Multi-Robot Coordination in Operations and Maintenance of Off Shore Wind Farms with Temporal Planning

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Abstract

This paper explores the use of temporal planning for multi-robot coordination in operation and maintenance applications. Due to limited resources and energy to perform multiple missions, an efficient tool capable of optimising mission allocations without the need for major re-planning of the missions is required. We improve the performance of centralised mission planner by combining an adaptive problem generator with temporal planning to obtain feasible plans. We create a simulator, a GAZEBO simulated environment unifying heterogeneous autonomous systems for offshore wind farms application, integrate our method, and demonstrate our approach to plan generation for an inspection, maintenance, and repair of an offshore wind turbine.

Introduction

Advancements in various (semi)-autonomous robots have opened up new opportunities in automation for Operations and Maintenance (O&M) of off-shore assets, search-and-rescue, and order-and-delivery systems. In remote O&M applications, such as maintaining offshore wind farms, advancements in robotics provide the possibility of deploying semi autonomous systems to inspect and repair a faulty component with the benefit that health-and-safety risks associated to human operators can be removed. However, creating a fully autonomous system for these applications not only requires solid coordination and execution across robots to accomplish complex tasks and achieve an optimal performance, but also must be built with robustness in mind to support long-term autonomous operation without human intervention.

This system demonstration showcases the application of planning technologies to multi-robot systems for coordinated missions to maintain and repair off shore wind farms. The system is being performed as part of the Innovate UK MIMRee project aimed at developing multi-platform systems with autonomous decision making and high coordination capabilities in extreme environments (Bernardini et al. 2020). One of the challenges faced by the autonomous decision making is to create an accurate heterogeneous multi-robot plan aiming to reduce the number of online re-planning during the execution. Any re-planning involving a fleet of multi-robot coming back to shore is a costly re-plan (Research 2019). In this instance, accurate plan generation is done by combining an adaptive execution monitoring system, which corrects the domain specification deviating from the actual world representation, and optimises action duration with stochastic duration; together with a temporal planning approach which implements action coordination to complete O&M missions. We focus on implementing (1) a planning system that becomes incrementally more accurate and is capable of avoiding plan failure due to time and resource limitations and (2) high-level mission plans that increase the performance of autonomous fleets of heterogeneous robots. Finally, we demonstrate the planning framework in a simulated wind farms (see Figure 1) which has unmanned aerial vehicles (UAV), an unmanned surface vehicle (USV), and an inspection-and-repair robot (IRR) to execute multi-robot coordinated missions.

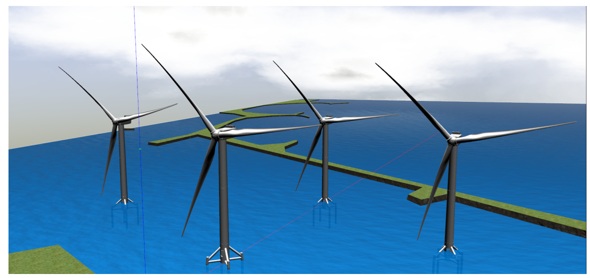

Figure 1: GAZEBO wind farm simulator. A video footage can be found in (pre 2021).

System Architecture Overview

Windfarm Simulator: Our simulation world is customised using models from Gazebo and the UUV-Simulator libraries (Manhães et al. 2016) (see Figure 1). The simulator allows multiple instances of different robotic platforms to coexist and implement complex missions with large goal sets. To accommodate the O&M mission scenarios, we built an MLV quadrotor model representing the unmanned aerial vehicles (UAV) and a Corin hexapod model representing the inspection-and-repair robot (IRR) (Khalili et al. 2020), and a

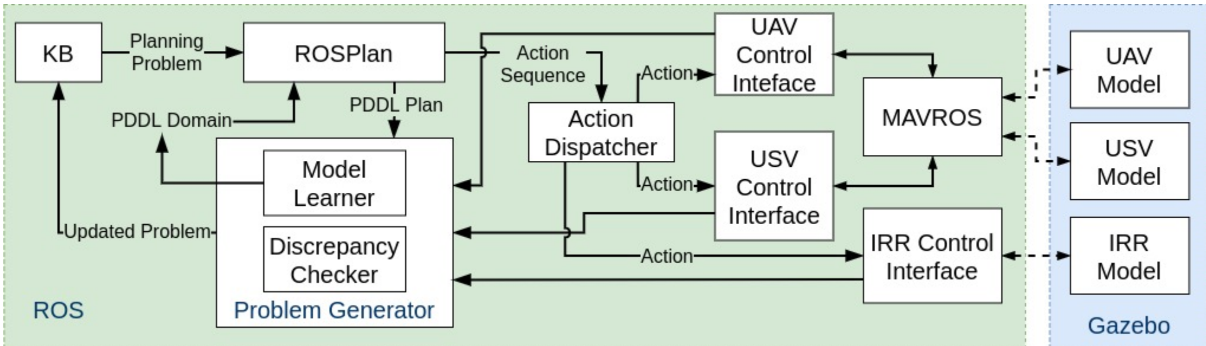

Figure 2: Autonomy architecture for Wind Farm O&M.

general unmanned surface vehicle (USV). MAVROS[1] package are used in UAV and USV as a system control of the vehicles. An advanced motion controller (Khalili et al. 2020) is used to help the IRR move through a wind blade.

Planning and Execution: The simulation world, together with all vehicle models and environment dynamics, is integrated with the ROS package ROSPlan (Cashmore et al. 2015), MAVROS, and our adaptive problem generator (see Figure 2). The simulation provides a world model, information about the robot states, capabilities, and information of the operating environment (e.g., wind turbines' position and their corresponding waypoints). The information is stored in the mission knowledge based and then used to generate missions, i.e. problem descriptions in PDDL format via a problem generator module. ROSPlan uses mission knowledge and a temporal planner to generate a mission plan. For this work, a temporal planner POPF is used to generate mission plans (Coles et al. 2021). A plan executive dispatches the plan, as a sequence of actions, to the robots for execution. The high level action is then translated by each robot into a low-level control.

Adaptive Problem Generator: In general, a problem generator translates tasks and state information into a PDDL problem. We enhanced the problem generator by making it more adaptive to changes and able to reason about: (1) the discrepancy between the actual sensors output and the expected one; and (2) the dynamics of an action duration and fuel consumption rate. We use a procedural approach to action refinement and execution monitoring. A function that refines an action operator, e.g. `usv_inspect_wt(?usv, ?wp)`, into low-level commands resides on each vehicle control interface (shown in Figure 2). Each of these functions communicates its completion of the action to the problem generator so that the corresponding predicates can be either removed from or added to the KB.

In our domain, time and costs are essential, and executing actions efficiently is necessary. Hence, the time that the robots take to perform each action must be accurately represented in the model. Similarly, the fuel rate consumption of each robot becomes an important feature in deciding the number of tasks that can be done in one single mission. We estimate and refine the dynamics of action duration and fuel rate consumption by introducing simple statistical models that keep track of the expected action duration and the expected fuel rate consumption. At the end of each action execution, the expected action duration is updated and the expected fuel rate consumption is adjusted.

For the system demonstration, we will illustrate its operation with a UAV, a USV, and an IRR autonomously coordinating to complete different O&M missions involving inspection and repair tasks in the simulated environment.

[1]https://github.com/mavlink/mavros

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