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

Autor: Álvaro Calvo Matos

Tutor: Jesús Capitán Fernandez

Dpto. Ingeniería de Sistemas y Automática
Escuela Técnica Superior de Ingeniería
Universidad de Sevilla

Sevilla, 2021

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

Autor:

Álvaro Calvo Matos

Tutor:

Jesús Capitán Fernandez

Associate Professor

Dpto. Ingeniería de Sistemas y Automática

Escuela Técnica Superior de Ingeniería

Universidad de Sevilla

Sevilla, 2021

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

Autor: Álvaro Calvo Matos
Tutor: Jesús Capitán Fernandez

El tribunal nombrado para juzgar el trabajo arriba indicado, compuesto por los siguientes profesores:

Presidente:

Vocal/es:

Secretario:

acuerdan otorgarle la calificación de:

El Secretario del Tribunal

Fecha:

Acknowledgment

To my tutor, Jesús, for guiding me in this project, for trusting me to join the research group to which he belongs, for supporting me in my decision to join a doctoral program, for always seeking the best for us despite of his preferences and for his kindness.

To all those department mates who have helped me every time I have needed it and all those who have ever volunteered to help. In particular, I would like to thank Fran and Arturo for all the time they have dedicated to helping me.

To Damián, for accompanying me in the easy and difficult moments, but above all, for being my friend, and for being there unconditionally for whatever I needed.

To my classmates, who despite being a difficult year with social distancing, have been as close as ever.

To all my friends, for being such good friends.

To my entire family, for their unconditional love and support, and for their patience and understanding.

Thanks for everything

Álvaro Calvo Matos

Sevilla, 2021

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 actividades 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].

Once UAV technology reached sufficient capacity and autonomy, the first applications for both single [22, 23, 24] and multi-UAV [25, 26, 27] equipment began to appear. There is great interest in the latter, as they can be configured in different ways [28], collect and process data in a distributed way, increasing the computational capacity of the equipment [29, 30], and generate global collective behaviour emerging from interactions between a large number of UAVs that individually are relatively simple, known as swarming [31, 32, 33].

Current applications often require human presence to carry out certain decisions, with the human pilot overseeing that everything runs smoothly and providing the cognitive capacity to analyse the generally dynamic environment and react to unforeseen situations [34, 35, 36]. This is because providing a UAV with sufficient cognitive capacity to operate fully autonomously in dynamic environments is a very complicated task and requires a great deal of processing power. In recent years, UAV technology has evolved rapidly, benefiting from advances in computing and artificial intelligence. As processors are becoming more powerful, efficient and smaller, UAVs are becoming more and more powerful 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 [1, 37]. At the same time, advances in artificial intelligence mean that the perception, analysis and sensory fusion capabilities of UAVs are getting better and better. Advances in technology are breaking down one of the barriers preventing UAV technology from achieving this level of autonomy, and with it, more and more research effort is being devoted to breaking down the other barrier, developing software that enables UAVs to have cognitive capabilities.

Mentioning some of the research that is currently being carried out, we can recall the well-known AERIAL-CORE European project[1], in which major European robotics teams are jointly participating with the aim of developing a fully autonomous robotic system with sufficient cognitive capabilities to work together with human operators in inspection and maintenance work on electrical networks [38]. The PILOTING European project[2] aims to develop a complete inspection platform that will

---

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

provide its users with the information they need to draw up maintenance plans for structures [39]. HYFLIERS [3] is a completed European project that focused on the inspection of long pipe arrays in hard-to-reach areas. This, unlike the previous two, is not fully autonomous, but needs a pilot to indicate the inspection points along the pipes, and to supervise the aerial robot while it operates [40]. It is also worth mentioning a recent NASA (National Aeronautics and Space Administration) achievement, which is no less than the first flight of an UAV outside the Earth [41, 42]. This is specifically the Martian helicopter called Ingenuity, whose mission was simply to take off, move around and land in the Martian atmosphere with the added difficulty that, due to the distance between the two planets, this had to be done completely autonomously.

2.2 Related work

According to the literature review conducted by Hazim Shakhatreh et al. in 2019 [1], the market value of UAVs for civil infrastructure inspection is expected to be more than $45 billion, representing 45% of the total UAV market. The development of heterogeneous UAV fleets and efficient algorithms for their communication and coordination is important to have multi-UAV teams capable of carrying out a successful inspection and maintenance mission. If the inspection equipment is to be fully autonomous, so that it can be operated by personnel not specialized in the piloting of aerial vehicles, a module capable of reacting to any unforeseen event and modifying the planning in real time if necessary is required. This module, which could be called a task planner, is usually part of a larger software architecture in charge of fleet management and which tries to provide intelligence to the equipment. The task planner developed in this thesis consists of two distinct modules, the task planner itself and the behaviour manager.

2.2.1 Task planning in multi-drone teams

2.2.2 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] HYFLIERS European project homepage: *https://www.oulu.fi/hyfliers/*

3 Problem Formulation

L orem 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

L orem 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

L orem 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

Bibliography

[1] H. Shakhatreh, A. H. Sawalmeh, A. Al-Fuqaha, Z. Dou, E. Almaita, I. Khalil, N. S. Othman, A. Khreishah, and M. Guizani, "Unmanned aerial vehicles (uavs): A survey on civil applications and key research challenges," *IEEE Access*, vol. 7, pp. 48 572–48 634, 2019.

[2] J.-Y. Park, S.-T. Kim, J.-K. Lee, J.-W. Ham, and K.-Y. Oh, "Method of operating a gis-based autopilot drone to inspect ultrahigh voltage power lines and its field tests," *Journal of Field Robotics*, vol. 37, no. 3, pp. 345–361, 2020.

[3] H. Baik and J. Valenzuela, "Unmanned aircraft system path planning for visually inspecting electric transmission towers," *Journal of Intelligent & Robotic Systems*, vol. 95, no. 3, pp. 1097–1111, 2019.

[4] C. Martinez, C. Sampedro, A. Chauhan, J. F. Collumeau, and P. Campoy, "The power line inspection software (polis): A versatile system for automating power line inspection," *Engineering applications of artificial intelligence*, vol. 71, pp. 293–314, 2018.

[5] R. Pěnička, J. Faigl, and M. Saska, "Physical orienteering problem for unmanned aerial vehicle data collection planning in environments with obstacles," *IEEE Robotics and Automation Letters*, vol. 4, no. 3, pp. 3005–3012, 2019.

[6] G. Silano, J. Bednar, T. Nascimento, J. Capitan, M. Saska, and A. Ollero, "A multi-layer software architecture for aerial cognitive multi-robot systems in power line inspection tasks," 2021.

[7] Wikipedia contributors, "General atomics mq-1 predator — Wikipedia, the free encyclopedia," https://en.wikipedia.org/w/index.php?title=General_Atomics_MQ-1_Predator&oldid=1041584540, 2021, [Online; accessed 27-September-2021].

[8] A. Simpson, O. Rawashdeh, S. Smith, J. Jacob, W. Smith, and J. Lumpp, "Big blue: high-altitude uav demonstrator of mars airplane technology," in *2005 IEEE Aerospace Conference*, 2005, pp. 4461–4471.

[9] S. S. Bueno, J. R. Azinheira, J. Ramos, E. Paiva, P. Rives, A. Elfes, J. R. Carvalho, and G. F. Silveira, "Project aurora: Towards an autonomous robotic airship," in *Workshop on Aerial Robotics, IEEE International Conference on Intelligent Robots and Systems*, 2002, pp. 43–54.

[10] S. N. Ghazbi, Y. Aghli, M. Alimohammadi, and A. A. Akbari, "Quadrotors unmanned aerial vehicles: A review," *International journal on smart sensing and Intelligent Systems*, vol. 9, no. 1, 2016.

[11] I. Kroo, F. Prinz, M. Shantz, P. Kunz, G. Fay, S. Cheng, T. Fabian, and C. Partridge, "The mesicopter: A miniature rotorcraft concept phase ii interim report," *Stanford university*, 2000.

[12] P. Pounds, R. Mahony, P. Hynes, and J. M. Roberts, "Design of a four-rotor aerial robot," in *The Australian Conference on Robotics and Automation (ACRA 2002)*, 2002, pp. 145–150.

[13] E. Capello, A. Scola, G. Guglieri, and F. Quagliotti, "Mini quadrotor uav: design and experiment," *Journal of Aerospace Engineering*, vol. 25, no. 4, pp. 559–573, 2012.

[14] R. Rashad, J. Goerres, R. Aarts, J. B. Engelen, and S. Stramigioli, "Fully actuated multirotor uavs: A literature review," *IEEE Robotics & Automation Magazine*, vol. 27, no. 3, pp. 97–107, 2020.

[15] A. Roshanbin, H. Altartouri, M. Karásek, and A. Preumont, "Colibri: A hovering flapping twin-wing robot," *International Journal of Micro Air Vehicles*, vol. 9, no. 4, pp. 270–282, 2017.

[16] A. G. Eguíluz, J. Rodríguez-Gómez, J. Paneque, P. Grau, J. M. de Dios, and A. Ollero, "Towards flapping wing robot visual perception: Opportunities and challenges," in *2019 Workshop on Research, Education and Development of Unmanned Aerial Systems (RED UAS)*. IEEE, 2019, pp. 335–343.

[17] R. Zufferey, J. Tormo-Barbero, M. M. Guzmán, F. J. Maldonado, E. Sanchez-Laulhe, P. Grau, M. Pérez, J. Á. Acosta, and A. Ollero, "Design of the high-payload flapping wing robot e-flap," *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 3097–3104, 2021.

[18] T. Tomic, K. Schmid, P. Lutz, A. Domel, M. Kassecker, E. Mair, I. L. Grixa, F. Ruess, M. Suppa, and D. Burschka, "Toward a fully autonomous uav: Research platform for indoor and outdoor urban search and rescue," *IEEE robotics & automation magazine*, vol. 19, no. 3, pp. 46–56, 2012.

[19] B. N. Chand, P. Mahalakshmi, and V. Naidu, "Sense and avoid technology in unmanned aerial vehicles: A review," in *2017 International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECCOT)*. IEEE, 2017, pp. 512–517.

[20] H. Aasen, E. Honkavaara, A. Lucieer, and P. J. Zarco-Tejada, "Quantitative remote sensing at ultra-high resolution with uav spectroscopy: A review of sensor technology, measurement procedures, and data correction workflows," *Remote Sensing*, vol. 10, no. 7, p. 1091, 2018.

[21] H. Ren, Y. Zhao, W. Xiao, and Z. Hu, "A review of uav monitoring in mining areas: Current status and future perspectives," *International Journal of Coal Science & Technology*, vol. 6, no. 3, pp. 320–333, 2019.

[22] F. Nex and F. Remondino, "Uav for 3d mapping applications: a review," *Applied geomatics*, vol. 6, no. 1, pp. 1–15, 2014.

[23] P. Radoglou-Grammatikis, P. Sarigiannidis, T. Lagkas, and I. Moscholios, "A compilation of uav applications for precision agriculture," *Computer Networks*, vol. 172, p. 107148, 2020.

[24] C. D. Drummond, M. D. Harley, I. L. Turner, A. N. A Matheen, W. C. Glamore *et al.*, "Uav applications to coastal engineering," in *Australasian Coasts & Ports Conference 2015: 22nd Australasian Coastal and Ocean Engineering Conference and the 15th Australasian Port and Harbour Conference*. Engineers Australia and IPENZ, 2015, p. 267.

[25] J. Martínez-de Dios, L. Merino, A. Ollero, L. M. Ribeiro, and X. Viegas, "Multi-uav experiments: application to forest fires," in *Multiple heterogeneous unmanned aerial vehicles*. Springer, 2007, pp. 207–228.

[26] J. Gu, T. Su, Q. Wang, X. Du, and M. Guizani, "Multiple moving targets surveillance based on a cooperative network for multi-uav," *IEEE Communications Magazine*, vol. 56, no. 4, pp. 82–89, 2018.

[27] J. Scherer, S. Yahyanejad, S. Hayat, E. Yanmaz, T. Andre, A. Khan, V. Vukadinovic, C. Bettstetter, H. Hellwagner, and B. Rinner, "An autonomous multi-uav system for search and rescue," in *Proceedings of the First Workshop on Micro Aerial Vehicle Networks, Systems, and Applications for Civilian Use*, 2015, pp. 33–38.

[28] I. Maza, A. Ollero, E. Casado, and D. Scarlatti, "Classification of multi-uav architectures," *Handbook of unmanned aerial vehicles*, pp. 953–975, 2014.

[29] D. Pascarella, S. Venticinque, R. Aversa, M. Mattei, and L. Blasi, "Parallel and distributed computing for uavs trajectory planning," *Journal of Ambient Intelligence and Humanized Computing*, vol. 6, no. 6, pp. 773–782, 2015.

[30] Y. Guo, S. Gu, Q. Zhang, N. Zhang, and W. Xiang, "A coded distributed computing framework for task offloading from multi-uav to edge servers," in *2021 IEEE Wireless Communications and Networking Conference (WCNC)*. IEEE, 2021, pp. 1–6.

[31] Y. Zhou, B. Rao, and W. Wang, "Uav swarm intelligence: Recent advances and future trends," *IEEE Access*, vol. 8, pp. 183 856–183 878, 2020.

[32] M. Campion, P. Ranganathan, and S. Faruque, "Uav swarm communication and control architectures: a review," *Journal of Unmanned Vehicle Systems*, vol. 7, no. 2, pp. 93–106, 2018.

[33] M. Chen, H. Wang, C.-Y. Chang, and X. Wei, "Sidr: a swarm intelligence-based damage-resilient mechanism for uav swarm networks," *IEEE Access*, vol. 8, pp. 77 089–77 105, 2020.

[34] Y. B. Sebbane, *Smart autonomous aircraft: flight control and planning for UAV*. Crc Press, 2015.

[35] Kristina Grifantini, "How to make uavs fully autonomous," https://www.technologyreview.com/2009/07/15/211604/how-to-make-uavs-fully-autonomous-2/, 2009, [Online; accessed 30-September-2021].

[36] A. Kopeikin, A. Clare, O. Toupet, J. How, and M. Cummings, "Flight testing a heterogeneous multi-uav system with human supervision," in *AIAA Guidance, Navigation, and Control Conference*, 2012, p. 4825.

[37] R. Shakeri, M. A. Al-Garadi, A. Badawy, A. Mohamed, T. Khattab, A. K. Al-Ali, K. A. Harras, and M. Guizani, "Design challenges of multi-uav systems in cyber-physical applications: A comprehensive survey and future directions," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 4, pp. 3340–3385, 2019.

[38] J. Cacace, S. M. Orozco-Soto, A. Suarez, A. Caballero, M. Orsag, S. Bogdan, G. Vasiljevic, E. Ebeid, J. A. A. Rodriguez, and A. Ollero, "Safe local aerial manipulation for the installation of devices on power lines: Aerial-core first year results and designs," *Applied Sciences*, vol. 11, no. 13, p. 6220, 2021.

[39] D. Benjumea, A. Alcántara, A. Ramos, A. Torres-Gonzalez, P. Sánchez-Cuevas, J. Capitan, G. Heredia, and A. Ollero, "Localization system for lightweight unmanned aerial vehicles in inspection tasks," *Sensors*, vol. 21, no. 17, p. 5937, 2021.

[40] A. Suarez, A. Caballero, A. Garofano, P. J. Sanchez-Cuevas, G. Heredia, and A. Ollero, "Aerial manipulator with rolling base for inspection of pipe arrays," *IEEE Access*, vol. 8, pp. 162 516–162 532, 2020.

[41] G. Schroeder, "Nasa's ingenuity mars helicopter: The first attempt at powered flight on another world." *American Scientist*, vol. 108, no. 6, pp. 330–331, 2020.

[42] N. Potter, "A mars helicopter preps for launch: The first drone to fly on another planet will hitch a ride on nasa's perseverance rover-[news]," *IEEE Spectrum*, vol. 57, no. 7, pp. 06–07, 2020.

[43] K. P. Valavanis and G. J. Vachtsevanos, *Handbook of unmanned aerial vehicles*. Springer, 2015, vol. 2077.

[44] A. Ollero and L. Merino, "Control and perception techniques for aerial robotics," *Annual reviews in Control*, vol. 28, no. 2, pp. 167–178, 2004.

[45] S. D. Ramchurn, J. E. Fischer, Y. Ikuno, F. Wu, J. Flann, and A. Waldock, "A study of human-agent collaboration for multi-uav task allocation in dynamic environments," in *Twenty-Fourth International Joint Conference on Artificial Intelligence*, 2015.

[46] A. Nikou, J. Tumova, and D. V. Dimarogonas, "Cooperative task planning of multi-agent systems under timed temporal specifications," in *2016 American Control Conference (ACC)*. IEEE, 2016, pp. 7104–7109.

[47] K. Jolly, R. S. Kumar, and R. Vijayakumar, "Intelligent task planning and action selection of a mobile robot in a multi-agent system through a fuzzy neural network approach," *Engineering Applications of Artificial Intelligence*, vol. 23, no. 6, pp. 923–933, 2010.

[48] Y. Gao, Y. Zhang, S. Zhu, and Y. Sun, "Multi-uav task allocation based on improved algorithm of multi-objective particle swarm optimization," in *2018 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery (CyberC)*. IEEE, 2018, pp. 443–4437.

[49] S. Sanner, "Relational dynamic influence diagram language (rddl): Language description," *Unpublished ms. Australian National University*, vol. 32, p. 27, 2010.

[50] Y.-q. Jiang, S.-q. Zhang, P. Khandelwal, and P. Stone, "Task planning in robotics: an empirical comparison of pddl-and asp-based systems," *Frontiers of Information Technology & Electronic Engineering*, vol. 20, no. 3, pp. 363–373, 2019.

[51] G. Canal, M. Cashmore, S. Krivić, G. Alenyà, D. Magazzeni, and C. Torras, "Probabilistic planning for robotics with rosplan," in *Annual Conference Towards Autonomous Robotic Systems*. Springer, 2019, pp. 236–250.

Glossary

NASA National Aeronautics and Space Administration. 7

ROS Robot Operating System. 3

RPA Remotely Piloted Aircraft. 5, 17

SITL Software In The Loop. 3

UAV Unmanned Aerial Vehicle. III, V, 1, 2, 5–7