Ground and Flight Segment for tracking and transmissions for Stratospheric Balloons

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The growing increase in space missions mainly in small satellites directs the development of Ground Stations with the objective to serve as a Multi Mission Platform, configurable and capable to meet different missions and operations scenarios. When analyzing the global scenario, we observe that more and more missions are validated through stratospheric balloon flights, mainly due to the agility in the testing phase and the low cost compared to a space flight. On the other hand, there is still a gap in solutions for tracking and data acquisition. This project aims to present a model of stations that perform tracking and data collection of payloads shipped in Balloons. The proposed structure combines and applies different existing methods, generating a reliable system for receiving mission data. The proposed system consists of two modules: the Flight Segment and the Ground Segment. The flight segment is composed of a hardware and software subsystem including a Payload embedded in a Balloon, being responsible for sending data to the Ground Segment, using radiofrequency in the UHF band. The Ground Segment - Ground Station - proposed consists of an omnidirectional antenna, a rotator, directional antennas, a support, a hardware subsystem and a software-defined radio (SDR), in addition to a control, storage and user interface software. The main objective of this Ground Station is to receive, through the omnidirectional antenna, the data sent by the Flight Segment, demodulate and calculate, in real time, the azimuth and elevation values of the balloon. Thus, knowing the position of the balloon, the Ground Station can control its rotator to point the directional antennas, enabling the transfer of data, according to the balloon's mission. This article describes the development process of the two segments, considering the requirements, implementation, individual tests and subsystem integration, in addition to presenting the results and future work.

1. Introduction

We are witnessing a new space race, where we have a more accessible and cheaper space. This new space race, called New Space, has brought great revolutions, mainly in terms of cheaper launches [1]. As a result, we can observe a large increase in space missions, especially those of Small Satellites.

These small satellites have taken the lead in this more accessible space. Especially when we observe that most of these satellites are developed by schools and universities.

This work aims to present a solution to facilitate tests of nanosatellites or payloads at high altitudes using stratospheric balloons, mainly in the acquisition of data from these tests, we will present a system that can be embedded in balloons, allowing the tracking of these artifacts automatically.

2. Systems Engineering

As a starting point in the development of this research we carried out bibliographic studies to analyze missions that carry out tests of their satellites or payloads using stratospheric balloons. An example of the analyzed missions is the Raiosat [2]. After this analysis we made some correlations with the techniques currently used and we propose a solution that gives greater accuracy in the reception of mission data, especially those that have a high data rate, both shown in Figure 1a and Figure 1b.

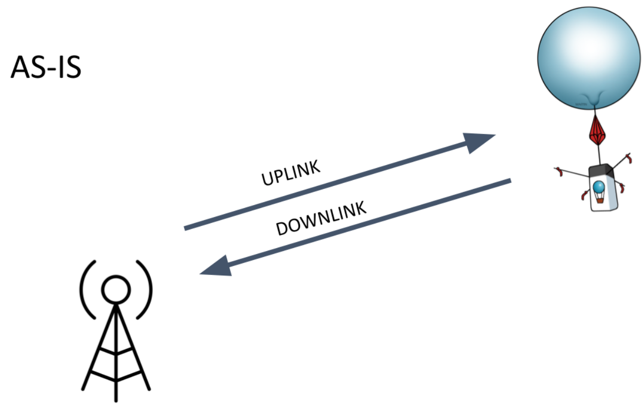


Figure 1a: How tracking is currently done.

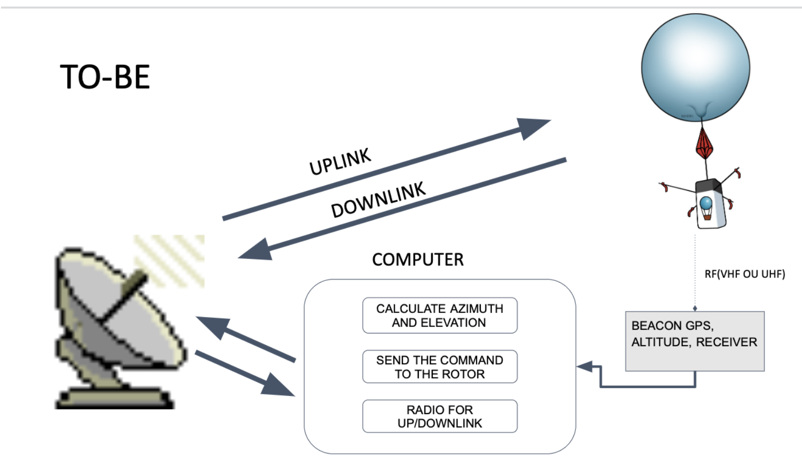


Figure 1b: First Idea of project.

From this analysis, it was then thought to develop a system divided into 3 parts: (1) the Ground Segment requirements, as shown in Table 1; (2) the Flight Segment requirements in Table 2; and (3) the Control Interface as shown in Table 3. From the definition of these three segments, requirements were raised to be met within the development of the project:

Table 1: Ground Segment Requirements.

ID	System Requirements.
RGS.1	Perform Balloon and Satellite Tracking.
RGS.2	Be a low-cost platform.
RGS.3	Possess easy adaptation for different types of mission.

Table 2: Flight Segment Requirements.

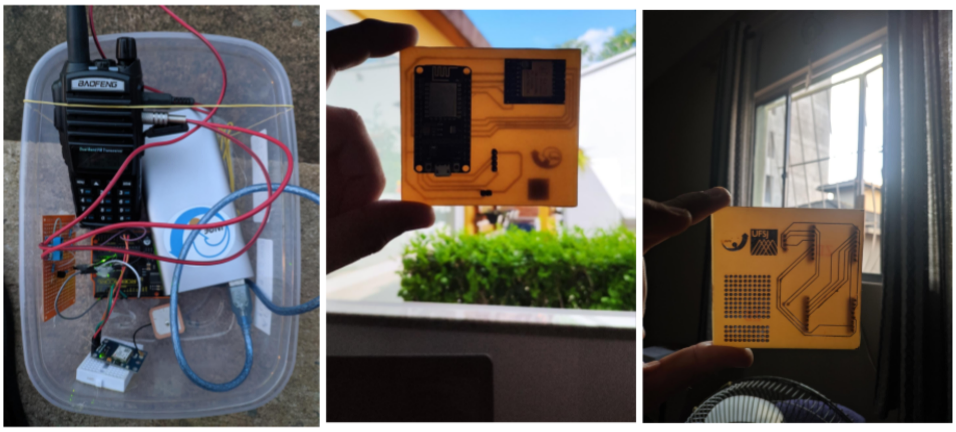
ID	System Requirements.
RFS.1	Have at least 90% off-the-shelf components.
RFS.2	Ability to send programmed beacons.
RFS.3	It has modularity for different types of mission.

Table 3: Control Interface Requirements.

ID	System Requirements.
RCI.1	Ability to perform azimuth and elevation calculations of the flight segment.
RCI.2	Ability to carry out the control of different types of rotators automatically.
RCI.3	Easy integration with different rotators.

3. Development

Based on the requirements raised, the development process of the three segments was initiated, starting with the Flight Segment. This segment is composed of the hardware and software that will be embedded onto the balloon. This segment is responsible for sending in real time the data needed to carry out the tracking of the balloon. As stated in section 2, the system has some requirements that were used during the development of the prototypes. In total, the team developed 7 hardware versions. Figure 2 shows some of the versions developed.



Version 1.0 | Version 2.0 | Version 3.0

Figure 2: Project Versions.

As version 3.2 is the latest and most robust version. We chose to present it in more detail. The Flight Segment was designed to operate independently of the Stratospheric Balloon, thus giving more autonomy to the system. The version 3.2 is composed of the following components, show in table 4:

Table 4: Components list.

Components.	Quantity
Lolin D1 Mini V4.0.0 Wemos Esp8266	01
SX1278 LoRa 433MHz Ra-02 Breakout Board	01
NEO-6M GPS Module	01

Following choosing the components, the printed circuit board was developed. Which is responsible for integrating the components, on figure 3 show.

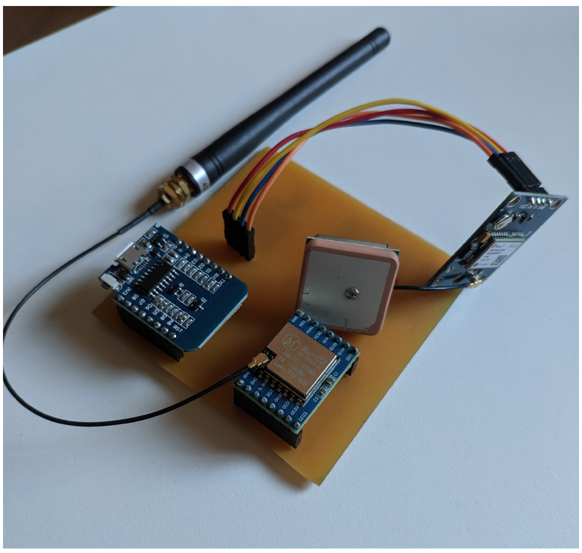


Figure 3: PCB and Components Flight Segment Version 3.2.

After the integration of the components, the development of the software was carried out, which was embedded in the Flight Segment hardware. This software was developed using the Arduino IDE platform [3], in its first version the system was able to send via RF (Radio Frequency) its location and altitude data.

Afterwards some analysis, we developed version 2.0 of the software, where we chose to add some more data needed for tracking. The final format of the packets is shown in Figure 4.

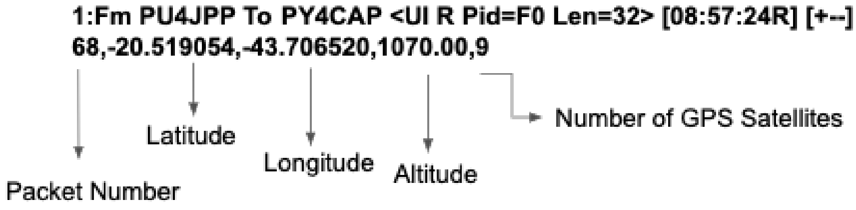


Figure 4: Packets data.

The control interface was developed to serve as an interface between the flight segment and the rotator. Being able to process the data received from the flight segment this data is used to calculate the azimuth and elevation that the rotator needs to point the antenna to downlink the data.

To calculate the azimuth, we use Haversine's Theorem, and to calculate the elevation we used as a basis the calculations performed by the Project Horus that are available on the Project's GitHub [4]. Following the calculation of the data necessary for the control of the rotator, the development of the control function was carried out.

This function has the objective to send the azimuth and elevation data via serial to the rotator connected to the control interface.

Another part that was developed by the team was Ground Segment. This segment is responsible for receiving and sending data to the balloon and its payloads on board, the system developed is composed of the following components: omnidirectional antenna, rotator, SDR (Software Defined Radio) and directional antennas.

The first components to be developed were the omnidirectional antenna and the balloon data reception system. As the flight segment sends a low amount of data, we chose to use a ground plane antenna, due to the low complexity and excellent performance in signal receptions using LoRa. To do the data decoding we developed a receiver which is responsible for sending the received from the flight segment to data to the control interface.

For the development of the rotator, it was decided to use an open-source system from SatNOGS [5], more specifically the 2.0 version of the hardware.

To assemble the system, we carry out some changes in the project to adapt the rotator to the realities of Brazil and the needs of the project. With the integrated system, as shown in Figure 6, we carried out some validations. The main validation was the tracking and reception of telemetry from the Alfacrux Satellite [6][7].

Figure 6: Ground Segment.

4. Tests

In this section we will present some tests and results obtained from this work. The first system tested and to have its validation performed was the control interface. To carry out the validation, we used data of stratospheric balloons collected by the SondeHub platform [8].

Following download of the flight data, we simulate the reception, treatment, calculations and finally the commands sent to the rotator. With this test we were able to validate the control interface and the communication with the rotator.

Then, the test was carried out to validate the reception of the data from the flight segment. Since the purpose of this test was to verify the behavior of the flight segment, we chose to use a drone in this testing phase, with 9 flights carried out. To analyze the data received, we plotted the points collected using Google Earth, as shown in the figure 7.

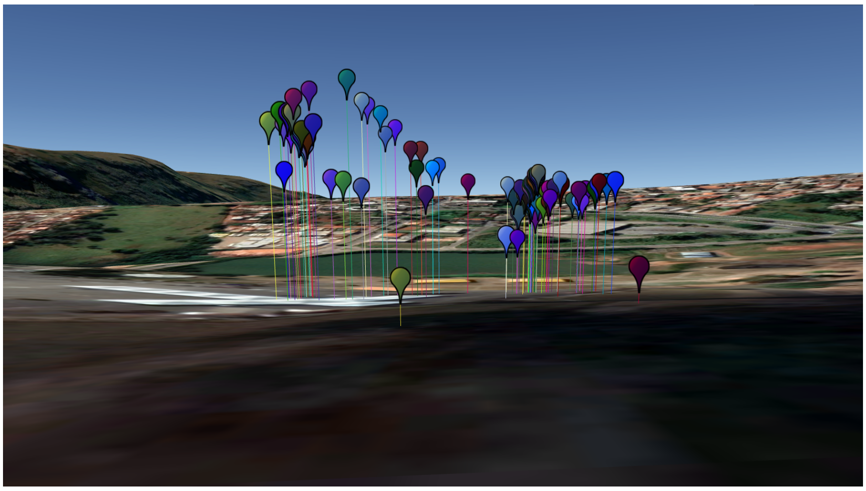


Figure 7: Flight Segment Validation

With all the parts that make up the system tested separately, we moved on to the most important test of our research: testing all three systems integrated and working together. A total of 6 flights were performed with all the integrated systems, as shown in figure 8. In this image we can see the integrated systems and the drone flying, carrying the flight segment.

Figure 8: Flight test with all integrated systems

After the flights, we can observe some problems that were not observed in the bench tests, such as the packet transmission time and the altitude variation collected by the GPS. This altitude variation can be compared from the data collected by the altimeter embedded in the drone. It is worth mentioning that for the next versions an altimeter will be added in our flight segment, to have greater accuracy with the altitude data.

5. Conclusions and Future Works

As presented at the beginning of the work, the objective of the project was to develop a tracking system for stratospheric balloons, mainly to help in collecting data from the payloads embedded in them. For this, we developed the flight segment, the control interface and the ground segment, which, when operated together, have the advantage of providing greater precision in pointing antennas for the reception of telemetry and sending telecommands for the payloads on board the balloons.

We can also highlight that this first phase of development fulfilled all the requirements presented in section 2, giving us the green light to develop the engineering model of our project. To then prepare the flight segment for the launch campaign where the system will be boarded in a stratospheric balloon. This launch is being organized by the National Institute for Space Research (INPE) which has a plan to carry out 3 launches of stratospheric balloons by the end of 2022.

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