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Research article

WILD HOPPER: A heavy-duty UAV for day and night firefighting operations

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ABSTRACT

Forest fires are among the most dangerous accidents, as they lead to the repercussions of climate change by reducing oxygen levels and increasing carbon dioxide levels. These risks led to the attention of many institutions worldwide, most notably the European Union and the European Parliament, which led to the emergence of many directives and regulations aimed at controlling the phenomenon of forest fires in Europe, such as the (E.U.) 2019/570. Among the proposed solutions, the usage of unmanned aerial vehicles (UAVs) is considered to operate alongside existing aircraft and helicopters through extinguishing forest fires. Scientific researches in this regard have shown the high effectiveness use of UAVs. Still, some defects and shortcomings appeared during practical experiments represented in the limited operating time and low payload. As UAVs are used for firefighting forest fires, they must be characterized by the heavy payload for the extinguishing fluids, long time for flight endurance during the mission, the ability to high maneuver, and work as a decision-making system.

In this paper, a new UAV platform for forest firefighting is represented named WILD HOPPER.

WILD HOPPER is a 600-liter platform designed for forest firefighting. This payload capacity overcomes typical limitations of electrically powered drones that cannot be used for anything more than fire monitoring, as they do not have sufficient lifting power. The enhanced capabilities of the WILD HOPPER allow it to complement existing aerial means and overcome their main limitations, especially the need to cover night operations. This allows reducing the duration of the wildfires heavily by allowing continuous aerial support to the extinguishing activities once the conventional aerial means (hydroplanes and helicopters) are set back to the base at night. On the other hand, WILD HOPPER has significant powerful advantages due to the accuracy of the release, derived from multirotor platform dynamic capabilities.

1. Introduction

Wildfires cause a lot of damage all over Europe; around 159,585 ha was burned in 2019, and Over 400,000 ha burned in 2020. It was clear that the increase in fire danger is expected to be especially large in western-central Europe. Still, the ultimate fire danger remains highest in southern Europe, with an estimated financial loss of about €2,000B per year. Although Adaptation measures, such as improved fire prevention and suppression, can substantially reduce fire risks, it is still not a sufficient way to deal with such a problem [1]. The social and environmental costs include the damage to human health and fatalities (estimated at 340,000 premature deaths per year due to fire), important damage to the wildlife and the soil leading to deforestation, and the release of greenhouse gases. The direct economic impact on the landscape (tourism) and the damage to infrastructures are also significant. Extinguishing a wildfire is an extraordinarily complex and expensive task for helicopters, hydroplanes, and firefighters. Current aerial means (hydroplanes and helicopters) are critical resources to support ground personnel from the air. Unfortunately, they have several limitations, being the most important one the need to stop operations at night due to safety concerns for the pilots. Thus, many fires reactivate at night. It is also significant that they put human lives at risk. Also, hydroplanes and helicopters are complex machines, and therefore their purchase price and operation costs are huge pain points for owners and operators. Also, both hydroplanes and helicopters have restrictions concerning the water release operation, compromising fire extinguishing efficiency. Unmanned aerial

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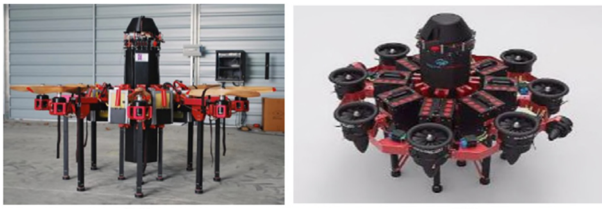

(a) (b)

Figure 1. Drone Hopper Platforms. a) AGRO-HOPPER. b) URBAN-HOPPER.

vehicles (UAVs) can overcome and limit these drawbacks, as no lives would be in danger during its operation or at risk even during night operations. To improve effectiveness, UAVs can fly at low altitudes during their firefighting missions, Unlike manned planes. During the research work, it was found that there is no single UAV in the market capable of extinguishing wildfires.

Almost all UAV tasks can be summarized in data collection, monitoring, and surveillance missions. This is because current drone technologies based on electrical systems lack the necessary power to lift heavy loads. DRONE HOPPER S.L. is a Spanish start-up created in September 2015 by Pablo Flores Peña (founder and CEO). The vision of Drone Hopper is to be a pioneer in the drone market by developing and commercializing a family of innovative heavy payload drones. Through this background, Drone Hopper created a flexible heavy-duty platform (HOPPER platform), capable of fitting different user needs by adjusting the size of the platform and integrating a wide array of engines of different power ratings (family concept). Our competitive differentiation strategy for new product development has allowed us to strengthen our market position and establish a common strategy for the future development of the family concept of our technologies. This technology development roadmap will allow Drone Hopper to take a low-risk approach to product development. So far, Drone Hopper has generated two patents: P201531246 Non-manned vehicle for extinguishing fires (2015), and P201830077 multirotor drone with the crossed system for reactive stability (2019). The research center in Drone Hopper has developed two drone platforms with success, as shown in Figure 1.

First, the Drone Hopper research center developed the AGRO-HOPPER, Figure 1a: a comprehensive fumigation technology used to efficiently and effectively spray crops for large-scale farms. AGRO-HOPPER is a 60-80-litre drone that uses programmed routes with waypoints to spray pesticides with precision at low altitudes. It is a simple functioning device with high speed that allows the completion of several missions in a short time with easy reloading to continue operation. Drone Hopper is in the certification process with Agencia Estatal de Seguridad Aerea (AESA), the Spanish Agency for Air Safety [2]. AGROHOPPER will be commercialized at a starting selling price of 250k€. URBANHOPPER is the second product, as shown in Figure 1b. Its water release mechanism is similar to WILDHOPPER. Both can work autonomously using their navigation systems, deciding the release point and moment.

The drone can nebulize up to 150 L of the water safely, covering nearly 300 m2. It also includes control systems, thermographic cameras, and navigation systems. URBANHOPPER can be refilled in a truck close to the fire area. This project has been awarded a Spanish grant (€190,000) from CDTI Innoglobal funds to develop the project in 24 months with the commercial partnership of Cast Craft from India. DRONE HOPPER has developed a family of heavy-duty multi-rotor unmanned aerial vehicles (UAVs) based on proprietary technologies that overcome the limitations of current drone technologies concerning payload and flight time capabilities. This is possible thanks to a proprietary attitude control system that allows using thermal engines instead of electrical motors powered by batteries. The 600-liter application described in this project, dubbed as WILDHOPPER, also has other proprietary features like the water release system that creates a high-speed water mist jet. This water mist jet can be directed precisely to the target, improving the efficiency heavily compared to conventional aerial means.

On top of that, it will offer an impressive low turnaround time (20 min) thanks to its local-based operations. WILDHOPPER is a natural evolution of prior developments and therefore shares many core technologies with our AGROHOPPER (60–80 L for agriculture) and our

(a) (b)

Figure 2. Wildfire problems. a) Footage of Pedrógão Grande, Portugal. b) Fire occurrence map [3, 20].

(a) (b)

Figure 3. WILD HOPPER operation during attacking wildfires. a) Operation. b) Wildfire attack.

Table 1. A comparison between WILD HOPPER and other competing solutions.

	Manned		Unmanned
	Helicopters	Hydroplanes	Wild Hopper
Alternatives in the market providing wildfire			
Capacity (l)	500 - 2.000	1000 - 6000	600
Water release efficiency	Low (Gravity)	Low (Gravity)	High (Water mist)
Needs landing track	YES	YES	NO
Human lives at risk	YES	YES	NO
Night operation	NO	NO	YES
Cost purchase (M€)	4 - 6	25 - 35	2,5
Time between releases (min)	30 - 40	30	15
Pilot service hours	Limited	Limited	No Pilot

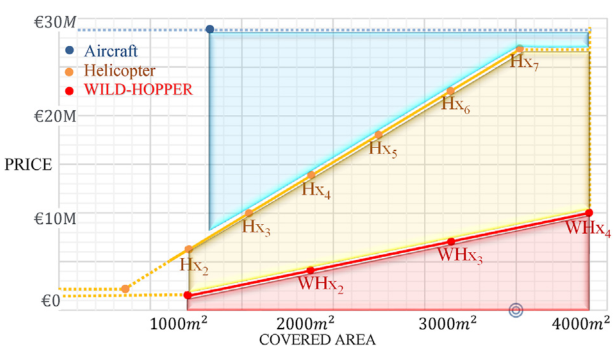

Figure 4. A comparison between an increasing number of WILD HOPPER platforms and current aerial means regarding price per area covered is depicted.

URBANHOPPER. This 150-liter drone can spray water with high precision to control fires in urban scenarios. This reduces the development time and risks heavily. The business opportunity of WILDHOPPER is well-sustained from the market side, as the project has received support from several potential clients, including direct public and private customers. This interest shown by potential clients has allowed us to validate the market opportunity. In this paper, a brief discussion and design issues for WILD HOPPER will be clarified to highlight the most powerful project that will save many human lives and overcome the financial losses due to wildfires disasters. This paper is organized into six sections; section two describes the problem of wildfires in Europe, section three shows the innovation in WILD HOPPER, section four discusses the state-of-the-art for the WILD HOPPER, section five shows the benefits in the WILD HOPPER design, and finally section six concludes the paper.

2. The global problem of wildfires

A lot of European countries face an ongoing threat from wildfires, as shown in Figure 2a. The number of large forest fires has been increasing – a trend attributed variously to climate change, protracted droughts, the abandonment of large tracts of land, and the expansion of the wildland-urban interface. Wildfires are a fatal disaster, causing death for humans, plants, and animals, destroying homes, and polluting the air with emissions harmful to human health. On top of that, a long-lasting detrimental effect is caused by wildfires on the landscape [18].

Recent fateful wildfires have proven to be a global problem. Figure 2a is footage of Pedrógão Grande after the wildfires from 2017 that hit Portugal [3]. Some examples of the worst recent events are California, USA, October 2018 & August 2018 (+100 people killed) [19], Attica, Greece, July 2018 (100 people killed), Portugal and the region of Galicia (Spain), October 2017 [3] (49 dead), and La Palma (Canary Islands), Spain, August 2016. Although natural fires play a role in managing the ecosystem, wildfires have a negative impact, destroying millions of ha of forest woodlands, causing the loss of human and animal lives, and immense economic damage. If global numbers are considered, wildfires affect 67 million hectares worldwide per year, approximately 1.7% of the land area [4]. The annual average global economic burden of fires considering firefighting, economic damage to infrastructures, financial losses of tourist and industrial sector, health issues, etc., are globally over €2,000B/year [5]. The social and environmental costs include the damage to human health – besides direct fatalities, it is estimated that 340,000 premature deaths happen each year due to fire [6] - the release of greenhouse gases, and damage to infrastructures. Post-fire environmental effects like accelerated flooding, soil erosion, mass movement, and pollution of water bodies are among the costliest impacts on society. The influences of Indirect social can be seen in the disruptions of the social processes and functioning disruptions, as in roads, air, and traffic, and the lockdown of daily human life. In addition, Land-use changes, climate change, and institutional constraints on sustainable forest and fire management have increased the risk of fire, affecting a larger area and burning with greater severity [7].

3. The innovation in WILD HOPPER

WILD HOPPER is the first UAV capable to carry 600L to extinguish fires. The breakthrough innovation of WILD HOPPER for firefighting operations can be summarized in the following points:

Table 2. Drone Hopper technological roadmap vs. the different technological bricks.

TRL	MILESTONES	PROTOTYPE
TRL 1-3 **2015-2016.** Business opportunity identification	Company creation. Start of detailed design. Preliminary concept design, water release simulation (CFD), and actuation system design. Patent for the water release mechanism. Agreement with University Carlos III Madrid. Electrical Ducted Fan (EDF) testing was launched for control purposes.	 A demonstration of water release technology prototype
TRL 4 **2016** First flight test in closed facilities and validation of water system.	The first unit was used to validate the liquid release mechanism and water tank design (5l.). Fairing design was tested. First test flight conducted. Achieving a TRL4 technology performs a stable behavior of the liquid mass (verification of tank design) with different liquid loads, even in strong wind conditions. The shape of a wet footprint on the ground (partial validation of the extinction method) is verified, showing excellent concentration rates. Finally, the increase in water release speed due to the airflow from the engines is verified.	 DH_001 High-end R.C. technology 5 liters capacity
TRL 5 **2016** DH_002 Prototype manufacture and ground testing	Manufacture a 160 cm diameter prototype with EDF (Electronic Ducted Fan - 36 electrical turbines) technology and with a capacity of 300 liters. Ground testing of the flyable drone with six power groups and controller. Water mist release mechanism tested and correlated with CFD model. The project was partially supported by the Spanish Ministry of Economy (ENISA).	 DH_002WIL D-HOPPER initial design with EDF
TRL 6 **2017-2018** DH_003 and DH_004 Technology demonstration in controlled fire extinguishing operation	Eighty liters unit with propellers instead of Electronic Ducted Fan (EDF) as the initial design. This became the first minimum viable product (MVP). Use as showcase unit for commercial purposes. The certification process started with AESA (Local Spanish Airworthiness Authority)	 DH_003 AGROHOPPER DH_004 80l. propeller initial design electrical demonstrator
TRL 7 **2018 - 2019** Inclusion of *Family Concept* strategy. First small-scale prototype of WILDHOPPER	This is our scaled prototype of the family concept structure for WILDHOPPER. This prototype has helped us to overcome the main technological challenge related to the attitude control system. Flight tests have been successfully conducted in strong wind conditions with the same control architecture in the WILDHOPPER platform.	 DH_005 WILDHOPPER scaled prototype

3.1. Payload capacity and night operation

WILD HOPPER can transport 600 L in a typical 30 min mission, and this is due to its thermal engines, which are being used instead of electrical motors and batteries. Giving 24h support in the night and harsh conditions complement current aerial means that can only operate in daylight conditions.

3.2. Water mist jet

This patented mechanism uses the airflow from the engines to convert the water into tiny water drops (water mist or nebulized) and mix it with the airflow, creating a wet airflow directed to the ground. The capacity of locating and applying nebulized water directly above the target enables high penetration compared to water reaching the ground only by gravity, like in conventional solutions.

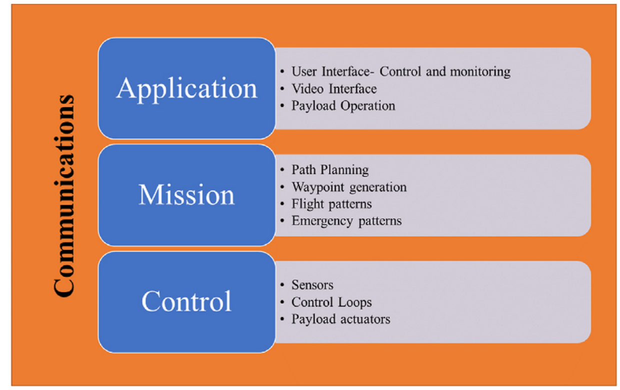

Figure 6. A primary WILDHOPPER control schema.

3.3. Precise positioning and No human lives at risk

Above the target with controlled horizontal speed, due to the inherent handling qualities of a multirotor platform, unlike conventional aerial means. Also, securing human lives as the pilot and all operators stay on a safe base station, away from the fire.

3.4. Fire extinguishing performance

One release of 2 WILD HOPPER (1,200 L) can cover an area of 2,000 m2, which is equivalent to the performance of a 5,500-liter hydroplane, as shown in Figure 3.

3.5. Stability system

A multi-layer stability system (patented) for improved aircraft stability during the flight in harsh conditions will make WILD HOPPER performance unique for its intended purpose.

3.6. Different attacking methods

WILD HOPPER can conduct direct and indirect attacks on the fire (Figure 3), offering various possibilities to the fire direction, pending fire scenarios. The indirect attack is very efficient to block fires by creating defensive or preventive firewalls, whereas direct attack is also possible for incipient or small fires. WILD HOPPER will be able to operate as a fire prevention method by creating and maintaining firewalls. This is crucial to protect people and infrastructures in real-time.

3.7. Operation timing

Local operation concept time (the refilling truck will be close to the fire area) from one release to the next one is reduced significantly to 20 min, compared to a minimum of 30–40 min for conventional aircraft.

3.8. Use of advanced sensors

Thermographic cameras, geo-localization, and navigation systems of the WILD HOPPER describe a hybrid system for positioning assessment: traditional satellite navigation and a ground-breaking technology based on visual pose estimation methods employing algorithms. These systems send real-time data from the seat of the fire providing constant information on critical aspects such as terrain conditions, localization, atmospheric conditions, and fire intensity. Real-time responsiveness will provide a technological advantage for managing the dynamic scenarios presented in a wildfire. Thanks to the communication system, WILD HOPPER will coordinate with emergency teams, evacuation procedures, and other required preventive actions.

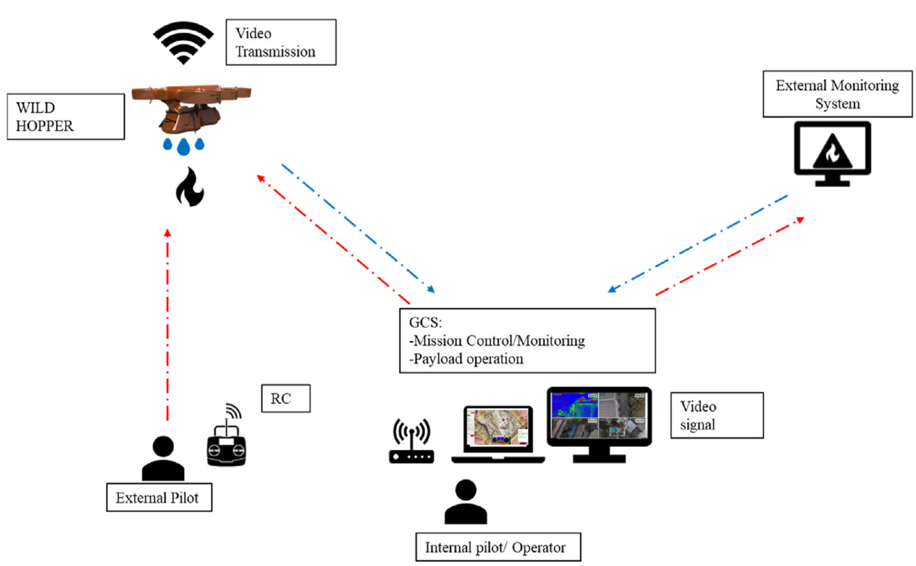

Figure 5. Schematic diagram of WILDHOPPER operations.

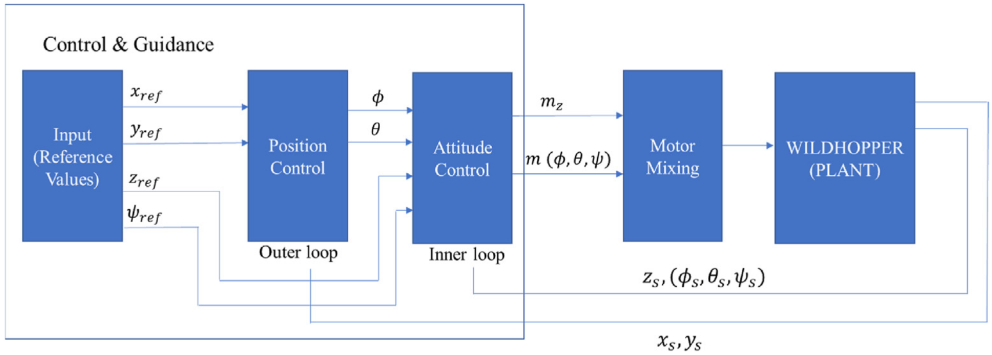

Figure 7. Basic WILDHOPPER control schema.

4. WILD HOPPER a state of the art UAV for fighting forest fires

Current aerial means are essential to support ground personnel in firefighting operations. Conventional hydroplanes and helicopters are currently performing and shall be considered as a benchmark to satisfy customer needs. Some firefighting UAV projects (fix-wings hydroplanes) have not demonstrated the feasibility to date. Table 1 demonstrates WILD HOPPER against all competing solutions, including the most commonly used manned aircraft for firefighting (helicopters and hydroplanes). It was found that the main limitation form SoA solutions are the need to retire after dusk. WILD HOPPER is the only solution that can operate at night and in harsh conditions (e.g., strong wind). Both manned solutions have to carry at least two pilots representing a threat in these critical operations. WILD HOPPER will be operated remotely as per definition, saving lives every year. There are two crucial limitations directly impacting real-life efficiency. One is the poor usage of the water volume in terms of extinguishing power per transported liter, derived from the reduced accuracy in the release process due to the dynamic constraints of the preferred platforms. Despite carrying less payload, WILD HOPPER will release the water more precisely, yielding more significant efficiency. The other is the extremely high cost per transported liter, both in terms of the purchase price (NRC) and operational and maintenance costs (R.C.). WILD HOPPER platforms are much fewer complex machines and, therefore, will decrease the cost of ownership. Moreover, after a reduced number of missions, conventional aircraft need to fly back to base and refuel. WILD HOPPER local operation ensures several missions per hour by locating the base in a close but safe, close-by location.

Approach WILD HOPPER outperforms manned aerial means in price per asset, and it will drastically reduce operations costs. WILD HOPPER will not put any lives at risk: administrations are taking wildfire safety

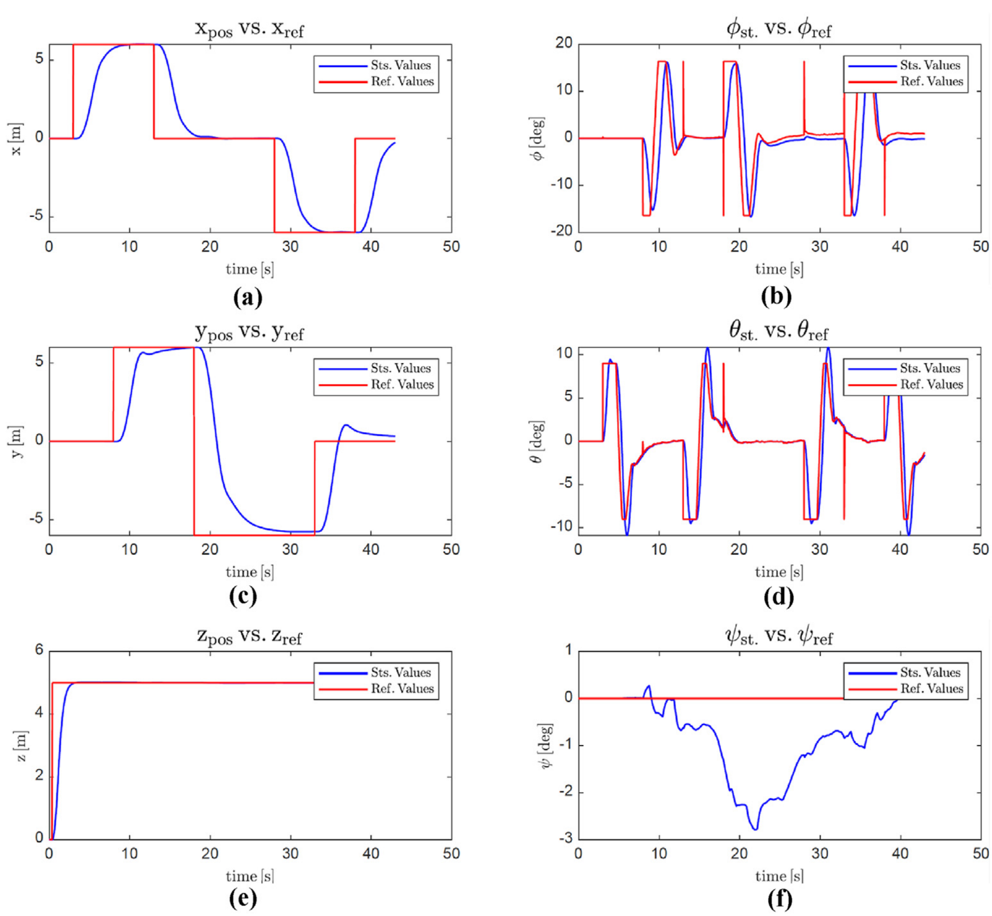

Figure 8. 2D results of controlling the WILD-HOPPER on a quadratic trajectory to compare the drone state and reference values, (a) Comparison of reference and state variables toward x-axis versus the time in a period of 43 s; (b) Comparison of reference and state attitude variables for the roll angle versus the time in a period of 43 s; (c) Comparison of reference and state variables toward y-axis versus the time in a period of 43 s; (d) Comparison of reference and state attitude variables for the pitch angle versus the time in a period of 43 s; (e) Comparison of reference and state variables toward z-axis versus time in a period of 43 s; (f) Comparison of reference and state attitude variables for the yaw angle versus the time in a period of 43 s.

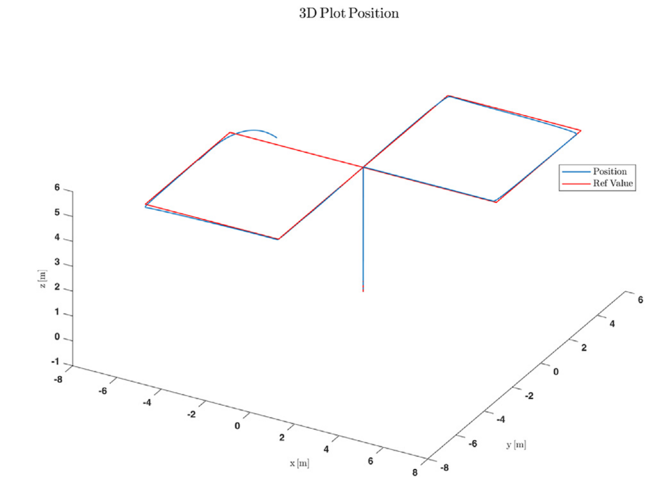

Figure 9. 3D result of the higher-loop controller on a quadratic trajectory compares the drone state and reference values.

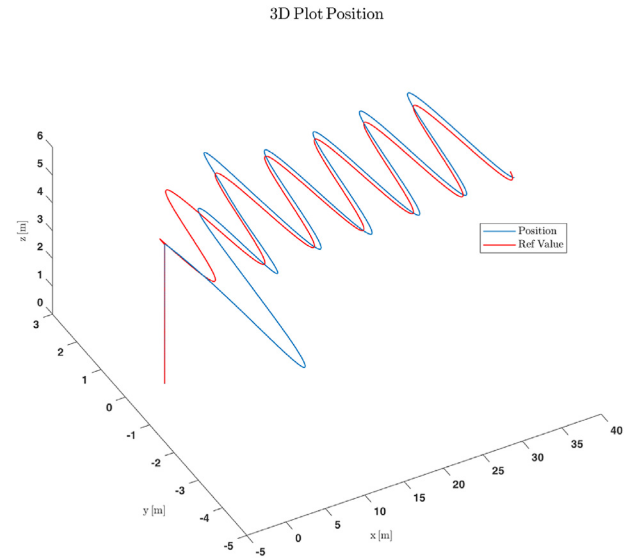

Figure 11. 3D result of the higher-loop controller on a sine wave compares the drone state and reference values.

issues seriously. The acquisition cost of aerial means for firefighting starts at €2.5M. Considering that firefighting operations usually require several airplanes or helicopters, this cost can rise to tens of millions of euros for an entire squad. Operating costs can also be significant when renting a helicopter, hiring a pilot, conducting maintenance, and paying operation and infrastructure fees. The cost of operation for an airplane tank is above €4,000/h. Administrations (in charge of civil protection and fire events) usually face budget constraints to acquire, maintain, operate, and/or rent a firefighting service, as shown in Figure 4.

Figure 4 represents our research impact comparing price versus performance (area covered) of aircraft (Canadair, Boeing, etc.), helicopters

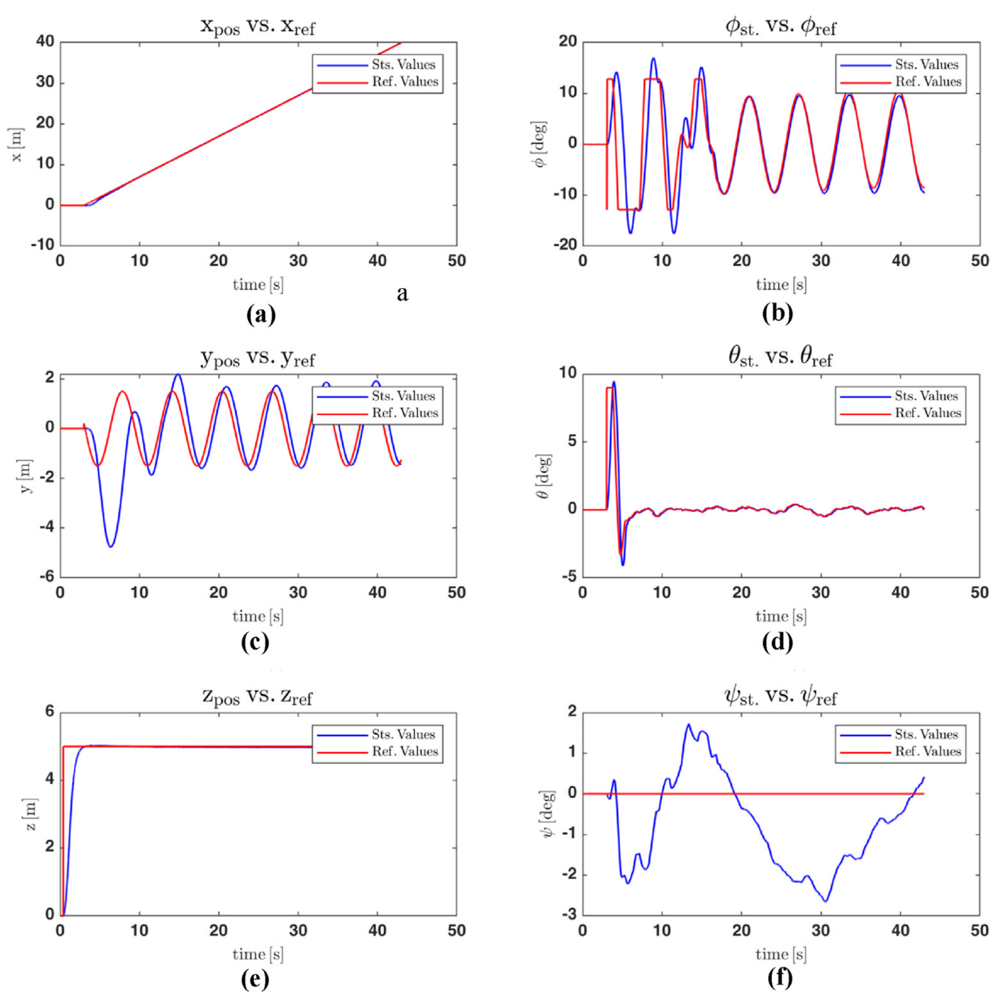

Figure 10. 2D results of controlling the WILD-HOPPER on a sine wave to compare the drone state and reference values, (a) Comparison of reference and state variables toward x-axis versus the time in a period of 43 s; (b) Comparison of reference and state attitude variables for the roll angle versus the time in a period of 43 s; (c) Comparison of reference and state variables toward y-axis versus the time in a period of 43 s; (d) Comparison of reference and state attitude variables for the pitch angle versus the time in a period of 43 s; (e) Comparison of reference and state variables toward z-axis versus time in a period of 43 s; (f) Comparison of reference and state attitude variables for the yaw angle versus the time in a period of 43 s.

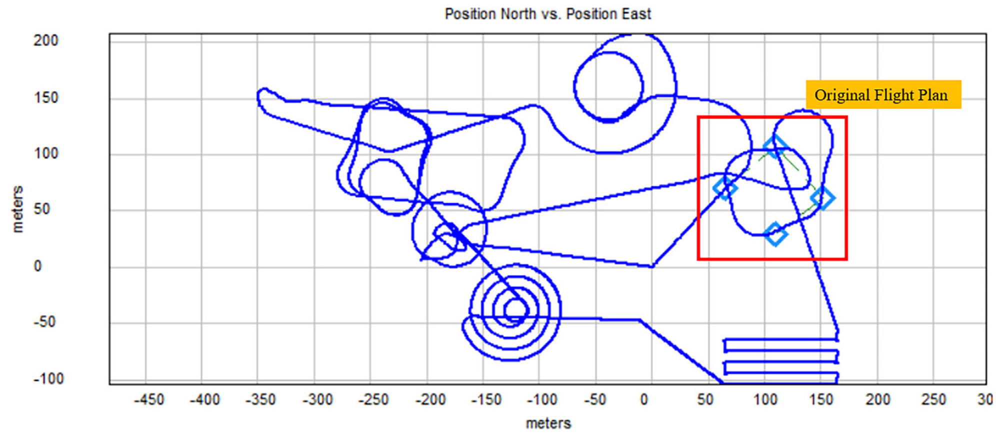

Figure 12. Flightpath using Drone-Hopper Mission Planning application.

for firefighting operations, and WILD HOPPER. Administrations (in charge of civil protection and fire events) usually face budget constraints to acquire, maintain, operate, and rent a firefighting service. Drone Hopper will target public administrations and firefighting companies as a primary client.

5. WILD HOPPER design benefits

WILD HOPPER design benefits from the technological development done by DRONE HOPPER in the past years. This can be summarized in 5 Technological Bricks, as shown in Table.2, where the research center in Drone Hopper starts to highlight the following parameters to the WILD HOPPER design:

5.1. Attitude control system

Heavy-load multirotor UAVs are a natural solution to overcome the limitations of current manned solutions. However, designing and manufacturing them is a technological challenge. The main technical barrier is the lack of electrical batteries capable of delivering the necessary payload and flight time. This leads us directly to the use of thermal engines to produce lifting power. Designing a stable attitude control system including this high-inertia low response engine is critical to ensure project feasibility. This is the reason why it is considered the backbone of our technology. For that reason, DRONE HOPPER has developed a unique attitude control system capable of stabilizing thermal-powered platforms.

5.2. Water mist jet creation system

A water mist jet creation technology has been developed for WILD HOPPER to be used explicitly on firefighting operations, heavily improving water usage. Apart from the patent, DRONE HOPPER has invested an important number of resources in simulation and testing to optimize the complex performance of the water nebulization system.

5.3. Platform architecture

The physical architecture defined for the Hopper family is also protected and specifically designed for heavy-load stable operations. It is also linked to the attitude control system and aligned with the different technological evolutions foreseen in our technical roadmap.

5.4. Mission control capabilities

The DRONE HOPPER research center had done a lot of research with several universities cooperating to improve the mission control system. The objective is to integrate state-of-the-art mission technologies (sensor fusion, image recognition, advanced sensors, swarm operation, self-awareness, etc.) to best-in-class available technologies integrated inside our platform.

5.5. Operational capabilities

The operational capabilities of the WILD HOPPER were designed to deal with firefighting scenarios that require a safe and fast mission planning and launching system. For this scenario, it is supposed that the operator does not have time to plan the mission; thus, the UAV must have a simple plan preloaded. Also, the system could require an external fire monitoring system to support the operator in decision making. During the mission, the GCS will monitor flight variables, errors, sensors, and the payload state. A schematic diagram for this scenario is presented in Figure 5.

Figure 5 demonstrates the action of the GCS receiving information from external monitoring and sending a defined coordination to the UAV.

The communication system for the WILD HOPPER is designed to have three frequencies respectively; 2.4 GHZ, 5.8 GHZ, and one emergency frequency 868 MHZ to work in emergency cases. The operational range for the WILD HOPPER is 4 km as it was tested in the practical tests.

The GCS operator could select and perform a mission plan or customized flight pattern based on the operational requirements. To deal with this function, a primary control schema is presented in Figure 6.

Through Figure 6, the communications layer will allow exchanging information among the different layers; in WILDHOPPER, external and internal communications are adaptable to the operation requirements (maximum range, latency, bandwidth, and others). Additionally, the autopilot manages the control layer, and the GCS controls the Mission and Application layers. The structure of the control layer is presented in Figure 7.

The simulations for the control layer are presented in Figures 8 and 9, 10, 11, and 12.

According to the results, quadratic trajectories are controlled better since the sine wave or other wave routes include several diverse directions in a small-time stamp. This phenomenon makes the position controller integrator in a summation chain so, in the long run, the control efficiency reduces to diverge. However, well-tuning the parameters of the controller results in a proper function, which is optimized abundantly during our tests.

Another challenge for a fast response operation is to customize predefined flight plans and launch them quickly. A custom application was developed that allows the user to select a point on the map, then configure a complex flight pattern as circular flight, racetrack, spiral flight, or area coverage flight (grid), and launch it. Consequently, the aircraft could switch from the main mission to this complex flight pattern almost instantly. The application was tested in simulation and helicopter platforms, and the navigation path results are shown in Figure 12.

Figure 12 shows a simulated operation where the operator must execute different flight patterns in several points. These flight patterns could perform tasks of monitoring or firefighting. As shown, the operator could change the plan during the flight dynamically and safely.

5.6. Performance optimization

DRONE HOPPER is currently patenting a performance optimization system to increase thermal engine output by redesigning intake and exhaust systems taking advantage of the specific Hopper platform layout. This development will bring up to 40% more useful power at specific engine ratings (maximum continuous power) and tackle any problem related to altitude performance decrease. In Table 2, a technological roadmap vs. the different technological bricks is shown. The current short-term, mid-term, and long-term view is to gain and maintain a technological edge on competitors.

6. Conclusions

This paper describes the development of the WILDHOPPER platform, including the technological road map and comparison with other solutions. In contrast, classical solutions as helicopters and hydroplanes have a low performance compared with the WILD HOPPER platform; however, other solutions described in state-of-the-art can compete with Drone Hopper systems in different aspects will be analyzed in the future.

As it can be noticed, the complete system requires integrating specific solutions for the different layers. In this context, the software developed for the top-level (mission and applications) could be used in other platforms.

The proposal of the WILDHOPPER is applicable not only for firefighting applications but for others that require a heavy load capacity UAV, including agriculture, logistics, transportation, and others. Depending on this, the payload and the software could change.

In future work, mission control capabilities will be improved by integrating onboard computing and cloud computing to process different data from the sensors. Other improvements include swarm capabilities; this will require developing and changing the current structure of the current control schema to improve communications, add a formation control loop and change the decision-making system.

Declarations

Author contribution statement

Pablo Flores Pena, Ahmed Refaat Ragab: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Marco Andres Luna: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mohammad Sadeq Ale Isaac: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Pascual Campoy: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

[1] Georg Winkel, Filip Aggestam, Metodi Sotirov, Gerhard Weiss, Forest Policy in the European Union, 2013, pp. 52–63, chapter 3, European Forest Governance: Issues at Stake and the Way Forward.
[2] D. Alexandrian, et al., Forest fires in the Mediterranean area, Unasylva No. 197, http://www.fao.org/3/x1880e/x1880e07.htm.
[3] Jesús San-Miguel-Ayanz, et al., Comprehensive monitoring of wildfires in Europe: the European forest fire information system (EFFIS)", European commission, joint research centre Italy. https://ec.europa.eu/environment/forests/pdf/InTech.pdf.
[4] Joaquim Vasconcelos Reinolds de Sousa, Pedro Vieira Gamboa, Aerial Forest Fire Detection and Monitoring Using a Small UAV", International Congress on Engineering — Engineering for Evolution, KnE Engineering, 2020, pp. 242–256.
[5] Amit Sharma, Pradeep Kumar Singh, Ashutosh Sharma, Rajiv Kumar, An efficient architecture for the accurate detection and monitoring of an event through the sky, Comput. Commun. (September 2019).
[6] Omar A. Saraereh, Amer Alsaraira, Imran Khan, Peerapong Uthansakul, Performance Evaluation of UAV-Enabled LoRa Networks for Disaster Management Applications, April 2020. Article in Sensors.
[7] Sezgin Kilic, Omer Ozkan, A self-adaptive UAV routing for forest fire risk mitigation: a conceptual model, in: Modeling & Simulation International (SCS) 22–24, SummerSim-SCSC, Berlin, Germany, 2019 July.
[18] Peter Hirschberger, Forests Ablaze Causes and Effects of Global forest Fires", © Copyright des WWF International ® Warenzeichen des WWF International, Berlin, Germany, 2016, pp. 15–24.
[19] Alex W. Dye, John B. Kim, Karin L. Riley, Spatial heterogeneity of winds during Santa Ana and non-Santa Ana wildfires in Southern California with implications for fire risk modeling, Sci. J. (JRNL), Heliyon. 6 (6) (2020) e04159.
[20] Paulo Pinto, Álvaro Silva, Atmospheric Flow and a Large Fire Interaction: the Unusual Case of Pedrogão Grande, 2018. Portugal (17 June 2017)", Parte: http://hdl. handle. net/10316.2/44517.