A Decentralised Strategy for Heterogeneous AUV Missions

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Aim: Improve the quality of multi-robot plans focusing on the optimisation of the goal distribution to enhance long-term autonomy and overall fleet robustness. This is achieved with a new strategy that enhance plan quality through the relaxation of plan search.

Motivation: The increasing demand for multi-platform solutions capable of implementing long-term missions more dynamically requires robust planning and execution tools which support the operation. Planning offers techniques for managing typical problems that arise in highly constrained missions. However, AI planners deal with the high-dimensionality of the state-space inefficiently, leading to multi-robot plans with poor plan quality.

Multi-Vehicle Temporal Planning

Temporal Planning: Automated planning is the process of reasoning about the actions needed to achieve a set of goals. Planning considers the states transitions to model the system. The state transition system is commonly defined as $\Sigma = (S, A, E, \gamma)$. Here $S$ is the set of possible states, $A$ is the set of possible actions, $E$ is the set of exogenous events, and $\gamma: S \times A \times E \rightarrow S$ is the state transition function.

Temporal Planning involves explicit representations of time in the planning problem, allowing more realistic modelling of real-world domains. We evaluate two benchmark temporal planners successfully tested in real underwater missions: Forward-Chaining Partial-Order Planning (POPF) and Optimizeing Preferences and Time-dependent Costs (OPTIC).

Underwater Oil Rig Scenario: A segmented environment for modelling multi-robot real-world problems.

Methods & Performance Evaluation

Domain Definition: The actions defined in the domain are associated with individual robot capabilities. The constraints influence the set of actions the robot implements. The goals set is a tuple $G := (R, RC)$, where $R$ is a set of robots and $RC$ represents the robot’s capabilities. The planning problem is a tuple

$$\Pi := (P, V, A, I, G, W),$$

(1)

$P$ is a set of Boolean variables, $V$ is a vector of real variables, $A$ is a set of actions which depends of the domain constraints, $I(P, V)$ is a function over $P \cup V$ which describes the initial state, $G := \{g_1, \ldots, g_n\}$ is a set of goals, $W := \{w_1, \ldots, w_m\}$ is a set of time windows.

Multi-Agent Approach & Architecture: Temporal planning is capable of dealing with multi-agent planning problems since time is modelled explicitly.

We introduce a Goal Allocation (GA) which adds a set of constraints to the PDDL problem to guide the planner’s search. GA is based on k-means approach to allocate the goal based on their coordinates. ROSPlan [2] framework is used to integrate high level task planner and the low level control.

Figure 1: A depiction of the domain which presents the initial position of surface and underwater robots, the docking point (DP) and transmission centre (TC).

Figure 2: Benchmark planners, POPF (bottom left) and OPTIC (bottom right), generate non-optimal goal distributions leading to sub-optimal plans for a fleet of three robots.

Figure 3: General system architecture (left) and goal spatial distribution (right) for a fleet of three robots using the GA results to generate the plan.

The performance analysis considers 6 problems of increasing complexity. We compare the plan quality based on the makespan and planning time results.

- Benchmark planners are sensitive towards changes in numeric constraints.
- For simple problems the GA+TP approach and benchmark TP present similar results.
- For complex missions GA+TP outperforms the benchmark planners due to the relaxation provided by the GA.

Figure 4: Plan makespan for a fleet of two robots (left) and three robots (right). The combination of the GA and temporal planning provides a solvable plan for all the problems.

- GA+TP generates the first solvable plan in shorter time period than benchmark planners (left – 2 robots, right – 3 robots).
- Plan generation time influences the capacity of the robotic system to react optimally during time sensitive tasks.

Figure 5: Planning time results for a fleet of two robots (left) and three (robots) using benchmark planners and GA+TP.

Conclusions

- Experiments with off-the-shelf temporal planners (POPF, OPTIC) using a comprehensive planning domain that supports the execution of realistic multi-vehicle AUV/ASV missions.
- A new strategy that combines a new Goal Allocation (GA) algorithm with Temporal Planning (TP) to improve plan quality for temporal multi-vehicle tasks.
- ROSPlan integration with robot simulators to execute multi-vehicle missions.

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References