# LEVERAGING HIGH-ALTITUDE BALLOONS AND MOBILE ROBOTICS FOR REAL-TIME WILDFIRE DETECTION AND MONITORING SYSTEMS

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## ABSTRACT

The recent difficulties in facing wildfires around the world have exposed the shortcomings of the current fire detection and monitoring infrastructures in dealing with the increasing frequency and higher intensity of these phenomena. In this context, high-altitude balloons (HAB) combined with aerial robots, e.g., flying wing drones, can provide a complementary solution to satellite- and ground-based infrastructures. In this article, we propose decentralized hybrid systems combining HAB and robotics means leveraging multimodal perception systems including thermal and visual range sensors. Moreover, we frame the efforts and launch campaigns pursued in recent years towards developing this solution, particularly in the context of the nationally funded research project Eye in the Sky.

## 1. INTRODUCTION

Environmental monitoring solutions are in ever-increasing demand, due to the urgent need for continued climate action to mitigate and adapt to climate change. However, despite the continued investment in Earth Observation technology in the past decades, there are still considerable challenges in providing systematic and fine-grained environmental monitoring.

Due to climate change, wildfires are becoming more frequent and severe in various regions worldwide, stressing the importance of enhancing wildfire research technologies and improving wildfire management infrastructures. In that sense, enhanced fire intelligence plays a pivotal role through the emergence of advanced technologies for early detection and real-time monitoring purposes, to allow a deeper understanding of these phenomena and enable better situational awareness for operational teams.

The evolution of remote sensing technologies has led to the development of monitoring systems using satellite-based information to forecast fire hazards and allow risk assessment. Nevertheless, while providing global coverage, the latency and spatiotemporal resolution of current satellite solutions are still a roadblock for an application as time-sensitive and safety-critical as wildfire detection and monitoring.

To address this issue, this work proposes a novel decentralized system-of-systems framework, composed of high-altitude balloons and drones that based on satellite and sensor networks data can assist in early detection and monitoring of wildfires. The proposed approach aims to build a mobile infrastructure that can be deployed in periods of increased fire risk and that can actively adapt to environmental changes in real-time.

## 2. RELATED WORK

The use of high-altitude pseudo-satellites for wildfire applications has been receiving increased interest in the past few years, namely specifically in the balloon community, particularly in the United States and Europe. Raven Aerostar has been collaborating on projects in this area [1,2], while stakeholders in the Earth Observation area like Airbus [3] are developing and testing sensor payloads to target surveillance applications in this domain.

In turn, research funding for investigation on applications around this topic has seen some uptake over the past decade, namely in countries highly impacted by the severity of wildfire events, such as Portugal, particularly in the aftermath of the large fires occurred in 2017.

In this context, ADAI and IDMEC have been actively collaborating on joint wildfire-related projects since 2014, ranging from field deployed fire safety applications using drones and aerostats [4,5], to proposing novel multimodal artificial intelligence research for wildfire detection and monitoring [6,7]. More recently, both institutions and IT-Aveiro collaborate on a nationally funded project called “Eye in the Sky” that aims to support fire management using high-altitude balloons.

### 2.1. Project Eye in the Sky

The project Eye in the Sky [8], started in 2019, aims to develop a hybrid solution that combines the advantages of high-altitude balloons with the flexibility of low-weight drones to provide image gathering and radio communications support to firefighting operations.

In that sense, the project proposes employing the low-cost sounding balloons as the carrier of a small flying wing, to allow positioning the drone in a region of interest without expending energy in propulsion to reach high altitude. Since the balloon is passively driven by the wind, when it starts moving away from the area of interest, the drone can be released and manoeuvre using its active control surfaces to remain in the desired area.

The overview of the several components being developed in the scope of this projected are outlined in Fig. 1. Besides the flight vehicle developments, an important part of this research project concerns the development of the image acquisition payload and the communications relay payload.

The image acquisition payload includes a thermal long-wave infrared camera and a higher resolution camera operating in the visible range. The complementarity in the spectral bands employed is of the utmost importance to circumvent the limitations of each of these devices by harnessing the advantages of each. Several artificial intelligence algorithms have been developed to process the data collected in real-time [6,7], which can take place either onboard or on the ground-station during the flight, or alternatively offline after the flight has been completed depending on the mission requirements.

The communications relay payload enables compressing the image data for making the transmission of the images collected by the image acquisition payload more efficient. Additionally, this communications subsystem also has the feature of being a relay for voice radio communications of the firefighters. The link between the balloon-drone system and the ground station employs the UHF radio band.

### 2.2. Future Decentralized Infrastructures

In the future, environmental monitoring systems will rely heavily on hybrid aerial infrastructures empowered by active environment perception systems that can perform on-demand tasks with a high level of automation due to their inherent mobility, intelligence, and adaptability.

Decentralized aerial networks of assets will bridge the gap between space- and ground-based measurements by leveraging aerial platforms operating from low-altitude up to near- space in the stratosphere, having the ability to combine sensing schema incorporating data from static sensors on the ground and dynamic sensors onboard mobile aerial platforms such as drones and high-altitude balloons.

However, while these platforms offer immense

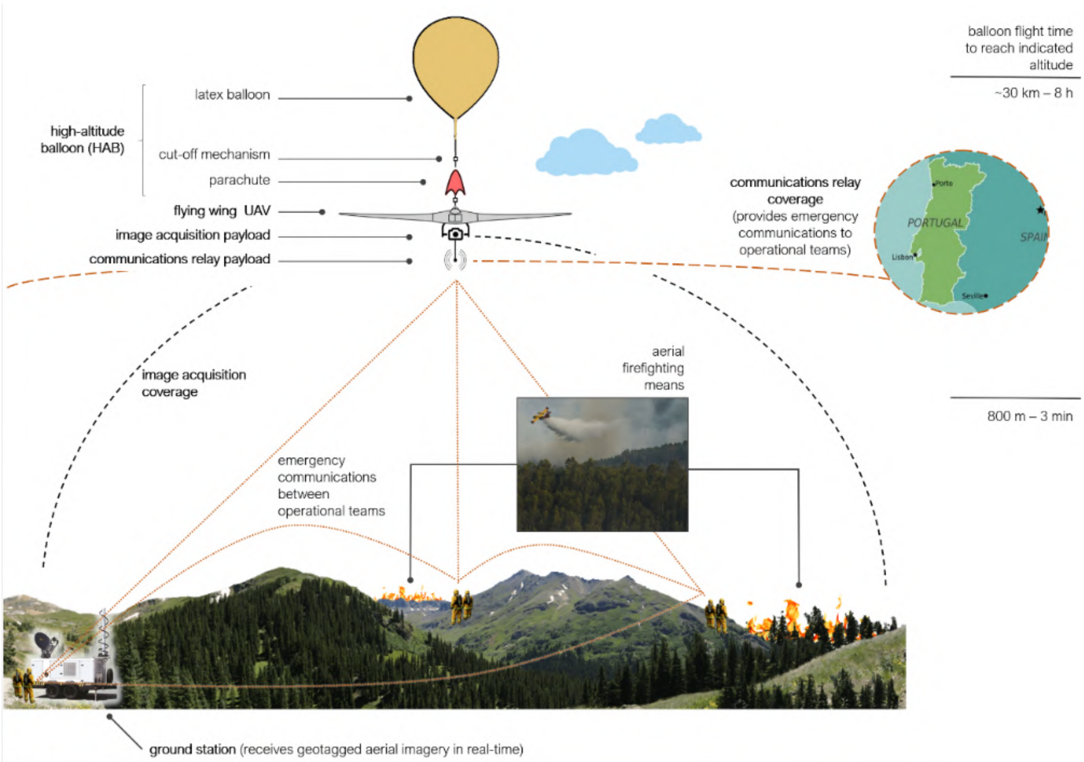


*Figure 1. Project Eye in the Sky overview.*

possibilities due to their low-cost, versatility and flexibility, these are still almost exclusively designed as standalone assets. While the development of unmanned aerial vehicle platforms expanded in recent years with growth of the drone industry, early autonomous solutions are generally particularly designed for military purposes or civilian applications in inspections with narrow use-cases. In that sense, existing drone platforms targeting those markets are by design unsuited for cost-effective and efficient long-duration missions requiring the large coverage of outdoor environments.

In turn, high-altitude balloon platforms by virtue of not requiring energy-draining propulsion systems can sustain longer duration missions and provide much greater spatial coverage capabilities. The potential of these platforms has been recently receiving more attention by governmental and commercial enterprises. Thus, further supporting the ensuing developments of solutions leveraging HABs and drones for fire support operations.

## 3. SYSTEMS OVERVIEW

This research proposes an integrated system based on satellite and sensor networks data to assist in early detection and monitoring of fire events. The system combines static sensors on the ground and dynamic sensors onboard mobile aerial platforms e.g., drones and high-altitude balloons (HABs), that can be deployed to monitor areas of high risk. The decentralized, multimodal, and dynamic nature of the proposed system enables its deployment in target regions in specific time-windows where there are forecasts of increased fire risk.

### 3.1. Architecture Description

The proposed architecture follows a System-of-Systems Engineering approach, justified by the need of interaction between an array of heterogeneous systems and assets that compose the decentralized network, but also by the inherent need to connect to a variety of existing legacy assets in the wildfire management and Earth Observation infrastructure.

This project proposes a three-layer system for wildfire detection and monitoring, combining aerial assets placed at different altitudes, ranging from drones at low altitude to high-altitude balloons operating in the stratosphere level (see Fig. 2). The decentralized network created by these assets corresponds the first layer of the system and can be deployed in wildland and at the wildland--urban- interfaces, that can relay real-time data relative to regions of interest. The second layer addresses the estimation and data aggregation, yielding environment perception states. The third layer employs intelligent soft-sensor approaches, identifying specific areas in the monitored region with higher risk. By providing real-time data to decision-makers, autonomous aerial means can be deployed to act cooperatively to maximize the area monitored, having the potential to enable a better optimization of resource allocation.

### 3.2. Key Developments and Innovations

Although balloon and drone technology has achieved a considerable maturity, the scaling and operation of the proposed decentralized system still requires key developments and innovations. The key features of such systems to enable operating these systems at scale with a high level of automation are as follows:

- Dynamic networks of sensing agents: high-altitude balloons, drones, ground-based sensors.
- Mobile infrastructures that adapt to environment changes in real-time using active perception or the environment.
- Distributed estimation algorithms provide fault-tolerance and lower computational demand on each sensing agent.
- Intelligent inference at the edge enables onboard-processing to a large extend to reduce the communication overhead and allow early-warnings and real-time monitoring.

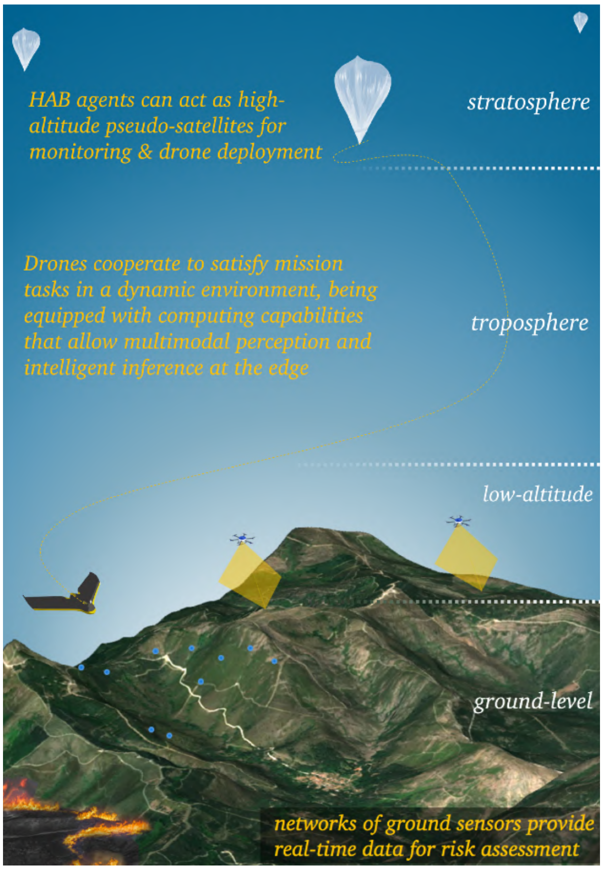


*Figure 2. Proposed networked multi-layer architecture.*

## 4. EXPERIMENTS

The experiments conducted to date encompass the testing of a variety of multimodal sensor payloads that include low-cost, commercially-off-the-shelf cameras. Several flights have been performed using thermal and visual range devices in tandem, or separately when the payload recovery could not be fully guaranteed. The field campaigns were performed in experimental burns organized by ADAI in the scope of wildfire research experiments, as well as in a real fire event in Portugal.

### 4.1. Data Acquisition Field Testing Using Drone

For testing the image sensors, comprehensive tests were performed using a multirotor drone in a controlled environment in an airfield in Lousã, Portugal. This allowed maximizing the quality of the data captured as well as experimenting different fire scenarios, e.g., with multiple fires, a fire front, hotpots detection, etc. Fig. 3 showcases selected samples of the data collected in these tests, captured with a Stereolabs ZED Mini camera [9] and a FLIR Vue Pro thermal camera [10]. The bottom row depicts the thermal camera data encoded with two distinct encoding schema and colour palettes [5] used to assess the sensor performance level.

*Figure 3. Thermal and visual range samples of data collected in drone flights during fire experiments in an airfield in Lousã, Portugal.*

### 4.2. Field Tests using High-Altitude Balloons

For testing the image acquisition capabilities at high-altitude, a balloon launch was performed during experimental burn tests. This test used a sounding balloon equipped with a GoPro Hero3+ camera set to record video and still images simultaneously. Fig. 4 illustrates the balloon flight train and a sample of the results achieved with a smoke plume visible (centre). Additionally, this image is juxtaposed with the satellite-based imagery counterpart showing the same hotspot.

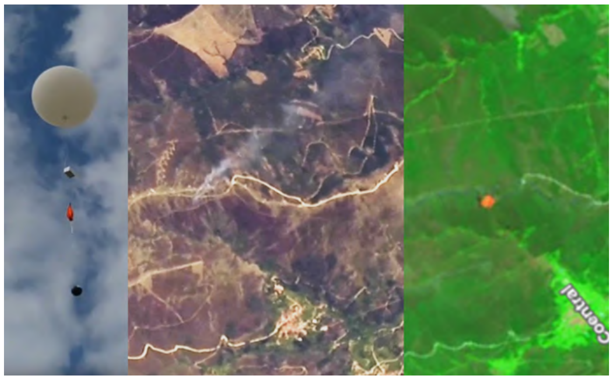

*Figure 4. Image data from the balloon launch over experimental burns near Coentral, Portugal, compared with satellite data (right).*

Moreover, a balloon launch was performed in an area adjacent to the fire perimeter of a real fire event. Fig. 5 shows the balloon flight path in blue and the area of the fire illustrated in orange.

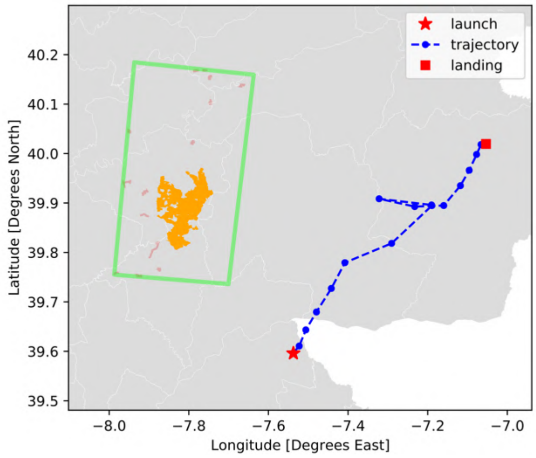


*Figure 5. Balloon flight path of the launch during the forest fire in Proença-a-Nova, Portugal.*

The main challenges observed in the experiment conducted in a real scenario stemmed from the time that launch was performed. Being an active fire scenario to a large extent difficult to predict, the travel time to the location of the authorized launch coordinates meant this test could only start in the evening, when sunlight was already reducing at a high rate. In Fig. 6, which illustrates a selected sample taken with a GoPro Hero7 during that flight, it can be observed that the presence of smoke also makes it difficult to clearly pinpoint the fire sources. Given this observation, the use of thermal camera could bring obvious advantages. However, it could not be tested in this trial due to the uncertainty in the recovery of the payload. The efficacy of such devices shall be tested in future field campaigns.

*Figure 6. Aerial view from one of the cameras installed in the flight train during a fire event.*

## 5. CONCLUSION

The proposed approach aims to contribute to the development of the next generation of resilient environmental monitoring infrastructures. Bringing novel observation capabilities to address wildfire events in research and operational applications, which can help to minimize the impacts of these phenomena. The experiments carried out show promising results with regard to the potential of this application. Being this use-case one that can provide a high-value service in the context of the wildfire detection and monitoring infrastructure, subsequent research and development shall be pursued to deepen the efforts to optimize the sensor payloads. Moreover, the development of future work would benefit from extending the network of stakeholders involved, to widen the scope of application to different regions and allow access to resources that can support the future scaling of the proposed systems.

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