Applying Safety Testing to Collaborative Unmanned Aerial Vehicles

Master's Thesis

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Context

Autonomous cyber-physical systems (CPSs) such as unmanned aerial vehicles (UAVs) must be tested to ensure safe behavior, especially when the systems are designed to collaborate with other CPSs. UAV usage is projected to increase [1], [2], and some of these systems include autonomous capabilities such as commercially-developed or open-source autopilots. To build on existing UAV capabilities, current research efforts are investigating how multiple UAVs may autonomously perform tasks collaboratively; for example, to execute collision-free group flight [3] or to transport a large payload [4]. As usage of autonomous UAVs increases, the need to ensure safe operation also increases.

Scenario-based testing is a simulation-based approach that has been applied to autonomous road vehicles to maximize confidence in the safe behavior of the vehicle despite the infinite number of possible traffic situations that could occur [5]. The process generates scenarios of interest and organizes them with specifications at different levels of abstractions. For the purpose of generating specific test cases, search-based techniques can be used to find "concrete" versions of the scenarios that are most challenging to the safe operation of the vehicle. Recently, this process of scenario-based testing combined with search-based techniques has also been applied to testing the safety of autonomous UAVs that are flying in an urban environment [6]. Since UAVs operate in a different domain than road vehicles, the process had to be adapted.

Similarly, the capabilities of a group of autonomous UAVs collaboratively executing a task will likely have differences compared to the capabilities of an independently operating autonomous UAV. Scenario-based testing and search-based techniques may be useful for testing collaborative UAVs for unsafe behavior, but further modifications to the existing approach may be required. For example: the methodology described in [3] for an agent in a swarm of drones to calculate its own flight path includes obstacle avoidance calculations, similar to an independently operating UAV. However, unlike an independently operating UAV, the swarm agent's flight path calculations also adhere to swarm "cohesion" requirements that depend on other agents in the swarm, creating a network of dependencies. These additional dependencies may affect behavior, and thus should be considered when attempting to examine safety.

Goal

The goal of this thesis is to propose a fitness function that can be used to find unsafe behavior when testing collaborative autonomous UAVs using the scenario-based and search-based testing process. This will require building an understanding of functional differences between an independently operating autonomous UAV and a group of collaborative autonomous UAVs. The existing process described in [6] should be applied to collaborative autonomous UAVs to establish a baseline for concrete scenarios generated. A possible system under test (SUT) for this effort could be based on one of the models created by the authors of [3] to simulate the collaborative flight of UAV swarms. To explore the effectiveness of the proposed fitness function, the testing process should be rerun to find better and/or additional concrete scenarios that were not identified by the baseline run. Note that one or more example logical scenarios will need to be defined to give the test generation process enough context to find concrete scenarios. However, deriving the "best" logical scenarios is not in the scope of this proposal (see [7] for details on the role of concrete and logical scenarios in scenario-based testing).

Working Plan

1. Become familiar with the literature on scenario-based testing and search-based techniques for identifying test cases, including [7] and the methodologies described in [6],[8]
2. Conduct a literature survey of autopilot functions for a single UAV and a group of collaborative UAVs, especially autonomous navigation and collision avoidance

3. Define a logical scenario for generating test cases, for example, where the scenario parameters are focused on describing obstacles in the operation environment
4. Implement the existing testing process on one of the drone swarm models built by the authors of [3] to establish a baseline list of concrete test cases
5. Using knowledge gained from workplan steps 2-4, and while treating UAV flight logic as a black box, propose a fitness function for the scenario search process
6. Run the test process using the drone swarm simulation again, but with the proposed fitness function to see if good concrete scenarios can be produced
7. Write the report and presentation

Deliverables

- Source code of implementation using MIT License incl. documentation
- Final thesis report written in English and in conformance with TUM guidelines, comprehensively describing the implementation and findings
- Presentation of the work at the Chair

References

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[8] T. Schmidt and A. Pretschner, *StellaUAV: A tool for testing the safe behavior of UAVs with scenario-based testing (tools and artifact track)*, 2022.

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