Space Tech - SEI Pioneer

Design of a fleet management software for Unmanned Aerial Vehicles: an application to Search & Rescue

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Executive summary

Space Tech-SEI Pioneer was born in collaboration with SEI - School of Entrepreneurship and Innovation and an industrial partner, Leonardo S.p.A.. The project originates from the technical challenge of designing a solution for the autonomous management of a fleet of Unmanned Aerial Vehicles (UAVs) in multi-objective, dynamic missions. Up to now, studies from literature have failed to satisfy the complex requirements from the user: they have considered simplified problems and they mostly focused on the performances of the algorithms.
In agreement with the partners, the application to Search & Rescue was selected. Three main points were evaluated: firstly, it is coherent with the request to consider complex inputs and inequalities among drones; secondly, the solution has large potentialities in expediting the search of who is in pressing need; and, lastly, it also relieves the operator from the danger of exploring impervious areas.
The design process followed systematic steps: a stakeholder analysis involved the application of user personas, supported by interviews; requirements were derived and, then, they were applied in the selection of the concept from the functional analysis. Interestingly, the process underlined that the availability of the complete paths of the drones is unnecessary at the onset of the operation and that similar approaches limit the flexibility of the code. Consequently, the final solution resulted in an optimization algorithm which follows a decomposition approach: once the inputs from the user are available, the regions to be scanned by each drone are identified; these are decomposed in sectors and, over each single sector, the waypoints and the path are progressively computed during the operation.
Additionally, the user experience was also analyzed, and a mock-up of the user interface was developed to satisfy the requirements. Overall, the validity of the solution has been proved with simulations in the Mission Planner environment.

Key Words

Unmanned Aerial Vehicles, Flight Management System, Search and Rescue, Decomposition Heuristics

Manually piloted Unmanned Aerial Vehicles (UAVs) are currently employed in Search & Rescue operations.

MULTI-UAV FLEET MANAGEMENT SOFTWARE

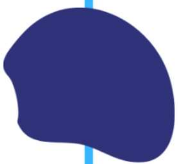
SEARCH-AND-RESCUE APPLICATIONS

PROBLEM STATEMENT

Design a software that can autonomously manage a team of UAVs that may have different capabilities, in terms of sensors and configuration but share the same objective.

OPTIMIZATION-BASED APPROACH

Objective: Minimize the distance travelled by each drone while maximizing coverage.



Universal transverse mercator based algorithm to convert input from user to coordinate-related system to be used for further analysis

Iterative generalized assignment problem-based optimization algorithm to define sub-regions to be covered by each drone

Particle swarm-based coverage and epsilon-approximated path-planning algorithms

KEY FEATURES

Autonomous
Fast
Collaborative
Clear
Intuitive
Efficient

SOFTWARE-IN-THE-LOOP VALIDATION

>90%
Coverage

<30s
Time to take-off

SPACE TECH

Project description written by the Principal AcademicTutor

The initial challenge from Leonardo involved the creation of an algorithm that could autonomously manage a fleet of UAVs with different capabilities and sensors, to achieve a shared objective. The students began by conducting a detailed problem exploration phase, where the key challenges were identified and listed. Through the literature survey, the Search-and-Rescue mission was found to be well aligned with the requirements from Leonardo and, therefore, it was chosen as the critical design scenario.

This was used as a basis to further elaborate the problem and investigations were performed by means of interviews with the key stakeholders. With the help of the tutors from SEI, they organized themselves in the Agile framework, and sub-divided the problem into its various constituent parts, which were each addressed separately.

The team then went through a series of diverging and converging idea generation phases, before arriving at the final concept, which is composed of several modules:

- A first pre-processing algorithm that transforms the input from the user to a computation-friendly format.
- A linear optimization algorithm that divides the search area into regions associated to each drone.
- A particle swarm algorithm to define the optimal location and number of waypoints.
- An epsilon-approximated algorithm which helps identify the most optimal path.
- A software-in-the-loop simulator to test and validate the system.
- Mock-ups representing the user experience journey and interactions.

Over the first six months, the students worked to complete the functional analysis and idea generation stages, and they developed a prototype of their Minimum Viable Product (MVP). This was presented at SEI Demo Day in December. In the second part of the project, they systematically tested the solution by considering various fleet configurations and scenarios: new optimization algorithms were considered, and the solution was refined. As a result, the students were able to create a code that addresses the initial challenge effectively, and that delivers concrete contribution to both the domain of research and to the practical application of Search and Rescue.

Team description by skill

The team leveraged on the competences in Operation Research provided in Aeronautical and Space Engineering. Considering personal interests, each team member has cooperated to provide the required competences in simulation environments, programming, and prototyping.

Goal

The project aims at coordinating a fleet of heterogeneous drones with a common objective. Differences are related to battery duration, performances, and sensor configuration. The desired product is required to elaborate high level inputs from the user, to consider modifications in the environmental conditions and to manage changes in mission parameters.

Understanding the problem

With rapid advances in their technology, Unmanned Aerial Vehicles (UAVs) have found widespread use across a range of industries and applications. The versatility and agility afforded by these systems makes them ideal for scenarios such as monitoring and surveillance. However, single UAVs are often limited by the constraints posed by their range and by the requirement of constant supervision by a trained pilot. This project aims at creating a software that can autonomously pilot a fleet of heterogenous drones.

This is a complex challenge, involving several steps – the division of the search area between the different drones, the discretization of the area, and subsequently, path planning for each drone. Prior researchers have proposed several different approaches to each of these sub-problems for both, single and multiple robot applications. Even so, few studies have focused on creating computationally inexpensive algorithms, that can ensure collaboration between heterogenous drones. In fact, even the most advanced commercially available software suites use highly simplified path planning algorithms, that cannot guarantee the optimality of the generated path from the energy and coverage perspectives and can only control one UAV. This study aims to address this gap, by creating an efficient, optimal, and commercially-applicable path planning system for multiple UAV systems.

Exploring the opportunities

A structured concept generation phase was followed to identify all potential innovative solutions that could be made for addressing this challenge. The first step was the analysis of all the stakeholders involved in the project. Buyer personas were defined for each of the stakeholders, and their specific needs were identified and listed. These needs were then translated into the core requirements for the project, stemming from both, the choice of the scenario, and the multi-UAV technology. Interviews with the primary stakeholders were conducted at each step, to validate the hypotheses.

A critical analysis was also conducted into the strengths and weaknesses of the existing solutions incorporated in the industry. This work laid the foundation for the functional analysis, which aimed at identifying the primary functions that must be performed by the solutions, and which could be used to identify the detailed features of the product, by means of a conceptual tree analysis. The three core functions identified were: an easy-to-use interface, efficient scanning and failure management.

Through an idea-generation phase, a total of 86 possible features were identified, which were then used to identify three concepts, including a comprehensive product vision, a minimum viable product (MVP) and an alternative fall-back solution.

Generating a solution

The interaction between the operator and the drones is managed by our software and the user interface largely influences the user experience. This was designed to provide all the required inputs to the system in a simple and immediate way, and a mock-up was realized as a proof of concept. Firstly, the user defines the characteristics of the fleet (of both drones and sensors), and these can be stored to be easily selected when operating on the field; then, the desired resolution is chosen in terms of the dimension of the target; lastly, the areas to be covered with specific sensors are simply drawn on a map. Additionally, the possible desired modifications of the input from the user were taken into consideration.

These inputs are then elaborated and sent to the code which controls the drones. As a result of the functional analysis, the management of the fleet is faced as an optimization problem, in accordance with what has been observed from literature. In the design process, it has been underlined how the availability of the complete solution is unnecessary to the beginning of the mission: the paths of the drone need only to be partially defined and calculations can proceed while the drones are flying. To exploit this fact, the approach is made modular, and the final solution is an optimization algorithm following a decomposition approach: the regions of the area to be scanned by each drone are identified; these are decomposed in sectors, and over each sector the waypoints and the path are progressively computed during the operation.

In the first portion of the optimization problem, a cost function is designed to be able to account for the total duration of the operation. The final formulation also promotes the assignment of continuous regions to each drone. Additionally, the constraints are set to comply with the requirement in the sense of sensors to be used and expected resolution. The problem is then solved iteratively with a greedy algorithm.

The actual coverage of the area is granted by requiring the transit over a specific set of locations, or waypoints. These are defined through a geometric set cover problem, which is solved with the employment of a particle swarm algorithm. If different sensors are needed over the same sector, the solution considers specific shapes to cover each portion of the area.

Lastly, these waypoints are ordered by facing a travelling salesman problem. The solution integrates two standard approaches: Christofides algorithm provides an initial solution which is then improved by a 2-opt local search algorithm. The coordinates are then available to the drone and appended to the list of locations to be reached.

During the project, the choice of the algorithm represented an iterative process: these were tested with respect to different inputs and with software-in-the-loop simulations, which allowed to gradually improve the code and to prove the validity of the final solution. Mission Planner, by ArduPilot, was chosen as the simulation environment. It also represented a first step toward real world implementation, because the protocols used to communicate between the software and the simulator are the same which are used to communicate with drones.

Lastly, the solution was proved to account for and to exploit the differences among drones. In conclusion, the application of the product to Search and Rescue is found to make the search operations faster, easier, and safer.

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