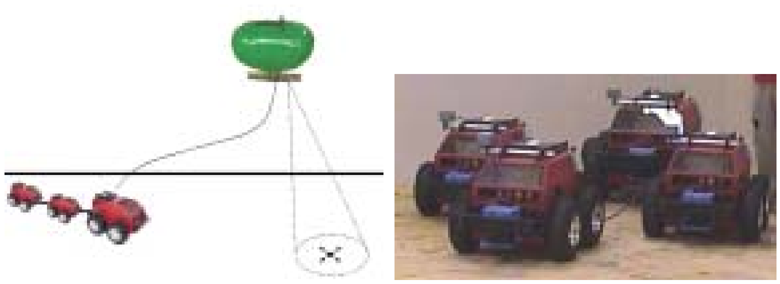

Figure 1: Planetary exploration scenario (left), rover test bed (right)

Previous Work: Our past research introduced Kirk [2], a fast graph-based temporal planner. To support fast mission planning as a graph search, Kirk compiles an RMPL [1] program into a temporal plan network (TPN), similar to those used by temporal planners, but extended for symbolic constraints and decisions. To robustly coordinate air vehicle or rover maneuvers we combine the Kirk planning algorithm with randomized algorithms for kinodynamic path planning. Kirk is suitable for cooperative autonomous vehicle missions, but does not address the planning for communication issue.

Approach: 1. Fast graph based temporal planning.

Kirk needs to be improved in several ways. Faster algorithms will be needed for graph search, since the planner must be able to respond in real time. The planner will be able to find optimal plans instead of just consistent plans. Also an efficient path planning algorithm, based on mixed integer programming, will be integrated with Kirk to support navigation in difficult terrain. The planner will output a set of commands to be executed on every rover to achieve the plan goals [3],[4].

2. Distributed algorithms for communication.

The rover test-bed can be viewed as a multi-agent system. When multiple agents operate in remote uncertain areas, planning for communication and contingencies is essential. Imagine a set of rovers being sent to Mars to explore the surface and send back results. The rovers need to have a plan for performing cooperative activities including setting up rendezvous locations and being able to plan for when to communicate.

We will be identifying the implications in performing cooperative rover missions and develop communicating algorithms that address the complex problem of executing plans on several vehicles while maintaining a consistent plan. When running a plan found by Kirk, a synchronization process must continuously take place in order to keep every rover up to date with the status of other rovers. The timing of when communication must take place is also an issue to be addressed, since some rovers might be unable to set up data links with other rovers in certain periods.

Impact: RMPL and Kirk have been demonstrated in simulation for cooperative unmanned air vehicles. This research brings the capabilities of Kirk to another level, because it enables the cooperation between Earth-bases and networked embedded systems. This research is a step into the future of robotic outposts on Mars.

Future Work: The capabilities of the planner will be demonstrated on our rover test-bed with appropriate scenarios. The demonstration is an end-to-end process, where a RMPL model is compiled to a temporal plan network, which is read by Kirk. Kirk will search for a consistent plan and send the output to plan runners on the rovers.

The communication capability will be integrated with the planner, and our ultimate goal is to demonstrate cooperating rovers utilizing a unified communication and planning capability.

Research Support: This research is funded by the DARPA NEST program under contract F33615-00-C-1702 and by NASA under contract NAG2-1388.

References:

[1] M. Ingham, R. Ragno, and B. Williams. A reactive model-based programming language for robotic space explorers. In *Proceedings of i-SAIRAS 2001*, 2001.

[2] Phil Kim, Williams Brian, and Mark Abramson. Executing reactive, model-based programs through graph-based temporal planning. In *Proceedings of International Joint Conference on Artificial Intelligence, Seattle, WA*, 2001.

[3] P. Morris and N. Muscettola. Execution of temporal plans with uncertainty. In *AAAI-00*, 1999.

[4] I. Tsamardinos, N. Muscettola, and P. Morris. Fast transformation of temporal plans for efficient execution. 1998.