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Eye in the Sky - Using High-Altitude Balloons for Decision Support in Wildfire Operations

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Abstract

The large fires that have occurred in recent years around the World have shown that the management of these events becomes much more difficult when the extension of the burnt area or the location of the fire fronts, among other fundamental information for those managing operations in theatre, is not known. In addition, the large involvement of firefighting resources often challenges the operability of the communications system, sometimes making it dysfunctional or with limited operability. This was a reality seen in several large fires, from which we highlight the Fire of Pedrógão Grande that occurred in Portugal in June 2017.

Aware of the need to improve operational technology for fire monitoring, the Eye in the Sky Project has been developed. Our approach within this project is to design and develop an easy to deploy kit that can be launched from anywhere and fulfil these needs, providing quality real-time aerial imagery of the wildfires and guaranteeing emergency communications. The proposed solution consists of a HAB that will carry a flying wing UAV with two different high-value types of payloads that meet these two specific functions of imagery collection in the visible and infrared ranges and communications repeater. The authors like to refer to the Eye in the Sky solution as a satellite dedicated to a specific fire.

Naturally, the development of such solution raises several challenges, particularly in terms of the operational functioning of this solution, the optimised use of the balloon/glider pair with the associated payload, the capture, automatic detection of the fire images and their georeferencing, and the communications system between the payload, the ground station and the users in the command centre. The several challenges that have arisen in the development of this solution, as well as the way found to solve them are hereby exposed.

1. Introduction

The recent increasing number of large wildfires leads to new challenges in the response operations. Involving larger areas and periods of extreme fire behaviour with high fire spread rates, the monitoring of the fire perimeter and the knowledge of the evolution of the fire front is not always possible with the conventional terrestrial means. Thus, drones have been increasingly used to meet this challenge. However, although very useful and versatile in terms of manoeuvrability, drones have some limitations, such as the short autonomy or safety issues due to the sharing of flight height with fire-fighting aircrafts. Another challenge posed by larger fires is associated with the greater number of agents involved in the theatre of operations and consequently the greater number of telecommunications carried out, which sometimes causes the operational communications system to collapse or requires its reinforcement with complementary communications antennas.

The project Eye in the Sky - Using High-Altitude Balloons for Decision Support in Wildfire Operations develops a solution (Figure 1) of a high-altitude balloon (HAB) that transports a flying-wing unmanned aerial vehicle (UAV) carrying a payload with equipment considered of interest for the operation, such as a combination of RGB and IR cameras, which allow monitoring the progress of the fire, or/and a communications link and repeater. Thus, the high-altitude balloon can be seen as an on-demand mini satellite specifically dedicated to the fire event. After being released from the ground, the balloon rises rapidly, leaving the firefighting aircraft operating height in some seconds, so no longer interfering with their activity. The balloon continues to rise until, by decision of the operator or because it has reached the limit of the pressure conditions, it releases the glider which begins its descending phase autonomously or commanded by the operator. This solution allows a continuous operation time that can exceed ten hours.

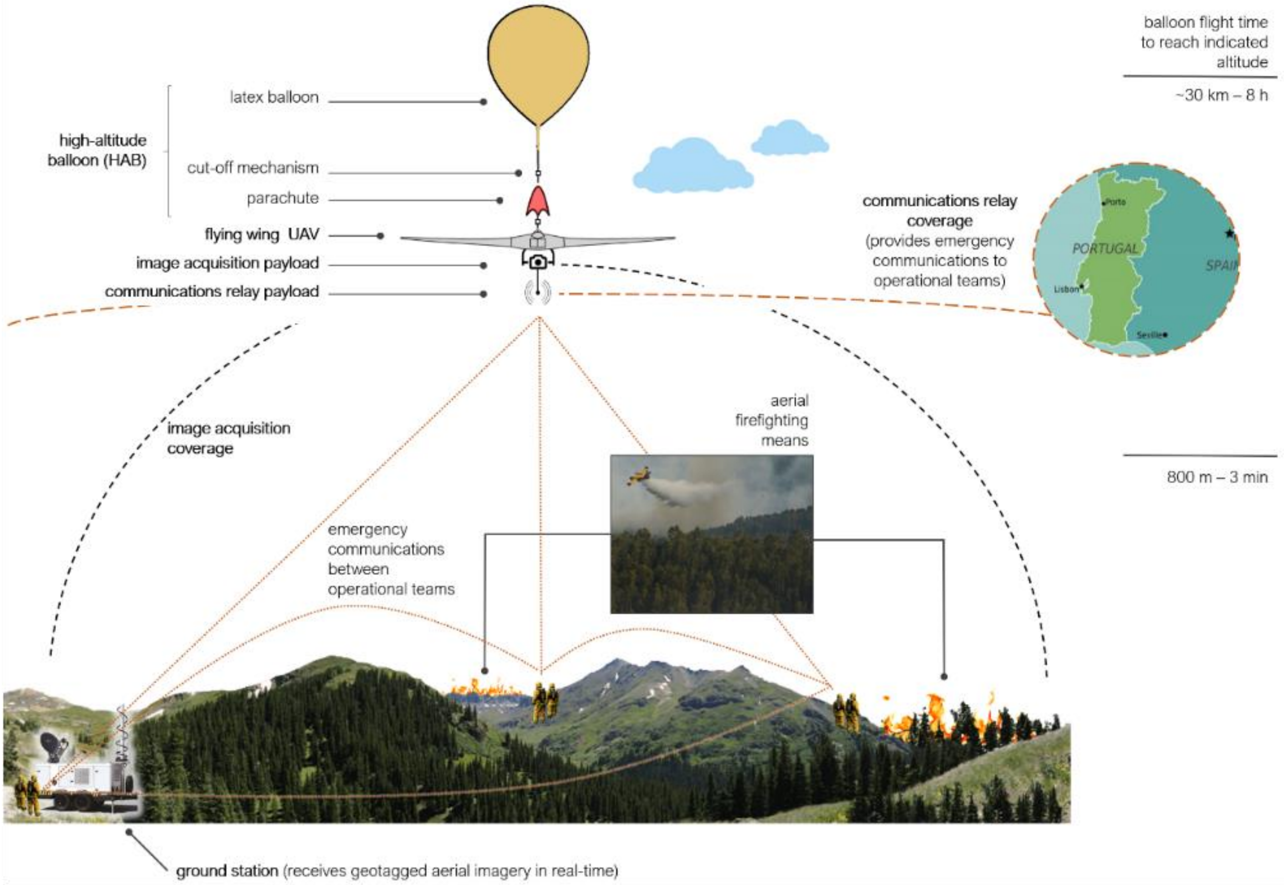

Figure 1 - Representation of the concept of using a high-altitude balloon in fire-fighting operations developed in the Eye in the Sky project (www.adai.pt/eyeinthesky).

In the Eye in the Sky project the described solution is being developed working on three main fronts, namely: a) high-altitude balloon payload stabilization, altitude control and mission prediction, and flying wing mission definition and control, b) automatic detection of fire and hot areas and respective image georeferencing before sending to ground station; and c) ground-to-ground transmission system to establish remote contact with the payload to transmit control orders and to access captured images, as well as to reinforce operational communications in theatre of operations. These topics are described in the following sections.

2. High-altitude balloon in fire-fighting operations

The HAB + UAV hybrid platform proposed incorporates the high cargo capabilities of an aerostat that travels passively through the atmosphere to reach targeted areas, but with low positional accuracy, and the navigation and positioning capabilities of an UAV glider with limited autonomy. These two elements, HAB and UAV together, significantly expand the working envelope of each independent solution, increasing the mission autonomy when compared with UAV-only-based solutions, making them particularly useful in fire monitoring applications.

A wildfire monitoring test was carried out in the context of the fire event that started in Conqueiros/Proença-a-Nova (Portugal) on the morning of September 13th, 2020. In this test, a balloon equipped with three cameras operating in the visible range was launched from Montalvão, in the municipality of Nisa, at 7 p.m. on 14th September. The balloon reached altitudes greater than 12km, covering the path shown in Figure 2.

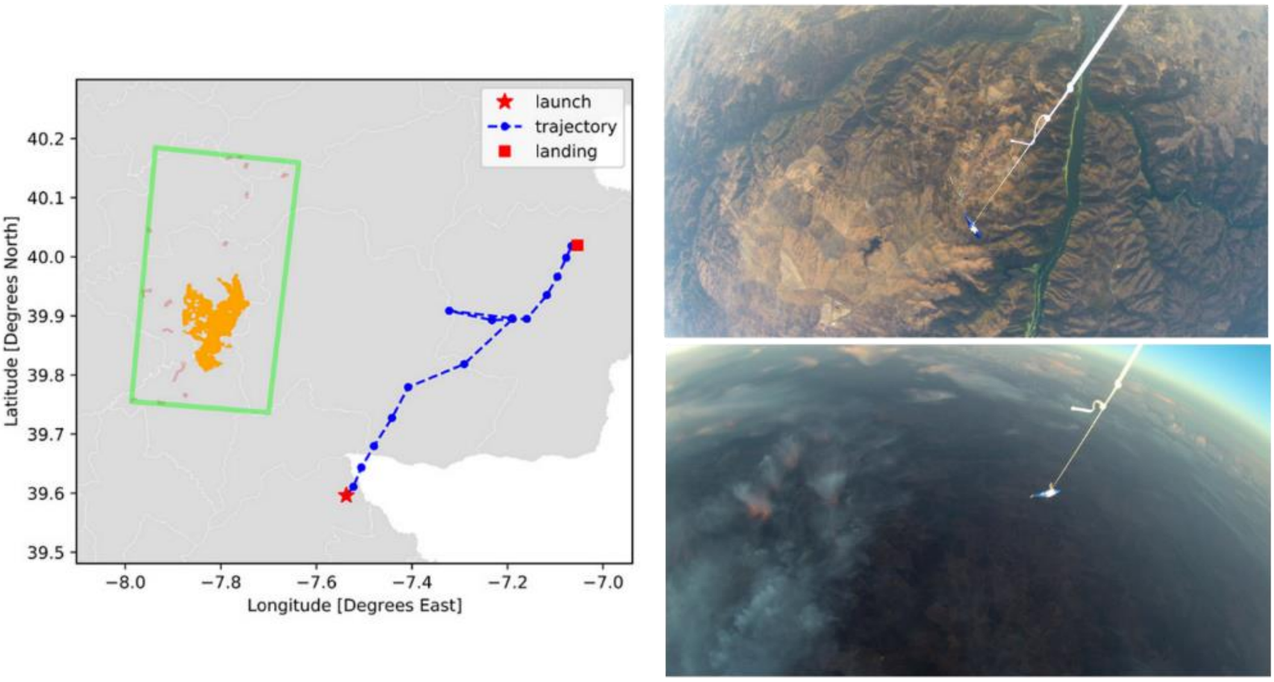

Figure 2 – Left: Balloon trajectory (in blue 'o', launch site '⋆', payload landing site '■') and fire event region (outlined in green) that led to the burned area (in yellow) in Conqueiros/Proença-a-Nova (Portugal). Right: Some images acquired in the same balloon launch at different altitudes by one of the cameras.

This launch had as main objective to test image acquisition at unset, with several cameras operating in the visible range. Although the results were limited by the balloon trajectory that did not pass directly over the fire due to the limitation in the definition of the launch zone and the direction of the existing winds, and the disturbance caused by the smoke column and the excess of artificial lights existing in the captured area, it is still possible to verify the large coverage of the balloon acquired imagery and the potential of the proposed solution.

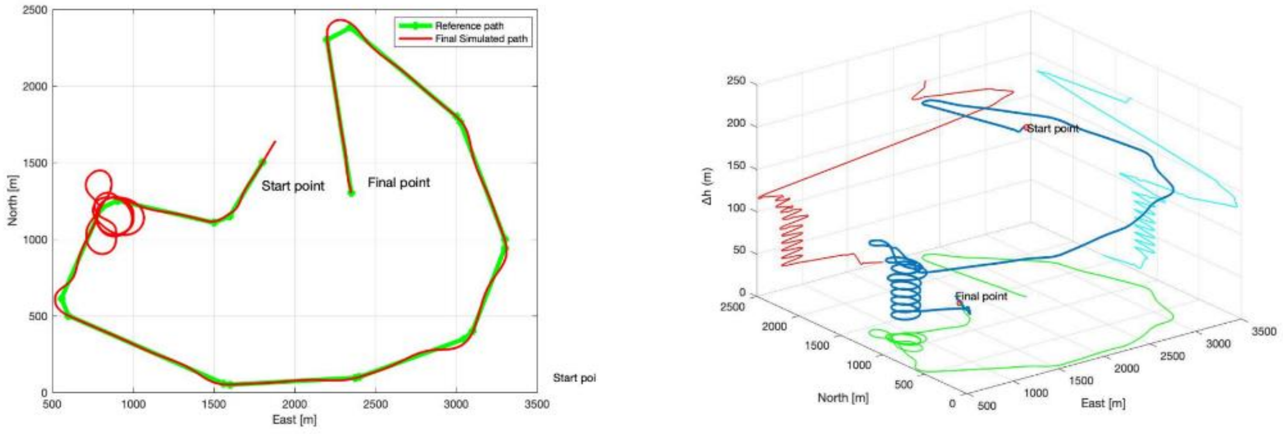

Figure 3 – Example of mission to be executed by the flying wing (reference) and its simulated performance. Vertical range was reduced to limit the loitering turns. (a) North-East visualization; (b) 3D visualization. (Yu (2021))

To guarantee the precision of the aerial imagery coverage, the mission definition of the flying wing UAV after remote cut-off from the HAB, and respective trajectory control, is essential. The implementation of nonlinear control solutions robust to wind disturbances and model uncertainties take gain from its gliding flight capabilities, guaranteeing the mission execution while maximizing flight time (Cordeiro et al. (2021)). An example of a UAV mission after deployment from HAB and stabilization, and simulated execution, is presented in Figure 3, where several points of interest are surveyed (vertical range was greatly reduced to limit the resulting loitering turns on descent).

3. Images

For the image acquisition system, a multimodal payload was developed encompassing thermal and visible range sensors. These two modes have complementary characteristics and enable developing fire detection algorithms that work separately on each of the modalities (Sousa et al. (2019), Sousa et al. (2020a)) or in tandem, allowing for better detection redundancy and robustness to occlusions in the data acquired by each sensor. Extensive field tests have been developed towards the characterization of the sensors, comprising flights with different altitude and horizontal profiles, varying different fire intensity, fire perimeter geometry and different ignition arrangements. These tests enabled identifying the best low-level image processing algorithms for encoding thermal data (Sousa et al. (2020b)). Figure 4 showcases an instance of data acquired including the different approaches taken that are made available in the dataset proposed in (Sousa et al. (2022)). Subsequently, the next steps involve improving the developed off-board automatic data annotation pipelines (Messias et al. (2021)) and applying intelligent system approaches to handle the image processing needs on-board the UAV.

Figure 4 – Examples of aerial images captured in the tests. Left: Tests setup; Middle: Visible range image in RGB color space. Top-Right: Thermal image processed with a linear automatic gain control algorithm, encoded with the GrayRed color palette. Bottom-Right: Thermal image processed with a plateau equalization automatic gain control algorithm, encoded with the Grayscale color palette.

4. Communications

During a fire event, the existence of alternative telecommunication relay systems is of extreme importance. In extreme events, the potential disruption of the communications service can cause severe damage to the firefighting operations. The main goal here is the research and implementation of an autonomous UAV-borne telecommunications service and the respective ground control system. The airborne system is responsible for transmitting all the telemetry data, images, and voice relay, while the ground system will receive these data and send mission controls back to the UAV/HAB. Another goal is the improvement of communications Quality of Service (QoS) between the local forces and the national entities to define adequate firefighting measures.

The image acquisition and respective analysis has an important role. To guarantee the quality of image transmission and reception, a communications relay system is deployed with the aerial platform, equipped with an omnidirectional antenna. This system provides the fire scene information across a high throughput transmission via radio frequency using the UHF band. The scenes go for an image conversion procedure before transmission like MPEG4, MPEG5, JPEG200, and others. The management of the entire aerial communication system is performed in an SDR device that is responsible to maintain a communication channel with different modulations schemes (AX.25, SARATOGA, DVB-T and others) and properly encrypted. To guarantee the voice relay, a TETRA radio channel is added to comply with the common technology used by the firefighters (SIRESP).

The ground platform includes a fully automated motorized antenna, with high directivity and gain, equipped with a high sensitivity receiver. The system will use the telemetry data of the aerial platform to point the antenna accurately and improve the communication channel characteristics (RSSI, BER, image quality). The images are decompressed and shared with the national entities (CDOS and CNOS) through a satellite internet service.

Figure 5 represents the block diagram of the entire communications system.

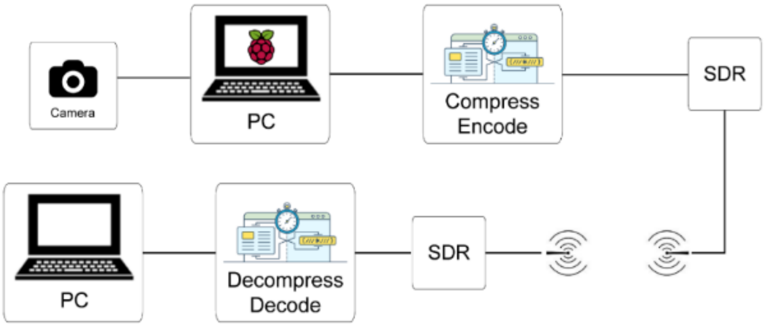

Figure 5 - Block diagram of the communications system.

5. Final Remarks

A solution was presented that is intended to become an important support tool for firefighting operations. This solution involves a high-altitude balloon carrying a glider plane and a payload that can be adapted to each situation. The payload is conceived to have a set of IR and RGB cameras for monitoring the fire and a communications repeater which will reinforce the communications system within the theatre of operations. This is a solution that allows a continuous operation that can exceed ten hours.

Although its main focus is the firefighting phase, as previously described, this solution can also be used in ignition detection operations or even in the aftermath phase in the search for hot spots that deserve greater attention by the forces remaining on the ground to avoid reignitions.

6. Acknowledgments

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7. References

R. A. Cordeiro, A. S. Marton, J. R. Azinheira, J. R. H. Carvalho, A. Moutinho (2021), Increased Robustness to Delay in Incremental Controllers using Input Scaling Gain. *IEEE Transactions on Aerospace and Electronic Systems*. DOI: 10.1109/TAES.2021.3123215

P. Messias, M. J. Sousa, A. Moutinho (2021), in *IEEE International Conference on Fuzzy Systems* (Institute of Electrical and Electronics Engineers Inc. DOI: 10.1109/FUZZ45933.2021.9494421

M. J. Sousa, A. Moutinho, M. Almeida (2019), Classification of potential fire outbreaks: A fuzzy modeling approach based on thermal images. *Expert Systems with Applications*. **129**, 216–232. DOI: 10.1016/j.eswa.2019.03.030

M. J. Sousa, A. Moutinho, M. Almeida (2020a), Wildfire detection using transfer learning on augmented datasets. *Expert Systems with Applications*. **142**. DOI: 10.1016/j.eswa.2019.112975

M. J. Sousa, A. Moutinho, M. Almeida (2020b), Thermal infrared sensing for near real-time data-driven fire detection and monitoring systems. *Sensors (Switzerland)*. **20**, 1–29. DOI: 10.3390/s20236803

M. J. Sousa, A. Moutinho, M. Almeida (2022), MAVFire: Thermal-visual-inertial-GNSS dataset for aerial robotics and fire applications. *(under review)*.

L. Yu (2021), "Pre-flight and real-time path planning of a balloon launched flying wing", MSc thesis, Instituto Superior Técnico, Universidade de Lisboa