Robust Planning Systems for Aerospace Applications

CENIIT 06.09: Final Report

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1 Summary of Project Results

This project has been concerned with the development of robust planning systems with a primary focus on aerospace applications and a secondary focus on general applicability in single- and multi-agent robotic settings. Concrete functionality requirements grounded in our cooperation with Saab Aerosystems have inspired several distinct research tracks within this general area.

Planning with Incomplete Information. Though the majority of planners in the literature require complete state information, this is not realistic in many scenarios. Several new techniques have been developed within this track.

One approach is a probabilistic planner based on Dynamic Decision Networks together with particle filtering techniques to represent probability distributions during planning and execution [34, 35]. The DARE method of dynamically generating abstractions of the environment was also developed in order to deal with the complexity of this type of planning, allowing plans to be incrementally refined as needed for execution [33].

We have also considered the need for temporal flexibility in plans to be executed in uncertain environments. This has led to the PARADOCS system [23–25], where actions are flexibly linked by the relations of the Allen interval algebra. Extensions to Temporal Action Logic (TAL [5, 29, 30, 32]) also provide support for composite actions and speech acts. The ANDI system [26–28, 31] generalizes this approach to also model non-temporal forms of incomplete information, to explicitly reason about its own knowledge as well as the knowledge of other agents, and to generate explicit loops when achieving a goal given incomplete knowledge requires an indefinite number of actions.

More recently, the TFPOP planner [18–20] was developed based on a novel hybrid of forward-chaining and partial-order planning techniques. Newly developed state inference methods allow considerably stronger state information to be inferred in the presence of temporal flexibility. This in turn allows the use of knowledge-rich planning techniques for significantly improved performance in complex planning domains. TFPOP allows the use of actions whose minimum and maximum duration are known, but where the actual duration (unlike planners based on for example Simple Temporal Networks) is not controllable by the executing agent – for example, where flying may take between 10 and 13 minutes depending on wind conditions. Finally, the TFPOP framework has been extended for planning with *delegation*, where the identity, number and capabilities of agents that will be available for plan execution are not known in advance [8].

Information gathering. Another track has dealt with the need to gather information dynamically when problem descriptions are incomplete – in particular, the necessity to always anchor the symbolic information that most planners work with in incomplete and noisy sensory information originating in the real world, which requires constant validation and updates of hypotheses [9, 10, 12]. This track was done in cooperation with Fredrik Heintz, who later received his own CENIIT grant and continued the research outside this project.

Surveillance and Communication Relays. We have developed several new algorithms related to surveillance and information gathering for single or multiple targets, where information must be relayed back to a base station through a set of relay UAVs [17, 36]. Two distinct algorithms deal with the single-target problem, generating a set of Pareto-optimal solutions for the placement of communication relays with distinct trade-offs between the quality of the solution and the number of relays required [1–4, 36]. Another algorithm generates trees of relays for multiple targets [37]. Though the intention was to continue towards moving targets, Per-Magnus Olsson decided to leave IDA after completing his licentiate thesis and the research track therefore continued outside this project.

Execution Monitoring. Robust plan execution requires the ability to detect failures, often called execution monitoring. We have developed an approach based on using formulas in a powerful temporal logic to succinctly express simple or complex conditions to be monitored during execution. While such formulas can be specified explicitly, we have also developed domain analysis techniques to automatically extract important classes of monitor conditions from planning domains [6, 7, 21]. As monitoring is dependent on timely state updates, we have also specified new algorithms for state synchronization and efficient incremental monitor formula progression in the DyKnow knowledge processing middleware framework [11, 13–16].

Diagnosis through Probabilistic Planning. In addition to fault detection, diagnosis is also essential for recovery from failures. In this track, we have (in close cooperation with Scania AB) focused on the combination of diagnosis and repair in the context of complex vehicular systems such as heavy trucks or UAVs. Probabilistic planning methods have been applied to this problem in order to determine what test and repair actions should be performed in order to guarantee, with minimal cost, that a vehicle is fully functioning. This has required research in modeling [38, 43], developing appropriate search heuristics ([42]), and generating suitable models where the tradeoff between precision and performance is explored [40]. A new planning algorithm applicable to troubleshooting as well as other stochastic shortest-path problems was also developed [39, 41]

Integrating Task and Path Planning. Planning for robotic systems usually requires taking motion constraints into account. We have therefore extended TFPOP to accept feedback from a vehicle-specific path planner in order to estimate the cost of certain actions, allowing it to find an inexpensive plan in terms of cost and distance travelled [7, 22]. Furthermore, we have developed a new method for choosing path replanning strategies when new obstacles are detected during execution, allowing higher quality plans to be generated [44].

2 Degrees to which the project has contributed

The project has contributed to licentiate degrees for Per Nyblom [35], Martin Magnusson [23], Per-Magnus Olsson [36] and Håkan Warnquist [39] as well as to the Ph.D. degree of Fredrik Heintz [9]. Jonas Kvarnström was employed as "universitetslektor" in 2010.

3 Staff

At varying points in time, this project has contributed to financing Jonas Kvarnström, Fredrik Heintz, Per Nyblom, Martin Magnusson, Per-Magnus Olsson, and Mikael Nilsson. Håkan Warnquist has participated with full funding from Scania AB.

4 Industrial Contacts

We have had two main industrial contacts. First, we have cooperated with Saab Aerosystems with a focus on planning for unmanned aerial vehicles. This cooperation has taken place both through the CENIIT project, through an NFFP project, and through smaller LinkLab projects. Results have been transferred through common workshops and other personal meetings, through scientific publications submitted to Saab, and through several reports on these topics written explicitly for Saab. Cooperation continues and several of the tracks initiated in this CENIIT project are still active through a new NFFP project. Though a main intention behind this cooperation has been knowledge transfer, Saab has also indicated an interest in testing our planners onboard their Skeldar UAV.

Second, we have worked with Scania AB on the industrial use of planning for troubleshooting. Results have been transferred through Håkan Warnquist, industrial Ph.D. student employed by Scania, as well as through group meetings and visits. This research track also continues after the end of the CENIIT project, with the intention to integrate results in Scania products in the medium to long term.

5 Contacts with Other CENIIT Projects

We have had successful cooperation with CENIIT project 10.04, Stream-Based Reasoning Grounded Through Sensing, led by Fredrik Heintz. Other than this, there has been little common ground with other CENIIT projects.

6 New Group

The CENIIT project has contributed to the creation of an Automated Planning group in IDA/AIICS, led by Jonas Kvarnström. The size of the group has varied over time. Currently the members are Jonas Kvarnström, Mikael Nilsson (PhD student) and Håkan Warnquist (PhD student, lic).

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