Effect of Simulation Fidelity on Testing Corner Cases of a Drone Swarm Controller

Master's Thesis

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Context

The popularity of unmanned aerial vehicles (UAVs), also known as "drones," has laid the groundwork for interest in cooperating UAVs. In particular, those groups of UAVs that are referred to as *swarms* are the subject of many research efforts [1]. Especially of interest to us are *decentralized* or *distributed* swarms, where the individual UAVs are autonomous in their decision-making rather than being controlled by a single centralized entity [2]. To challenge the behavior of autonomous systems, existing approaches utilize scenario-based testing (SBT) combined with metaheuristic search methods to test UAVs that operate individually [3]. This approach is based on established methods that have been utilized in the autonomous car domain to build relevant scenarios and search for scenario configurations that elicit "corner case" unsafe behaviors of the system under test (SUT) [4]–[7].

SBT usually relies on models and simulation environments, especially when iterative methods are used. Modeling and simulation is inherently about abstracting the real world, but different tools and environments implement that abstraction at different levels of fidelity. *Higher fidelity* means "more realistic" and *lower fidelity* is the opposite; usually, the computational cost increases with higher fidelity. *SwarmLab* is a simulation environment that was developed for rapid prototyping and testing of UAV swarm controller models and includes simple representations of an environment that a swarm might fly through [8]. In comparison, *AirSim* was developed to provide a high-fidelity physics-based simulation environment for drones [9]. Current work at the Chair has involved applying existing SBT approaches to testing a swarm controller. However, to the best of our knowledge, no existing work on SBT for swarm controllers compares how different simulation fidelity levels may affect the results.

Goal

This thesis topic aims to (1) compare the parameters available in both a low-fidelity and high-fidelity simulation environment for testing drone swarms and to (2) characterize the sensitivity of a "corner case" test case to those parameters. If the SUT passes a test case in the lower-fidelity environment but fails the test case in the higher-fidelity environment, then the higher-fidelity environment may include parameters that should be considered essential to testing a drone swarm. We propose using the SwarmLab and AirSim simulation environments and using the swarm model in [8] or [10] as the SUT. We also propose evaluating the system's safety in a simple transportation mission, where the swarm must fly from a starting point to a destination point while avoiding obstacles.

Working Plan

1. Use existing literature to build an understanding of drone swarm operational environments.
2. Design a scenario using existing scenario-based testing approaches and implement it in both the lower-fidelity and higher-fidelity simulations. Note where simplifications or additional assumptions must be made, and identify the additional parameters included in the higher-fidelity simulation.
3. Use existing tools and the lower-fidelity simulation to generate a test case that approaches failure but does not fail (i.e., approaches a corner case).
4. Replicate the test case in the higher-fidelity simulation and hypothesize about whether or not the higher-fidelity version of the test case is also near failure.
5. Vary simulation parameters and characterize the effect on the test case result, e.g., via a sensitivity analysis.
6. Write the report and presentation.

Deliverables

- Half-way point:
  - Draft of thesis introduction section describing the research problem, the gap in existing literature, and your proposed solution.
  - Short presentation of this content.
- Final:
  - Thesis written in English and in conformance with TUM guidelines, comprehensively describing the methodologies, implementation, and findings.
  - Presentation of the work to the Chair.
  - Source code of implementation using MIT License incl. documentation.

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