Using high-altitude balloons for decision-support in emergency scenarios – a proof of concept on wildfire detection and monitoring

Alexandra Moutinho
IDMEC, Instituto Superior Técnico
Universidade de Lisboa
Lisbon, Portugal
alexandra.moutinho@tecnico.ulisboa.pt

Diogo Henriques
IDMEC, Instituto Superior Técnico
Universidade de Lisboa
Lisbon, Portugal
carlos.diogo@tecnico.ulisboa.pt

Nuno Ferreira
IDMEC, Instituto Superior Técnico
Universidade de Lisboa
Lisbon, Portugal
nuno.p.ferreira@tecnico.ulisboa.pt

Dário Silva
IDMEC, Instituto Superior Técnico
Universidade de Lisboa
Lisbon, Portugal
dario.silva@tecnico.ulisboa.pt

Miguel Almeida
ADAI, Mechanical Engineering Dep.
University of Coimbra
Coimbra, Portugal
miguelalmeida@adai.pt

***Abstract*—This paper demonstrates the use of high-altitude balloons for decision-support in emergency scenarios, providing a proof of concept for wildfire detection and monitoring. High-altitude balloons are compared against satellites and unmanned aerial vehicles as remote sensing platforms. A brief tutorial on planning and deployment of high-altitude balloons is provided before demonstrating these platforms capabilities as on-demand customizable satellites for monitoring from high altitude experimental burns that took place in Coentral, Coimbra, Portugal.**

***Index Terms*—high-altitude surveillance, remote sensing, customizable payload, on-demand satellite, rural fires**

I. Introduction

Wildfires are a recognized hazard, affecting people and infrastructures, gaining new dimensions and risks with climate changes. To minimize their propagation and consequent effects, the early detection of wildfires and the monitorization of their evolution are key actions that require access to informative, near real-time data. Other examples of emergency situations with widespread consequences that require timely and overarching data for decision-support of the operational teams are floods or earthquakes.

Satellites are recognized as the primary remote sensing tool for providing complete earth coverage over time and space, although with limited resolutions [1]. The different satellite constellations provide a broad range of measurements from multi- and hyperspectral cameras, radars, radiometers, and other earth observation sensors [2]. Although with an exhaustive list of sensors available, the satellites payload is not easily redefined, requiring a new satellite launch.

Unmanned aerial vehicles (UAVs) are a clear option to satellites when it comes to remote sensing [1]. Being highly maneuverable and accessible, they can survey any area at any time, providing data at good time and space resolutions. Their main drawbacks are the limited autonomy, which impacts on limited coverage and payload.

High-altitude balloons are an interesting complement to the previous solutions, ranging from costly platforms able to transport tons of payload [3] to disposable latex balloons with limited payload. With its ascent defined by its buoyancy, it can endure long missions with customized payloads, being able to provide from high resolution to wide coverage information. Its downside is its nonexistent, or very limited, controllability, being dragged by the prevailing winds, therefore requiring a careful planning of its mission to survey the relevant area. Table 1 resumes the comparison of these different platforms.

TABLE I
Comparison of remote sensing platforms
(+ good, □ not relevante or average, and − negative performance)

Metrics	Platforms		
	Satellite	UAV	High-altitude balloon
Spacial / temporal resolution	−	+	+
Controllability	□	+	−
Autonomy	+	−	+
Customization	−	+	+
Coverage	+	−	+
Cost	−	+	□

Given the benefits of high-altitude balloons, this paper addresses their use for decision-support in emergency scenarios, either for data acquisition or as communications relay, providing a tutorial for balloon launch planning and deployment, and a proof of concept in wildfire detection and monitoring.

In the remainder of this paper, section II addresses the planning and deployment phases of latex high-altitude balloons, while section III presents an example of the use of high-altitude balloons for detection and monitoring of wildfires, referring a test done during experimental burns. Finally, section IV closes with some final remarks.

II. Deploying high-altitude balloons

Latex balloons are used daily all over the world for meteorological sounding purposes. For this or other objectives, they are usually composed of (see Figure 3) a latex balloon filled with helium (or hydrogen in case of helium shortage), the payload – which may be separated in several boxes, and a parachute to reduce the descent rate of the payload after the balloon burst. A simple balloon has a constant ascent rate depending on its buoyancy (dependent of the helium used) and respective weight. After launch, it will continually ascend at a constant rate while expanding the latex due to reduced atmospheric pressure with increasing altitude. When the latex reaches its extension limit it will burst (see Figure 6) and start the descent phase. The maximum altitude reached will depend on the size of the latex balloon envelope used and the quantity of gas inflated, with the balloon being able to reach the stratosphere at around 35 km high, thus justifying the high-altitude denomination.

In the following, a simple tutorial is presented for the latex balloon planning and deployment launch phases towards a successful mission of a high-altitude balloon.

A. Planning

The planning phase comprehends the following tasks:

1) Define mission objective and balloon payload.
2) Apply for the necessary legal authorizations in time. E.g., in Europe, check the European Union Aviation Safety Agency (EASA) Balloon Rule Book.
3) Consider doing a civil liability insurance.
4) Use a latex balloon trajectory predictor (e.g. CUSF Predictor at predict.sondehub.org):
    a) Define launch site coordinates, and date and time of launch. One should remember that after the balloon falls, one still has to track the payload, based on the landing site prediction (the more accurate the data provided in the next step, the more accurate the prediction) and the last received payload position. This recovery may take some time, so it is important to consider this activity still in daylight.
    b) Define balloon flight parameters (e.g. ascent and descent rates, depending on payload and balloon masses and target burst altitude). One may use the Burst Calculator available in the Launch Card of the CUSF Predictor to compute these values, obtaining also the time to burst, the launch volume and neck lift. To compute the descent rate, one may use a Parachute Descent Rate Calculator, which requires a parachute model and the weight to be carried.
    c) Run the predictor and check the estimated balloon trajectory, point of burst and landing site. Confirm the landing site is not in a populated area or a hard to access region. One may export the data in kml format to see the trajectory with altitude profile in Google Earth, for example.
5) Check the weather conditions are appropriate for the launch date and the defined objectives.
6) Check the material list, e.g. latex balloon, helium, helium regulator, parachute, cord, polystyrene payload boxes to accommodate the payload, GPS trackers, communications (satellite, mobile, and/or radio) between balloon and a ground station, etc..

B. Deployment

The balloon deployment comprehends the following tasks:

1) If possible, prepare a flat, clean surface to inflate the balloon. The latex is quite sensitive, so it is important to make sure it does not get in contact with any rough edges.
2) Have the payload prepared to attach to the balloon when necessary.
3) Check the GPS fix, i.e., the GPS is receiving data from enough satellites and is able to determine and provide its location, and that the communications are working between payload and ground station.
4) Inflate the balloon with the volume defined in the planning stage. Preferably, one should use latex gloves when working with the balloon.
5) If required, contact the authorities to inform of expected time to launch and obtain clearance.
6) Attach the payload and the parachute to the balloon and confirm all is ready to launch.
7) Launch the balloon when ready.
8) Track the balloon coordinates on the ground station while approaching the predicted landing site.
9) Search and recover the payload in the end of mission.

III. Proof-of-concept: Coentral experimental burns

In order to demonstrate the capability of high-altitude balloons for wildfire detection and monitoring, we proposed ourselves to make a proof-of-concept in a challenging situation. Instead of demonstrating their benefits in a real wildfire scenario, we did a simple test in a very small scale, therefore more challenging, situation regarding experimental burns. The objective was twofold: i) to demonstrate that it is possible to launch an uncontrolled balloon, driven by forecasted winds, and guarantee that the balloon trajectory surveys a location of interest, and ii) obtain aerial images of the location of interest, in this case where the experimental burns took place, in Coentral, in the centre of Portugal, on May 15, 2020. Figure 1 provides an image of the experimental burns site, with some parcels already burned.

We followed the procedure described in section II-A and defined the location of launch to be in Coimbra, guaranteeing

Fig. 1. Experimental burns site at Coentral, Portugal.

the balloon would fly over the experimental burns site. The executed trajectory can be seen in Figure 2, confirming the success of the first objective. Nowadays the winds forecast is getting more and more reliable, so with accurate flight data inputs it is possible to estimate a fairly good trajectory of the balloon. Knowing the predicted trajectory tendency, and having a particular region where the balloon had to fly over, we run some simulations to determine the launch site, where several locations where possible depending on how high or low we wanted to fly over the experimental burns site. Launching from Coimbra, the balloon surveyed the experimental burns at around 8500 km altitude.

Fig. 2. High-altitude balloon trajectory in Coentral launch.

The balloon was launched with two separate payloads (see Figure 3). A smaller payload box (payload 1), located immediately bellow the parachute, contained a tracker, that sends GPS data using satellite communication. The second and larger box (payload 2) had the sensors payload, with a GoPro camera facing downwards, a particulate matter sensor, and an APRS (Automatic Packet Reporting System) communication link, also providing GPS coordinates. Redundancy regarding communications is an important factor to guarantee the recovery of the payload after landing. It is also important to guarantee the GPSs fix and that all communication links are being received by the ground station prior to launch. The GoPro camera was set in video mode and recorded during the complete flight. An example of the aerial view from the high-altitude balloon is given in Figure 4.

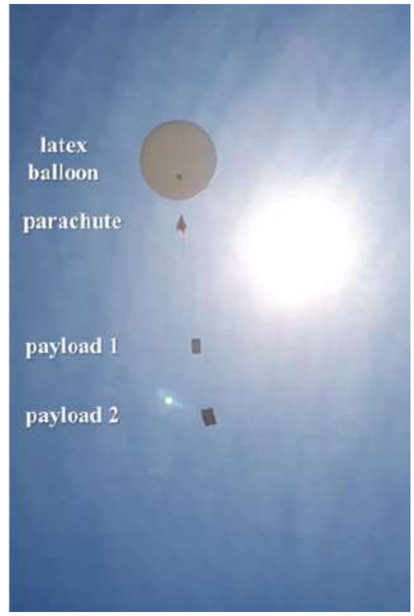

Fig. 3. High-altitude balloon launch and respective payload.

Fig. 4. Aerial image during balloon ascent.

The balloon flew over Coentral at around 8500 m, recording a small plume of smoke (see the image on the left of Figure 5). To confirm the smoke was indeed the result of the burning tests, we compared the aerial image with Copernicus Sentinel data, where the superposition of both demonstrated that the smoke indeed resulted from a hot source, represented by a small red dot (see the image on the right of Figure 5). Having decided on a closer launch site relative to the experimental burns location, the balloon would fly over the burns at a lower altitude, providing more detailed information. However, if one wants to have a broad view in case of an uncontrolled wildfire, altitude is key to achieve that goal.

The balloon continued its ascent until the altitude of 33700 m. At this point, the latex balloon had expanded to

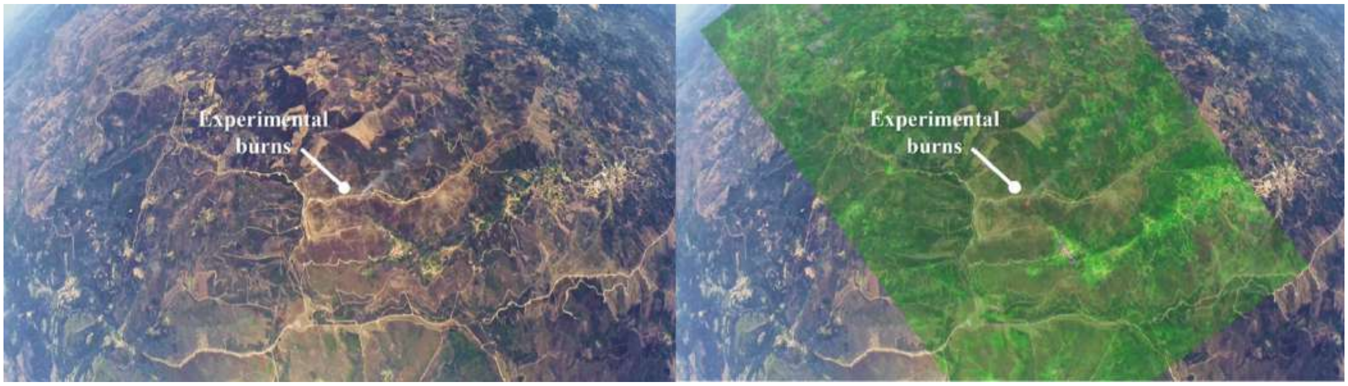

Fig. 5. Balloon aerial view over experimental burns at Coentral, on the 15th May, at 8500 m altitude (left) and Copernicus Sentinel-2 MultiSpectral Instrument data for the corresponding time, where the hot spot is clearly identified in the satellite data in red (right).

its limit, and the balloon bursts. This instant can be visualized in Figure 6, obtained in a previous flight when the payload had a camera facing upwards to capture this moment.

Fig. 6. Instant when the balloon starts bursting, having achieved its expansion limit.

An image captured shortly before the payload started its descent supported by the parachute may be seen in Figure 7. The limits of the Earth are clearly visible, as the high-altitude balloon is high in the stratosphere, providing a wide coverage aerial view, as a close to earth satellite would.

Fig. 7. Aerial image before balloon burst at 33700 m altitude.

During the flight the particulate matter sensor was also acquiring data, represented in the graphic in Figure 8. Although the sensor was not calibrated, and therefore the scale is not accurate, the spikes during the flight probably correspond to the experimental burns, and other eventual small fires occurring along the balloon flight path, demonstrating the ability of these platforms to acquire also atmospheric data, relevant for example in the Cumbre Vieja vulcanic eruption in December 2021 [4].

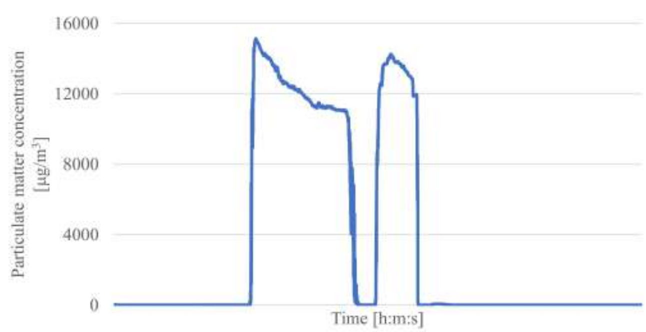

Fig. 8. Data obtained from particulate matter sensor during flight.

IV. Final Remarks

This paper contribution is twofold: i) to provide a simple tutorial for latex high-altitude balloons mission planning and deployment, and ii) to demonstrate their capability to serve as on-demand satellites in emergency situations, providing good coverage aerial imagery. A proof of concept was presented based on an experimental burns use case.

The results allowed to demonstrate the use of high altitude balloons for acquiring on-demand high-altitude information, which may prove critical in emergency situations. Another important contribution of these platforms in these scenarios is as communications relay. Being high in the air, and with extensive line-of-sight, the balloon may provide a communication link between communication shadowed regions, guaranteeing the operational teams on the ground may communicate between themselves and with the central command, or equivalently, serve as communication relay between a network of ground and/or aerial sensors.

ACKNOWLEDGMENTS

This work was financed by national funds through FCT – Fundação para a Ciência e Tecnologia, I.P., through IDMEC under project Eye in the Sky (PCIF/SSI/0103/2018), and through IDMEC under LAETA, project UIDB/50022/2020.

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