Trabajo Fin de Máster
Máster en Ingeniería Electrónica, Robótica y Automática

Aerial co-workers: a task planning approach for multi-drone teams supporting inspection operations

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Álvaro Calvo Matos

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Abstract

This master's thesis has addressed problems arising from the recent increase in the applications of cooperative Unmanned Aerial Vehicle (UAV) teams, which are the autonomy to operate over a long period of time with robustness to possible failures, and the difficulty of providing the team with cognitive capabilities to be able to operate in dynamic environments with humans.

Many of these applications are currently being executed by humans, making the activities much more expensive, time-consuming, and in some cases even dangerous. This is why there is currently a great deal of interest and effort being put into developing solutions to the problems posed.

The aim of the work was to develop cognitive planning techniques for coordinating fleets of quadrotors to assist human operators in inspection and maintenance tasks on high-voltage power lines. These techniques should also extend the autonomy of the system, ensure that safety requirements between drones and human workers are met, and ensure the success of the mission.

A software architecture has been proposed based on a central planner and a distributed behaviour manager. To carry out the planning, a cost has been defined, which is calculated for each task. Thus, each one is assigned to the UAV that consumes the least executing it. On the other hand, to control the behaviour of the drones and ensure the safety of the aerial equipment, a behaviour tree has been implemented.

As a result, it has been possible to develop a software architecture capable of dynamically planning missions while ensuring the safety of the equipment involved. This provides a good base that can be easily adapted and from which more complex planners can be developed in the future. Compared to the typical way of implementing behaviour managers, involving complex finite state machines that are difficult to read, reuse and extend, the use of behaviour trees is a great improvement and will allow the creation of increasingly complex behaviours.

Resumen

Este Trabajo de Fin de Máster ha afrontado problemas que surgen del reciente aumento de las aplicaciones de equipos cooperativos de UAV, los cuales son la autonomía para operar de forma prolongada en el tiempo con robustez ante posibles fallos, y la dificultad de aportar al equipo capacidades cognitivas para poder operar en entornos dinámicos con humanos.

Muchas de estas aplicaciones están siendo ejecutadas actualmente por humanos, haciendo las actividaded mucho más costosas, lentas, e incluso en algunos casos, peligrosas. Es por eso que actualmente existe un gran interés y se están destinando muchos esfuerzos para desarrollar soluciones para los problemas planteados.

El objetivo del trabajo era desarrollar técnicas cognitvas de planificación para coordinar flotas de drones que asistan a operarios humanos en tareas de inspección y mantenimiento en líneas eléctricas de alta tensión. Estas técnicas debían además extender la autonomía del sistema, garantizar que se cumplen los requisitos de seguridad entre drones y trabajadores humanos, y asegurar el éxito de la misión.

Se ha propuesto una arquitectura de software basada en un planificador central y un gestor de comportamiento distribuido. Para llevar a cabo la planificación se ha definido un coste, que es calculado para cada tarea. De esta forma, cada una se asigna al UAV al que cueste menos. Por el otro lado, para controlar el comportamiento de los drones y asegurar la seguridad de los equipos aéreos, se ha implementado un árbol de comportamiento.

Como resultado, se ha conseguido desarrollar una arquitectura de software capaz realizar la planificación de las misiones de forma dinámica asegurando mientras tanto la seguridad de los equipos involucrados. Esto constituye una buena base que se puede adaptar fácilmente y a partir de la cual se pueden desarrollar futuros planificadores más complejos. Comparado con la forma típica de implementar gestores de comportamiento, ivolucrando complejas máquinas de estados finitas difíciles de leer, reutilizar y ampliar, el uso de árboles de comportamiento supone una gran mejora y permitirá la creación de comportamientos cada vez más complejos.

Short Outline

Contents

1 Introduction

The use of UAVs has grown considerably in recent years for numerous applications including real-time monitoring, search and rescue, providing wireless coverage, security and surveillance, precision agriculture, package delivery and infrastructure inspection [1]. With the rapidly developing technology in this area, and demonstrations of what UAVs can do, there are increasing efforts to bring this technology to other applications. With the expected increase in applications for this technology, new problems and challenges arise, including autonomy, safety, obstacle avoidance and coordination of multi-UAV teams. Developing the technology to solve these problems will be a major effort, but as UAVs have proven to be critical in situations where humans are at high risk or highly inefficient, and they have proven their capacity to evolve and develop even more potential in the short term, companies are investing in developing all sort of UAV-based solutions.

1.1 Motivation

With the increase in global electricity demand, a challenge has arisen for electricity supply companies to maintain and repair power grids in a way that minimizes the frequency of outages. According to [2], one of the main causes of power outages is damage to transmission lines due to bad weather or inefficient inspection campaigns.

Figure 1.1 Operators getting off the helicopter during a maintenance mission.

The strategy often used by electric companies to reduce power outages is to schedule periodic maintenance operations on active lines. This is the most suitable method if the correct functioning of the system is to be ensured and when replacing a circuit is unacceptable [2]. These maintenance missions are carried out by experienced crews on board helicopters and equipped with safety suits and harnesses among other things that prevent the operators from receiving an electric shock (see figure 1.1). The problem with this solution is that these activities are dangerous for the operators, as they are working at high altitude and on electrified lines, are extremely time-consuming and expensive ($1500 per hour) and are subject to human error [3].

These are the reasons why distribution companies have the need to develop more efficient and safer maintenance methods. Multiple solutions have been proposed to automate this task [4], but the best of them seems to be the use of UAVs because of their flexibility and ability to inspect at different levels [2]. To achieve this, there are still some important barriers to overcome, such as the limited autonomy of these devices, the strong electromagnetic interference to which they would be subjected due to being close to power lines and the ability to detect and avoid obstacles of different nature that can be found in this type of environment [3]. Providing UAVs with the cognitive capability to operate autonomously in such dynamic environments and with the presence of humans, and providing them with a rapid on-line planning method [5], is key to address these complexities and to safely and successfully accomplish the assigned mission with UAV fleets.

A versatile and reliable software architecture will be essential to integrate and interconnect all the heterogeneous components that compose these cognitive multi-UAV systems. In [6], as part of the AERIAL-CORE European project[1], a multi-layer software architecture is presented for carrying out such missions cooperatively between human operators and a fleet of quadrotors. One of the layers of software that compose it is a high-level task planner. Its function is to coordinate the entire fleet of UAVs to generate high-level behaviours in order to efficiently, safely and successfully complete the maintenance or inspection mission. This type of work has the characteristic of being dynamic, since it is not possible to know in advance what the outcome of the inspection as such will be in order to plan offline, but rather, as the mission develops, new tasks will arise that the fleet will have to attend to. Therefore, the task planner should be able to react to unexpected events (new task, failure of a UAV, loss of connection, less autonomy than calculated, etc.) and to replan online. Thus, this layer will be the main cognitive block of the system [6].

1.2 Objectives

The overall objective of this project was to develop a cognitive task planner that would be in charge of governing the behaviour of multi-UAV teams for the inspection and maintenance of power lines in a collaborative way with human operators, being one of the software layers that compose the aforementioned software architecture [6] developed for the AERIAL-CORE European project. The fleet of governed UAVs acts as an aerial co-worker and can perform various tasks such as delivering a tool to an operator, inspecting regions of the power line or monitoring a worker while operating to ensure his safety. The planner receives both high-level input and feedback from the different equipments that make up the fleet, and processes all the information to elaborate a plan to manage the UAV team or modify it in reaction to an unforeseen event. To achieve this, the following objectives were defined:

- Ensure that resources are used and tasks are executed efficiently.
- Comply with all security requirements and ensure the integrity of equipment and mission success.
- Be able to replan online to react to unforeseen events.

[1] AERIAL-CORE European project homepage: *https://aerial-core.eu/*

- Implement the software layer in Robot Operating System (ROS) and manage the necessary communications with the rest of the software layers and modules that make up the architecture.
- Carry out Software In The Loop (SITL) simulations to prove that the algorithm is able to govern the behaviour of the fleet efficiently and safely, and that it is able to react to unforeseen events dynamically, demonstrating cognitive capabilities.

2 Preliminaries

This chapter focuses on the current state of the art of those technologies related to this project, as well as on the tools used for the development of the task planner as a software layer of a multi-layer architecture. In addition, the research work carried out on the state of the art in work related to the technologies and techniques used in this project is presented.

2.1 Current technology

Although in the last decade the use of UAVs has spread to a large number of applications, the origin of this technology dates back to 1898 with the invention of radio control and the appearance of the first unmanned aircraft, baptised with the name of drone. These were not yet unmanned aerial vehicles, and were mainly used for military purposes.

Figure 2.1 General Atomics MQ-1 Predator. A Remotely Piloted Aircraft (RPA). Source: Wikipedia.

Later, with the development of technology, the first computers of sufficient size and computing power to run the software necessary to operate a UAV autonomously and even to control aircraft with more complex and even unstable dynamics (gliders [7, 8], airships [9], quadrotors [10, 11, 12, 13], multirotors [14], flapping wings [15, 16, 17], etc.) appeared. Even though computational capacity was still insufficient for some applications, the development of UAV systems was made possible by performing calculations on the ground. What was done was to run the critical and most important systems for autonomous flight on the on-board computer (controls, data acquisition, obstacle avoidance, etc.), and to run the more demanding calculations that are not necessary in real time on the ground computers [18].

Figure 2.2 GRIFFIN's flapping wing robot [17].

For an aerial vehicle to operate autonomously, it is necessary to acquire data from the environment and process it in real time. A large number of different sensor configurations as well as numerous data acquisition and processing techniques can be found in the current literature [19, 20, 21].

UAV technology has evolved very rapidly in recent years, benefiting from advances in computing. As processors are becoming more powerful, efficient and compact, UAVs are increasingly capable of higher computing power without increasing their weight or compromising their autonomy. With the increase in the number of operations per second that UAVs can perform, this opens up the possibility of using drones for previously unthinkable applications, applications that require a large amount of processing and usually have to be performed in real time.

2.1.1 UAVs

2.1.2 Multi-drone teams

2.1.3 Aerial co-workers

2.2 Related work

2.2.1 Inspection applications with UAVs

2.2.2 Task planning in multi-drone teams

2.2.3 Drone behavior management

2.3 Tools

2.3.1 ROS

2.3.2 Gazebo

2.3.3 Rviz

2.3.4 UAL

2.3.5 Behaviour Trees

2.3.6 Groot

3 Problem Formulation

Lorem itsum

3.1 Description of tasks

3.1.1 Inspection tasks

3.1.2 Monitoring tasks

3.1.3 Tool delivery tasks

3.2 Battery recharges

3.3 Connection losses

3.4 Task replanning situations

4 Design of the proposed solution

Lorem itsum

4.1 Node diagram

4.2 Centralized module: task planner

4.3 Distributed module: behavior manager

4.3.1 Main tree

4.3.2 Inspection task tree

4.3.3 Monitoring task tree

4.3.4 Tool delivery task tree

4.4 Lower and upper level modules faker

5 Results

Lorem itsum

5.1 Task planning

5.1.1 Battery

5.1.2 Connection lost

5.1.3 Replanning

5.2 Drone behaviour manager results

5.2.1 Battery management

5.2.2 Connection lost management

5.2.3 Replanning management

6 Conclusions and future work

6.1 Conclusions

6.2 Future work

6.2.1 Augmented reality

List of Figures

List of Tables

List of Codes

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