

An Open-Source Framework for Closed-Loop Multi-UAV Planning and Execution

Demonstration Track

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ABSTRACT

We present AUSPEX, an open-source framework that integrates deliberative and closed-loop planning and execution capabilities for multi-UAV systems. AUSPEX adopts a modular design, enabling the integration of heterogeneous UAV platforms, as well as different AI planners and execution logics. Hardware-in-the-Loop (HIL) validation tests were conducted on AUSPEX based on a Search and Rescue (SAR) scenario. Additionally, AUSPEX can be connected to third-party simulation environments for Software-in-the-Loop (SIL) tests. A video of the HIL-demonstration is available here: <https://youtu.be/Ml4c3v8C8X4>.

KEYWORDS

multi-UAV system; AI planning and execution; decision-making; search and rescue

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1 INTRODUCTION

A heterogeneous multi-UAV system comprises flying robots of different types or sizes, equipped with various hardware and software with diverse capabilities. Such systems enable specialized task allocation to efficiently fulfill mission goals, despite the limited

capabilities of individual UAVs [2, 14]. Consequently, they are well-suited for applications such as industrial inspection [3], situational mapping in disaster-stricken areas, and SAR operations [11, 15, 16].

Existing software solutions for multi-UAV systems [1, 22, 25] primarily focus on path generation and navigation aspects, with limited consideration of task-level decision making. Other alternatives rely on outdated ROS 1 software [4, 24] or exhibit limitations for high-level planning [9].

2 SYSTEM ARCHITECTURE

AUSPEX is a holistic, open-source framework that provides high-level planning capabilities specifically designed for decision-making in multi-UAV systems with a focus on portability. It features a modular architecture to facilitate the integration of components aimed at addressing closed-loop planning and execution [8]. An overview of the high-level system architecture of AUSPEX is shown in Figure 1.

2.1 Deliberative Functions

AUSPEX-PLAN is the central component, designed to create a coordinated mission plan for the UAVs, comprising an action sequence for each UAV to achieve the mission goals, while fulfilling pre-defined constraints. In the currently published implementation, AUSPEX-PLAN includes different planning capabilities, such as Unified Planning for AI planning [13], Adaptive Large Neighborhood Search (ALNS) [23], and Say'n'Fly, an LLM-modulo planner [6], although each planner requires adaptations.

Further, AUSPEX-PLAN communicates the computed plan to AUSPEX-EXEC, the execution module that tasks the UAVs in real-time accordingly, and receives feedback from the UAVs, which will be used to determine if replanning is necessary [5].

AUSPEX-KNOW is the knowledge base that serves all modules. On the one hand, AUSPEX-KNOW maintains static knowledge, including mission parameters that are only updated upon request. On the other hand, AUSPEX-KNOW continuously streams and updates dynamic knowledge, such as telemetry data from the UAVs.



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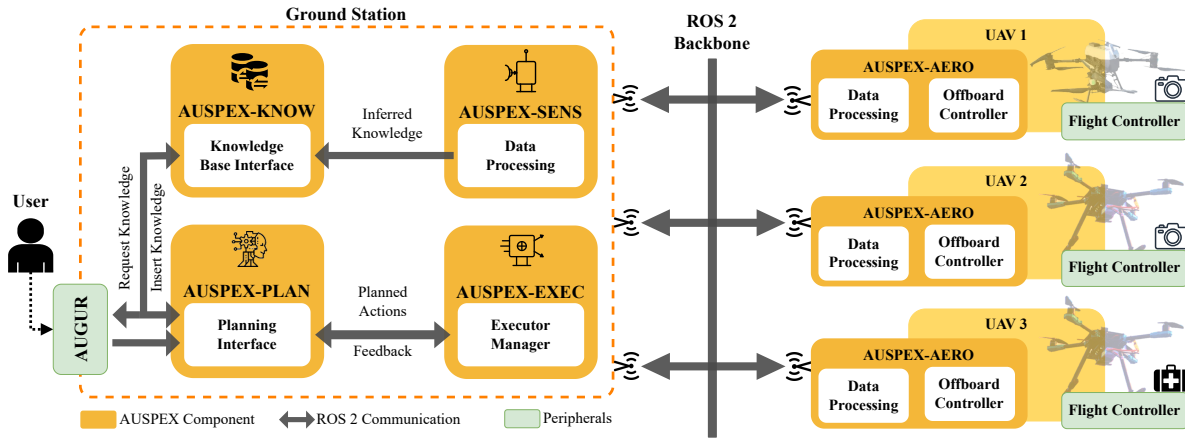


Figure 1: AUSPEX architecture overview, including the GUI AUGUR. Modules are connected via ROS 2 communication backbone. This figure is adapted from [8].

AUSPEX-PLAN queries AUSPEX-KNOW for the parameters that are necessary to define the current planning problem [5].

2.2 Platform-Specific Functions

While the aforementioned modules are platform-agnostic, AUSPEX-AERO and AUSPEX-SENS are platform-dependent, as they rely on the onboard controller or sensor payload of the UAV.

AUSPEX-AERO, being the module communicating directly with the UAV, receives tasks from AUSPEX-EXEC and translates them into flight controller commands. To avoid communication loss, AUSPEX-AERO is typically deployed on a companion computer attached to the UAV, thus remaining part of the airborne system. In cases where this is not possible (e.g., for off-the-shelf UAV platforms), AUSPEX-AERO can also be deployed off-board, requiring a stable connection link to the UAV.

AUSPEX-SENS is a sensor data processing module that extracts information from the continuous incoming data streams originating from the UAV sensors, by performing, for example, object detection. Inferred information is included in AUSPEX-KNOW, making it accessible to all modules. Typically, AUSPEX-SENS can be deployed either offboard or onboard on the companion computer [8].

2.3 Peripherals

Accompanying the AUSPEX modules, AUGUR can be connected to the ROS 2 backbone of AUSPEX, and serves as the human-machine interaction interface for mission control and supervision, as well as for mission definition, including the formulation of mission goals in natural language [7].

3 EXPERIMENT AND DEMONSTRATION

The AUSPEX framework was validated based on SAR missions, using HIL- and SIL-tests. Today, UAVs support first responders in SAR operations; they are easy to deploy and provide rapid aerial situational awareness in impervious areas, while being cost-effective [12, 14, 19, 21]. Although scaling up the UAV fleet size can improve mission efficiency, it increases the demand for UAV operators, thereby reducing cost efficiency [8, 10, 21]. Closed-loop

planning and execution for the coordination of heterogeneous UAVs can overcome such challenges [2].

3.1 Real-World HIL-Validation

We consider a heterogeneous multi-UAV system consisting of two Holybro X500v2 UAVs and a Multikopter MK-U20 UAV, each supporting MAVLink protocol. The Holybro UAVs use a Pixhawk 6C flight controller (FC) with the PX4 Autopilot interface and a Raspberry Pi 5 as offboard controller. The Multikopter MK-U20 utilizes a Cube Orange+ FC running ArduPilot and features an Nvidia Jetson Xavier NX as a companion computer. Each UAV is equipped with a 4G USB surf stick to connect to the cellular networks, enabling connection via a VPN to the Ground Control Station (GCS) and the ROS 2 backbone of AUSPEX [8]. In our HIL-tests, AUSPEX-PLAN, AUSPEX-EXEC, AUSPEX-KNOW, and AUSPEX-SENS were deployed on the GCS. Video streams from the UAVs to the GCS were set up using the RTSP protocol [17, 18].

In the considered scenario, a target representing a missing person is to be located. Once located, a first aid kit will be delivered to the target’s location. One UAV of our heterogeneous multi-UAV system is equipped with a first aid kit, while other UAVs carry a camera payload to locate the target. The mission commands were given via AUGUR, where the operations can be monitored. Typically, in the first planning loop, UAVs equipped with cameras are tasked to search the areas. Upon the identification of the target, a replanning takes place, after which the UAV carrying the first aid kit takes off and delivers it to the vicinity of the target. The UAVs return to their home positions once all mission goals are fulfilled.

4 CONCLUSION

This paper presents a HIL-demonstration of a closed-loop planning and execution framework for multi-UAV systems applicable for SAR missions. While AUSPEX can be deployed either as a whole or partially through selected modules in HIL-flights, it can be used for SIL-tests, for example, with Dynamic REAP, a photorealistic simulation environment based on UNREAL Engine [20].

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