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Towards Robust Mission Execution via Temporal and Contingent Planning

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Abstract. In this work, we present a general approach to task planning based on the combination of temporal planning, contingent planning and run-time sensing. The strategy provides a solution for generating plans that can adapt during mission execution by reasoning about the data acquired by the sensory system. The approach detects actions that can change the initial plan and evaluates possible outcomes. We demonstrate the effectiveness of our approach on two different experiments in a maritime environment where the robots have to inspect the state of a valve and execute actions based on the online sensor information.

Keywords: Multi-Robot Systems · High-Level Task Planning · Contingent Planning · Temporal Planning · Marine Robotics.

1 INTRODUCTION AND MOTIVATION

In recent years, marine robotics has experienced an exponential demand for more complex systems which support the robust execution of tasks in dynamic environments. Automated planning is capable of generating such missions without the need for human intervention, while managing robot resources at levels that support long-term deployments. The implementation of planning strategies for real-world solutions usually requires a detailed description of the domain of operation, often supported by temporal notions to improve the quality of the generated plans [2]. Several planning solutions for robotic applications [2, 3] are based on deterministic planning models, where operators have fully predictable outcomes and completely known initial states. However, the applicability of such models is limited in cases where some aspects of the domain are incomplete or unknown, and the planner must consider a set of possible values for certain state features (e.g., `valve_state` could be `on` or `off`). *Contingent planning* [7, 6, 8] copes with these types of situations by constructing a plan divided in a set of conditional sub-plans (branches) for the different contingencies that could arise. However, few contingent planners consider temporal constraints [5] which restricts their use for implementing coordinated multi-robot missions.

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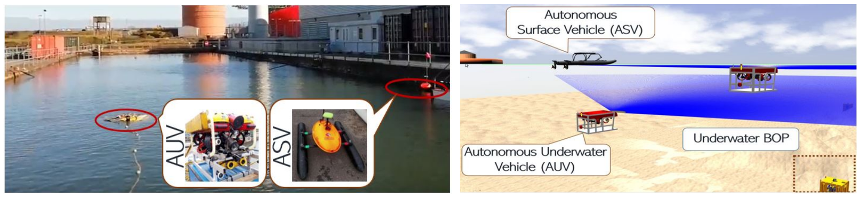

Fig. 1. Execution of multi-robot inspection tasks in real-world (left) and simulated (right) environments.

In this work, we present a strategy that combines the advantages of temporal planning and contingent planning to improve the generation of complex missions in the underwater domain. We use a construction-based approach, based on ideas from previous work (e.g., [8]), to add contingent plan branches to a generated temporal plan. Here, we use the OPTIC temporal planner [1] as a benchmark solver which is combined with a new Contingency Analyser algorithm and online sensing to produce more complex plan generation and execution. As an application of this solution, we consider a maritime scenario where an Autonomous Underwater Vehicle (AUV) must complete multiple inspection tasks, and an Autonomous Surface Vehicle (ASV) is used to support the AUV refuelling process. Figure 1 shows a real and simulated scenario for the inspection of underwater structures. The full description of the mission scenario is presented in [2].

2 BUILDING TEMPORAL CONTINGENT PLANS

We propose a framework that enables temporal planners to generate multi-robot plans with contingent branches. A new *Contingency Analyser* method interacts with the OPTIC solver to reason about the incomplete knowledge and perceptual information available during the planning process and plan execution. Figure 2 (left) shows the system architecture which contains two main modules. The *Planning Framework* acquires information from the world and the robots to define the domain and problem instance using the standard Planning Domain Definition Language (PDDL). This module is built on the ROSPlan architecture [3]. OPTIC generates a solvable plan by considering a set of possible initial states defined in the problem file, representing the incomplete or unknown information in the environment. The *Contingency Framework* evaluates whether a plan solution contains actions that require contingent plans. If so, the Contingent Plan Generation module defines a set of new initial states and re-triggers OPTIC to obtain a new plan. This process is repeated until all the possible initial states are exhausted. The resulting plans are then merged in a single contingent plan solution which is processed by the Contingent Parsing Interface to be dispatched to the robots. During plan execution, the contingent branches are evaluated by the Sensing Interface which uses online sensory information provided to the robot platform through *semantic attachments* [4]. The appropriate plan branches are dispatched to the robot for execution, enabling the plan to adapt to real-world

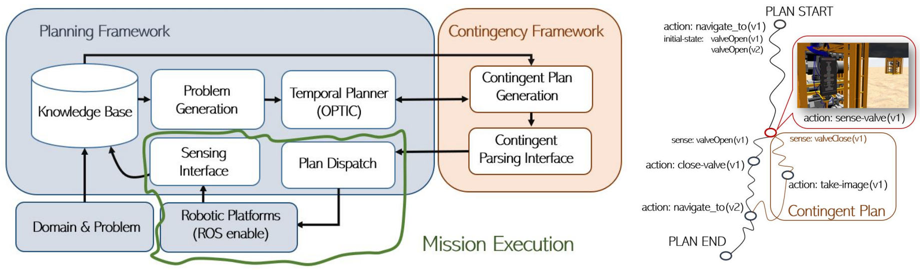

Fig. 2. System architecture supporting temporal and contingent planning (left) and a temporal contingent plan solution based on possible valve states (right).

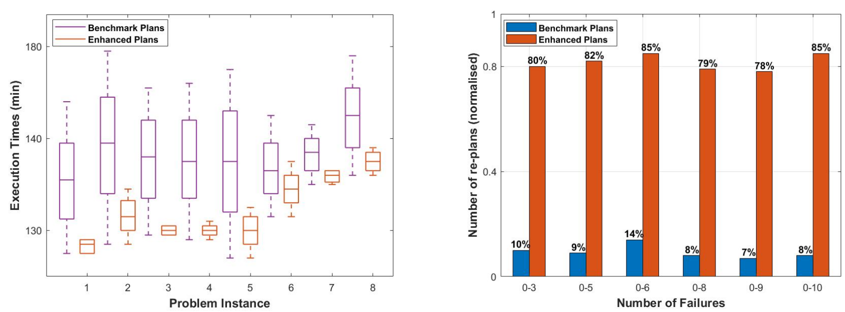

Fig. 3. Plan execution time in 8 problems over 50 runs (left) and cumulative replanning for problem instance 8 over 10 runs.

conditions based on real sensor data, potentially reducing mission failure and the need for replanning.

Figure 2 (right) shows a general representation of a plan where a robot has to inspect and close valves in the environment. The strategy generates a plan based on a set of initial conditions which are assumed as true. The method then identifies actions in the plan that might require contingent branches, based on the incomplete/unknown information in the initial states (e.g., `sense-valve` in this example), and augments the plan with these alternative plan paths.

3 EXPERIMENTS AND RESULTS

We evaluate our approach in two experiments. In Figure 3 (left), we analyse the mission execution time for 8 different problems with the introduction of 5 forced failures during the mission, associated with the valve state. Generating contingent branches during the planning stage significantly improves the mission implementation times. This is mainly due to the time required by OPTIC to replan in order to achieve a plan solution that responds to the real state of the valve. Contingent plan generation also reduces the risks associated with replanning in non-quiescent environments. However, contingent plans do suffer from small time variations associated with the delays resulting from the system choosing the contingent branch to follow. Figure 3 (right) shows the results of the second experiment for different sets of failures in problem 8, where the contingent strategy outperforms the benchmark planner. Contingent plans enable the system to execute missions without replanning around 80% of the time while benchmark solver needs to replan around 90% of the time.

4 CONCLUSION AND FUTURE WORK

In this paper, we present a strategy for improving the robustness of robot plans in the marine environment by combining ideas from temporal planning and contingent planning with online sensing. A new Contingency Analyser strategy considers opportunities for introducing plan branches into a standard temporal plan. The resulting approach constructs contingent plans during the planning process, with appropriate branches selected during mission execution based on information returned from the online sensory system. The approach was successfully tested with multiple robots in a simulated marine environment. Results show that the method improves the quality of mission execution by reducing the mission failure and replanning rate. Future work aims to explore methods that reduce the computational costs of constructing such temporal contingent plans.

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