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Modeling of the Meteorological Balloon-Cube with LoRa-Based Ground Station

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Abstract. Every day 80,000 weather balloons are launched to the Earth's upper atmosphere with meteorology payloads to provide accurate meteorological data. Meteorological data could be used for airport stations and weather stations. Meanwhile, there are many remote sensing satellites above the Earth’s atmosphere, but balloons are still essential due to increased weather prediction accuracy. Many balloons launch into the atmosphere daily, but it would be a one trip tripe because this balloon goes to the atmosphere then transmits the meteorological data to the ground segment, and that is all no one looks to recycle it, on the other hand, if the balloon could be recycled there would be many financial benefits. This project presents a high altitude meteorological balloon-Cube relative to measuring atmosphere humidity, temperature, air pressure, and a photography payload for surface imaging that ascended up to 20Km altitude Cube reach this altitude will eject box on the ground. The telemetry data are transmitted to the ground station through two communication applications, first using a LoRa based transceiver at which it receives a command from the LoRa ground station and the second one, and payload transmits the data by an SMS in 5min after it lands on the ground. Therefore, it could be recycled. This paper presents a Cube-Balloon fabrication and flight test information to acknowledge this Cube's feasibility for real meteorological projects.

Keywords: weather balloon, space education, CubeSat, communication, recyclable balloon.

1 Introduction

Meteorology balloons are usually launched into high upper atmosphere altitudes. They transport scientific payloads to 40 km altitude. Every day 80,000 meteorological weather balloons are launched at 00:00 GMT and 12:00 GMT in different locations across the universe. The activities provide a snapshot of our upper atmosphere two times a day [1]. Meanwhile, we have the satellite observe the Earth and give us enough information about our atmosphere, but we still need a meteorological balloon to have high-quality pictures, a wider angle of view of the Earth’s surface meteorological data. Also, the cost of meteorological balloons is less than remote sensing satellites. Depending on their missions and weight, sounding balloons could ascend and descend freely without human effect or could be by a ground segment command. Balloons applications are very diverse, from remote sensing photography missions to meteorological weather balloons. Even in emergencies, balloons act as an air-based communication relay for distributing the internet into rural/ urban areas [2]. Weather balloons could be utilized for senior students' final projects and educate them by implementing metrological balloons from primary concepts until a ready-to-flight fabricated model and preparing them for industry and faculty [3]. Balloons in stratospheric layers migrate by wind velocity. This speed can affect the horizontal balloon coordinate; meanwhile, the attitude directions are essential in missions. Integration population is one of the significant problems of balloon’s attitude to the desired direction, which is investigated at [4]. This article presents a meteorological weather balloon with photography payloads, this high altitude balloon flights maximum to 20 km and measure data of atmosphere’s pressure, humidity, temperature and magnetic fields directions, at which the balloon reach 20 km altitude the payload automatically inject the balloon and descend with on the ground by its parachute.

The camera is faced to the ground and record video to check the performance of the balloon's ejection mechanism. Whenever the balloon landed, an SMS consisting of the payload location will send to an adjusted phone number. Another communication link is by the LoRa-based transceiver, which receives a command from the ground segment. The payload replies back with a massage about balloon location and the meteorological sensors data. On previous weather balloons, the balloons launch to the atmosphere and send back weather data, and most of them do not have a backup system to find it after the balloon is landed. This paper aims to design and fabricate a low price weather balloon with a backup system that it will send an SMS to its operator after it lands; therefore, the balloon can be used several times and presents financial beneficiaries. This first section presents every module's system technical details and function until the fabrication of the components on the flight model PCB board. The second section presents the balloon operation out of the laboratory environment when it carries with a helium balloon and drives until 20 km distance then stops in this case if the board is operating functionality then an SMS must send to its destiny. The sensors data are illustrated in figures. The results verify that the balloon is ready for meteorological stations.

2 Research Methodology

2.1 System conceptual design

Balloon weather requires to design accurately since the balloon would be out of access when it launches into the atmosphere. Therefore it is a sensitive design. For example, if EPS is not chosen to provide enough power during flight and landed time, the payload would be lost and cannot be recycled by its operators. The weather balloon does not have a complex subsystem such as a satellite, the most vital subsystems would be TTC and EPS subsystem and rest subsystems. Their sensitivity could be ignored. For example, for structure, a simple MDF box can be utilized. This system contains four PCB layers, EPS, MCU and sensors layer, TTC layer, and the camera layer, respectively, connected through a 1x40 pin header.

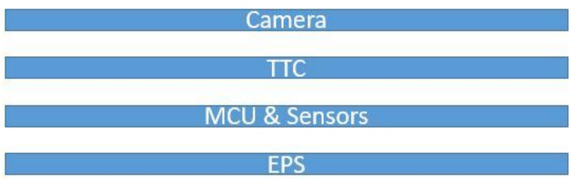

Figure 1 – Balloon’s layers sketch

EPS design: the power subsystem only uses the batteries as a power generator, and there would not be any solar panels. The battery must prepare enough power to keep the whole system functional during the flight and landed, phased to accomplish the meteorological mission and capability to stay active, when it descends on the ground and start to send its location to its operator to be able to find the payload and recycle it. Additionally, all subsystems measure atmospheric data continually. The camera uses an internal battery, which would be enough for 1-hour flight recording. Table 1 shows the power budget [5].

Table 1 – Power budget

Element	*V*, V	*I*, mA	*Qty*	*P*, mW
mega2560	5.0	13	1	65.0
DHT11	3.3	0.5	3	1.65
MPU5060	5.0	0.1	1	0.50
BMP180	3.3	0.065	1	0.20
SIM808	5.0	500	1	2500
LoRa	3.3	120	1	100
Total usage	–	633.7 mAh	–	2.7 Wh

According to Table 1, the total power consumptions are 2667.35 mWh with 633.665 mAh. The selected batteries are three Li-ion batteries with 2200mAh capacity, which would be estimated to keep the system active for 12 hours, which is appropriate for the duration of flight and recycling phases of the Cube.

TTC design: The balloon transmits the atmospheric data through a LoRa based UHF transceiver. It could receive commands from its ground station and restart if any emergency circumstances happen. This balloon ascends a maximum of 20 km. Therefore the maximum distance must be insurance that the ground segment can have the communication link at the critical altitude. Logically the link budget calculations specifically whether the hardware are reliable or must replace with another higher power transmitter [6]. We can calculate the link budget with a particular formula that appears in:

$$SNR_{dB} = P_{t,dBm} - 30 + G_{t,dBi} + G_{r,dBi} - L_{p,dB} - 10\log_{10} k - 10\log_{T_s} 10 - 10\log_{10} R \qquad (1)$$

Based on formula (1), the margin would be 30 dB for 20 km altitude. Additionally, the LoRa module has already been implemented on a Low Earth Orbit small satellite, and it had 5 dB margin for 500 km altitude. Hence, it was already doable, and the calculations assure the hardware characteristics [7].

2.2 Balloon detail design

In previous sections, we discussed the conceptual design and vital subsystems that t Followed section emphasizes the balloon’s hardware fabrications and functions. As is illustrated before, the balloon contains four PCBs layers, EPS, MCU, TTC, and camera, respectively.

EPS: Electrical subsystem contains 3 Li-ion 2200 mAh batteries with a simple power bank module to accumulate with batteries and charges them before the flight. This layer is illustrated in Fig. 2.

Figure 2 – Electrical subsystem fabricated circuit

Lithium polymer batteries could be this project, but since this power bank module is very adaptive with Li-ion batteries, the ion batteries were chosen and reduced the electrical subsystem's complexity.

MCU: MCU layer contains the weather measurement sensors, SD card for saving the data, Atmega2560 as a microcontroller, two 5V relies upon external ejection payloads based on ground commands or automatically if needed in future projects, buzzer to spread noises and LEDs to blink when it lands on ground to convince recycling phase of the balloon. See fig. 3.

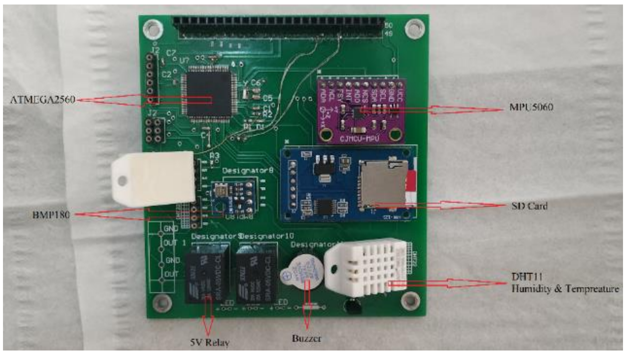

Figure 3 – Main computer and measurement sensors PCB board

TTC: LoRa and SIM808 modules operate as telemetry tracking and command subsystem. The LoRa transfer the location data and altitude through UHF frequency into the handset ground station. See fig.4.

There would be the possibility of losing the communication link due to many noises and physical barriers such as mountain or long trees. Hence SIM808 performs as a backup radio subsystem and sends an SMS with the only location data to a predefined phone number. Whenever the operator sends a massage titled “Location”, it replies back with location data. Meanwhile, SIM808 sends SMS location data when it lands.

Camera: CMUCAM4 is an Arduino-based camera, low power consumer and lightweight, which in robotic systems operates for image processing and can track objects with a uniform color, meanwhile many options that this camera services it would be only used for recording videos while the balloon-Cube is on the atmosphere.

Figure 4 – SIM808 and LoRa module PCB board

Figure 5 – CMUCAM4 the camera

All subsystem design and fabricated is the time to integrate the PCBs referenced to the layout and integrity test performed. Whenever the system integrated must stay active for around 12hours and transmit location and altitude data to the ground segment every 1min through the UHF transmitter and SMS location every 5 min. Additionally, the local environment data such as temperature, humidity, pressure, and altitude save into the SD card. Hence the SD card has essential functionality [9].

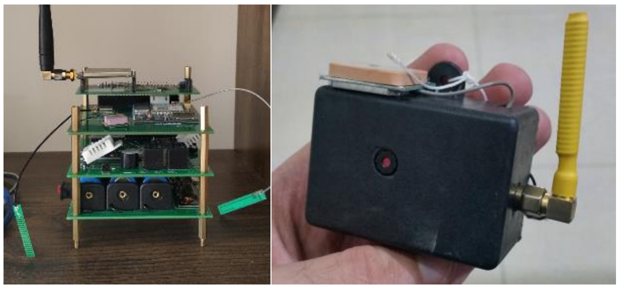

Figure 6 – Integrated balloon-cube (left) handset ground segment (right)

3 Results

Balloon-Cube is ready for flight and trial its capability to be utilized as a recyclable metrological weather balloon. The Cube occupied inside an MDF box then with Mountaineering ropes knot with a helium balloon, the parachute stick on the top of the box freely because its small size would not create disturbance to the flight dynamic. Since the Cube is fixed inside the box, several commands send to the Cube to manipulate malfunctioning to identify any error. Subsequently, when the Cube passes before the flight test, the balloon release into the atmosphere to accomplish the weather measurement mission.

Figure 7 – Balloon-cube on the flight condition

The Cube transmits the Location data by UHF transmitter to track the balloon route and landing location, and if the link is lost, the SIM808 module sends SMS to the operators. In the end, the mission conclusions have been illustrated in Fig. 8 and Fig. 9.

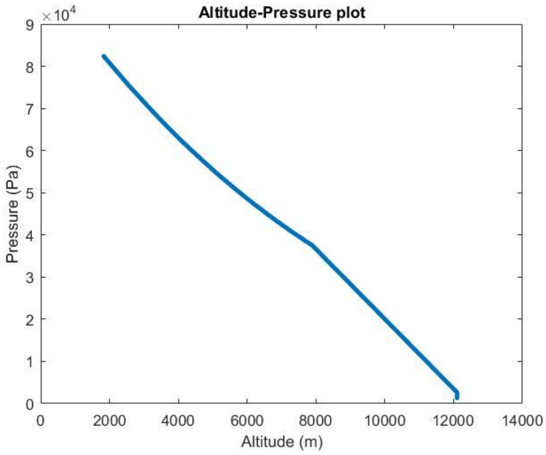

Figure 8 – Altitude-pressure plot

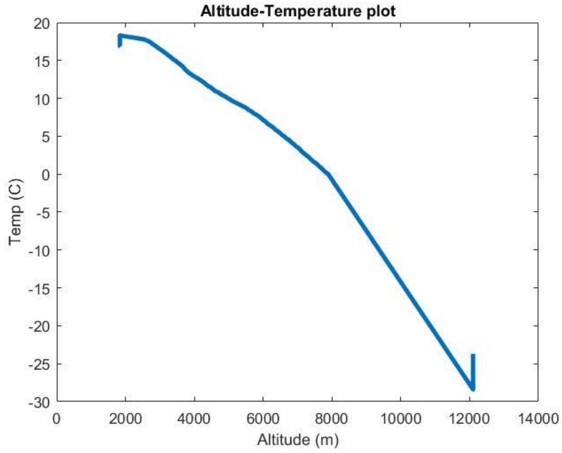

Figure 9 – Altitude-Temperature Plot

4 Conclusions

This paper presents a low-price recyclable weather Cube-balloon from the designing stage until fabrication and flight test data sample to verify this Cube's feasibility for meteoroidal weather report stations. In the figures, we can see the temperature and pressure changes based on the altitude. This experimental procedure shows the functionality of the used sensors of this project. Those low price sensors reduce the price of a weather balloon to less than 200 USD.

The Cube could be recycled, which means it flights, measures atmospheric data, lands, and sends location data. Logically, the Cube could be found and prepare for the subsequent missions. Recycling the balloon weather would reduce the expenses of weather monitoring. Making this Cube on different four-layer gives this capacity to either implement new missions or change some subsystem. Subsequently, it does not require redesigning the system. Only designing a new layer would be enough. There are still some non-connected pins that make the system flexible for new future needed missions.

This Cube can also be utilized as an educational instrument to teach young space students about CubeSat and small satellite because the Cube-balloon design is similar to a CubeSat design and fabrication, the Cube-balloon has 1U CubeSat size and weight.

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