# CAPÍTULO 04

## STRATEGIES TO REDUCE POWER CONSUMPTION IN PICO-SATELLITES

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**ABSTRACT:** To assess and rehabilitate degraded forests are global challenges. Due to the various causes and severity of degradation, they typically show a very diverse structure, which makes acquiring a detailed inventory, as a first step toward rehabilitation measures, difficult and costly. Area-based inventories based on satellite imagery are a well-established methodology to assess and classify the forest cover, but the information obtained is often not detailed enough to fulfil the needs of site-adapted rehabilitation in degraded forests with a highly diverse structure. Furthermore, due to the great variability of the forest structure, a great number of ground sample plots are necessary to establish statistically sound predictions of structural parameters. We propose to test a real mission in Azores Island, based on the typical pico-satellites architectures, after provide some strategies to create a new architecture design and predict power consumption, based on the sentences of low-power, very small scale, low-cost and very integrated system.

**KEYWORDS:** Pico-Satellites; Reduce Power Consumption; ESP32, Raspberry Pi; Microcontrollers; Very Small Scale; Low-Power; Soc; Predictive Model; Data Mining.

**RESUMO:** Avaliar e reabilitar florestas degradadas são desafios globais. Devido às várias causas e à gravidade da degradação, elas geralmente apresentam uma estrutura muito diversificada, o que torna difícil e dispendiosa a aquisição de um inventário detalhado, como primeira etapa para as medidas de reabilitação. Os inventários por área baseados em imagens de satélite são uma metodologia bem estabelecida para avaliar e classificar a cobertura florestal, mas as informações obtidas geralmente não são detalhadas o suficiente para atender às necessidades de reabilitação adaptada ao local em florestas degradadas com uma estrutura altamente diversificada. Além disso, devido à grande variabilidade da estrutura da floresta, é necessário um grande número de parcelas de amostragem no solo para estabelecer previsões estatisticamente sólidas dos parâmetros estruturais. Propomos testar uma missão real na Ilha dos Açores, com base nas arquiteturas típicas de picosatélites, depois de fornecer algumas estratégias para criar um novo projeto de arquitetura e prever o consumo de energia, com base nas frases de sistema de baixa potência, escala muito pequena, baixo custo e muito integrado.

**PALAVRAS-CHAVE:** Pico-Satélites; Redução Do Consumo De Energia; ESP32; Raspberry Pi; Microcontroladores; Escala Muito Pequena; Baixo Consumo De Energia; Soc; Modelo Preditivo; Mineração De Dados.

## 1. INTRODUCTION

New technologies, such as Unmanned Aerial Vehicles (UAV) or balloons or pico-satellite – CANSAT missions, allow the acquisition of detailed images, but until now they are mostly used to estimate forest attributes only in small scale applications, and if a precise Digital Terrain Model (DTM) is available, since optical sensors cannot sense terrain under dense canopy covers. However, the frequent canopy gaps on degraded forests would allow the partial assessment of the terrain, and the combination of wall-to-wall satellite imagery with partial cover UAV imagery would allow larger scale inventories of acceptable accuracy and reliability without the need for an increased number of ground sample plots. Another fundamental part is integrate radio communications part in UAV, balloons like it use in pico-satellites, so it means that not only the process to put in the air and stay (UAV, balloons or pico-satellites) to covered some area is important, but also the capacity to communicate to the ground or between the “air devices” and Internet of Thing (IoT) all the conditions to be integrated in that devices using standard cellular radio technology like 3rd Generation Partnership Project (3GPP). Recognizing the importance of IoT, 3GPP has introduced a number of key features for IoT in its latest release, Rel-13. EC-GSM-IoT [1] and LTE-MTC [2] aim to enhance existing Global System for Mobile Communications (GSM) [3] and Long-Term Evolution (LTE) [4] networks, respectively, for better serving IoT use cases. Coverage extension, complexity reduction in the devices, long battery lifetime, and backward compatibility are common objectives. A third track, Narrowband Internet of Things (NB-IoT) [5], shares these objectives as well. In addition, NB-IoT aims to offer deployment flexibility allowing an operator to introduce NB-IoT using a small portion of its existing available spectrum. NB-IoT is designed mainly targeting ultra-low-end IoT applications. NB-IoT is a new 3GPP radio-access technology in the sense that it is not fully backward compatible with existing 3GPP devices. In this paper we present results about a real mission, based on CANSAT concept, in Santa Maria Island in Azores and we discuss about other new technologies focus on low-power, low-cost, very small scale and technologies that support reconfigurable part to give more modularity in the hardware and a very integrated.

## 2. SYSTEM ARCHITECTURE

The CANSAT (satellite shaped tin) is a functional model of a pico-satellite, in that all electronics systems are integrated into the volume of a soda can. It is launched by a rocket to a predefined altitude (1000 meters) so that during the descent is possible to carry out a scientific experiment, to capture the emitted signals (telemetry) and ensure a safe landing. So, the CANSAT Portugal is an educational project of ESERO Portugal, organized by the European Space Agency (ESA). This initiative enables the design and build a functional model of a pico-satellite whose base systems (antenna, battery and sensors) will have to be integrated in a volume equivalent to a can of refrigerant, this model has two missions, where the primary mission is measurement of air temperature, atmospheric pressure and altitude during the descendent and transmit the parameters to an earth station, using radio communications 433MHz. The secondary mission is to obtaina 3D ground mapping of the surface of Santa Maria Island in Azores. We also associate,in each photo, data coming from the GPS signal (Latitude, Longitude Altitude, Speed and Time), atmospheric pressure and temperature sensor. So, our 3D mapping is not onlybased on images, latitude altitude and longitude, as the common 3D mapping. To do that task, we include two 8M pixels RGB cameras in the satellite to take, simultaneously, photos. The cameras are in different places on the can, one in front and other on the downside of the can. The gold of this scientific mission (secondary mission) was using the parameters described previously, we intend to analyze: the relief, biodiversity and itsfauna and flora. This knowledge helps in deforestation, species control and terrain mapping with the intention of inspect regularly and using an easy way, like our secondarymission. The project is directed to the environmental aspect in order to take care of the ecosystem of the Island of Santa Maria in Azores.

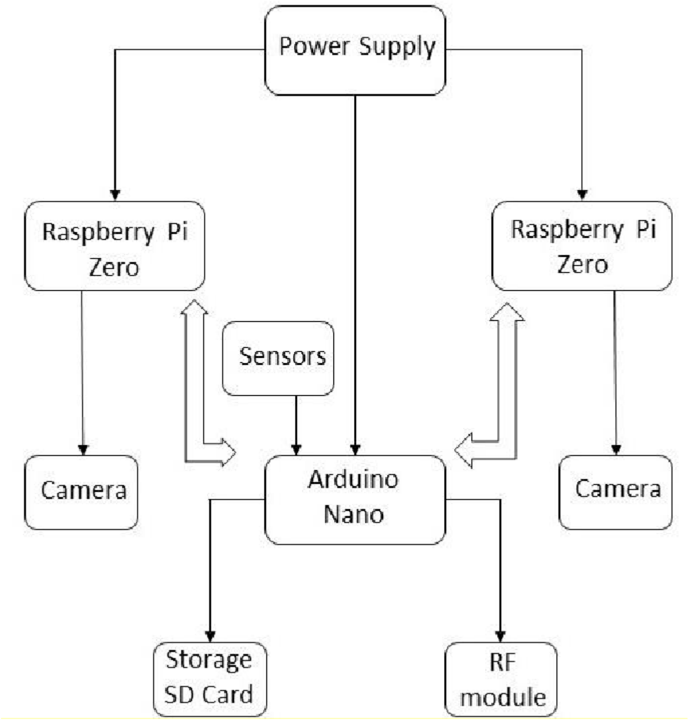
This kind of mapping can also be helpful to the forestry supervision. With detailed maps, illegal logging can be detected and tracked, tree count can be determined, and the health of the forest can be monitored. With this data, they can effectively distribute theirresources for a timely response. The system architecture, present in Figure 1, consists oftwo raspberry pi zero with two cameras in each responsible for video and photos acquisition. The system includes a microcontroller, Arduino Nano, for data acquisition from sensors (altitude, pressure and temperature). All data collected are stored in SD card.Microcontroller is responsible for RF communication at 433MHz to the ground station. This system have the following technical aspects: radio transmission rate for data collected from sensors, 19200 bps and 15 imagens per second, stored in SD card forraspberries. The total consumption is 523 mA, the details are present in Table 1.

**Table 1.** Total consumption.

| | |
|---|---|
| Radio 433 MHz | 42 mA |
| Sensor: BMP280 | < 1mA |
| Arduino plus SD card | 140 mA |
| Two raspberries plus SD card | 240 mA |
| Two cameras | 100 mA |

We use 9V DC batteries for power supply of the pico-satellite. This is also alimitation of this system because we don’t optimize the space inside the can.

**Figure 1.** System architecture.




## 3. CASE STUDY - 3D GROUND MAPPING THE SURFACE OF SANTA MARIA ISLAND – AZORES

We test in Azores Island this mission, our pico-satellite is launched using a rocket, 1 km. and we have the following results, present in Figures 2, 3 and 4.

**Figure 2.** Pressure and Temperature during the mission.

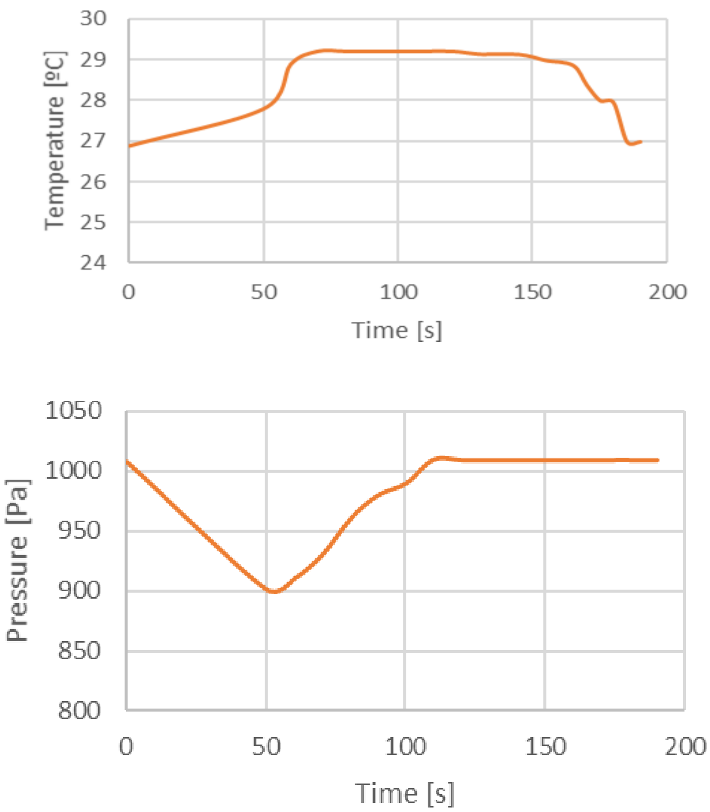
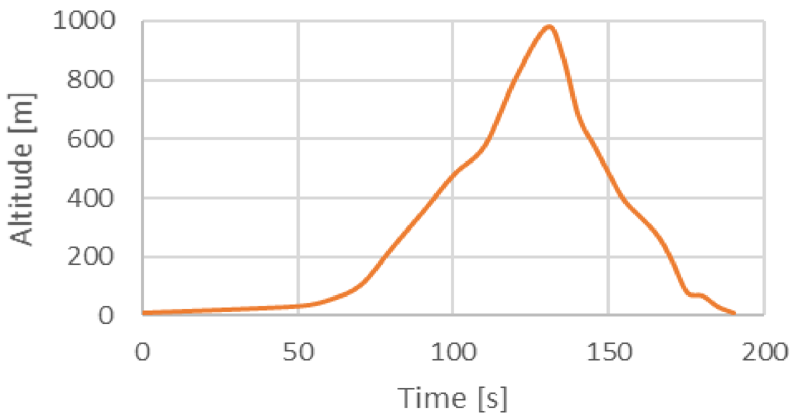
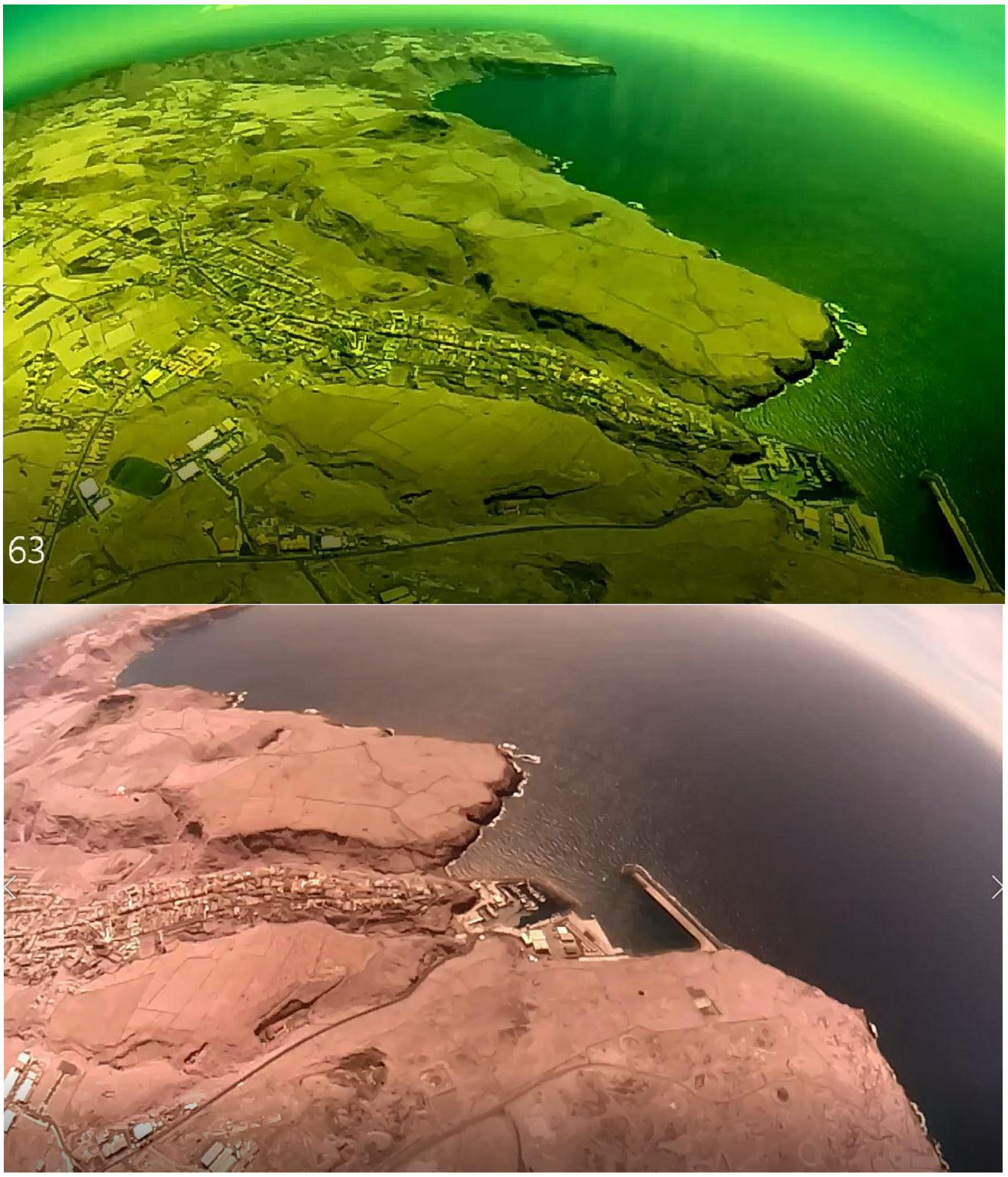



**Figure 3.** Altitude during the mission.




CANSAT launch and descent is 200 seconds as we can see in the Figures 2 and 3. In Figure 3, is possible to see the major altitude of 1 km and the time of descent, 75 seconds. The transmission radio was aproximately 200 seconds, but only 75 seconds is need because the of 125 seconds the pico-satellite is inside the rocket. So based on this aspect we can develop another approach to focus only in this 75 seconds to transmit in real time photos and data from sensors. Another important aspect is trying to reduce the power consumption of the pico-satellite, based on the integration of hardware.

**Figure 4.** Photos of the Santa Maria Island

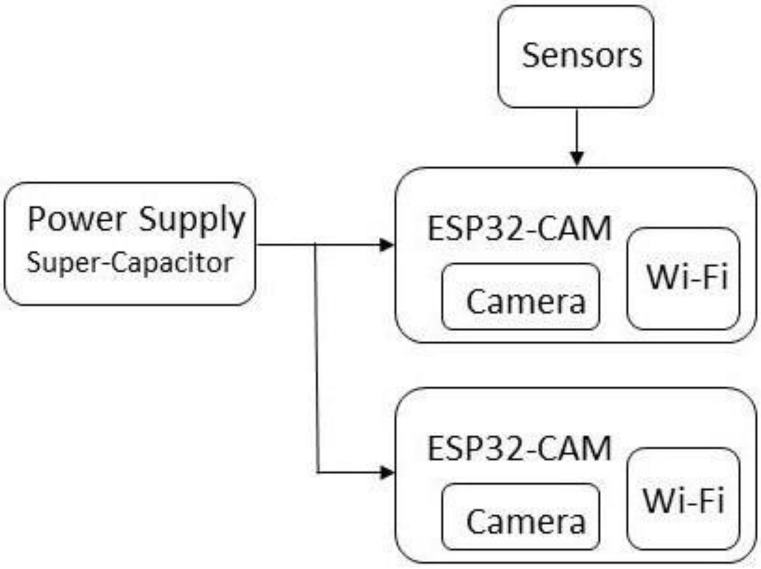



So, our new objective is proposing a new data rate of transmission changing the radio interface, more integration of all hardware, reduce power consumption and the scale of the pico-satellite.

## 4. NEW HARDWARE DESIGN OF PICO-SATELLITE

This new design consists in two ESP32-CAM with 4 MB memory, 160 MHz of clock frequency, camera interface inside and Wi-Fi communication – 2.4 GHz, the sensors used is the same, BMP280.

**Figure 5.** New System Architecture




Using ESP 32 it's possible to change de Tx power consumption, impossible to change using the previous RF module. Now we change to 1 mW Tx power consumption using 802.11b with a transmission rate of 1 Mbps and a power consumption of 310 mA with the flash lamp turn on. Reduced to half with flash lamp turn off. So, with this new design based on SoC module (ESP32-CAM), we reduce approximately 67% of the power consumption and also the size of the hardware, very important to fit inside the can.

We tested the new system architecture in laboratory and after we launched pico-satellite from a building at an altitude of 110 m. Radio was completely satisfactory because we got all data before, during and after the launch of the pico-satellite. The pressure vs time graphic is shown in Figure 6, pressure is calculated every second during the falling motion (at time=0s the pico-satellite was throw from the building, while t=34sis landing time). The measurements with the temperature sensor showed an excellent accuracy too (Figure 7). We know that in normal conditions temperature decreases with the increasing of altitude.

**Figure 6.** Pressure during descendent

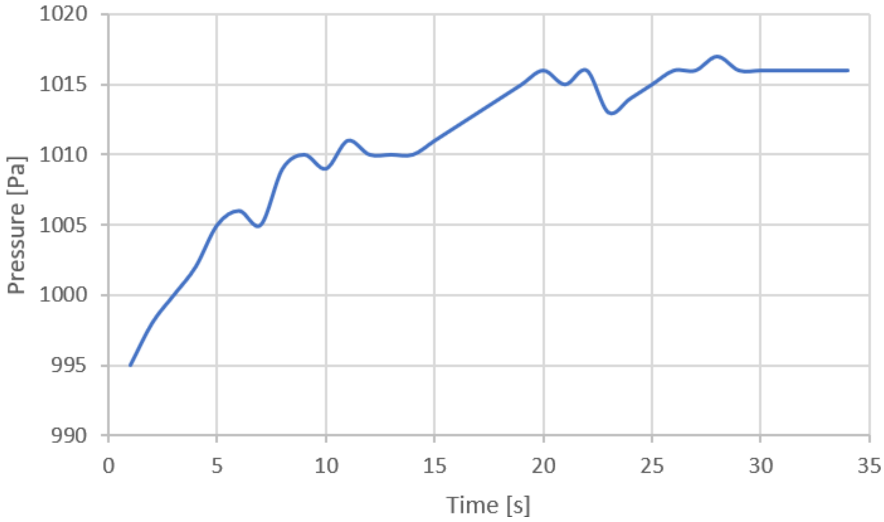



**Figure 7.** Temperature during descendent

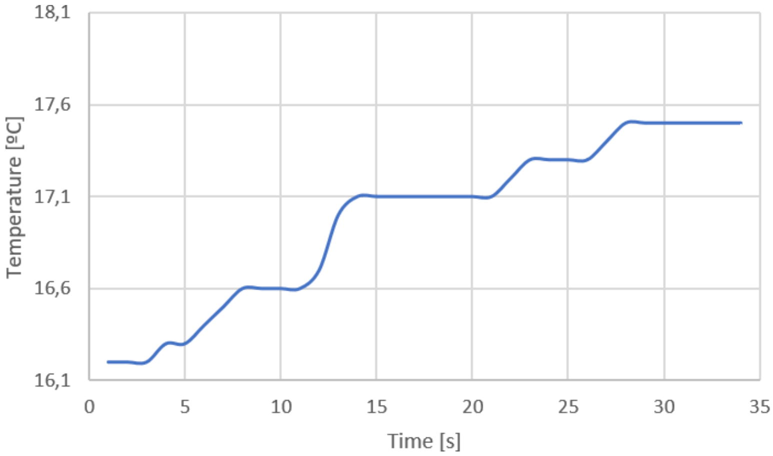
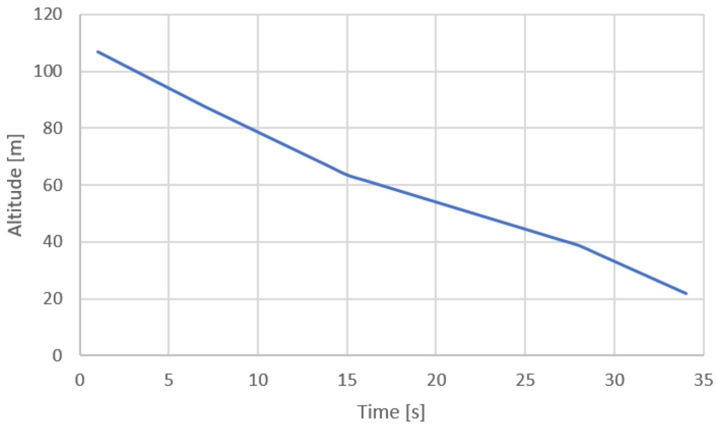



**Figure 8.** Altitude during descendent



## 5. PREDICTIVE MODEL FOR POWER CONSUMPTION

Based on the results in laboratory and the launch of the new pico-satellite design we try to find the best capacitance for the super-capacitor. Power consumption, P is givenby:

$$P = V \cdot I \qquad (1)$$

where V is power supply of the pico-satellite in V and I, current consumed in mA. Energy, W in J, is given by:

$$W = P \cdot t \qquad (2)$$

where t in the descendent time of the pico-satellite in seconds and also

$$W = \frac{1}{2} \cdot C \cdot V^2 \qquad (3)$$

where C is the capacitance of the super capacitor in F. If we related (1), (2) and (3), it can be obtained (4),

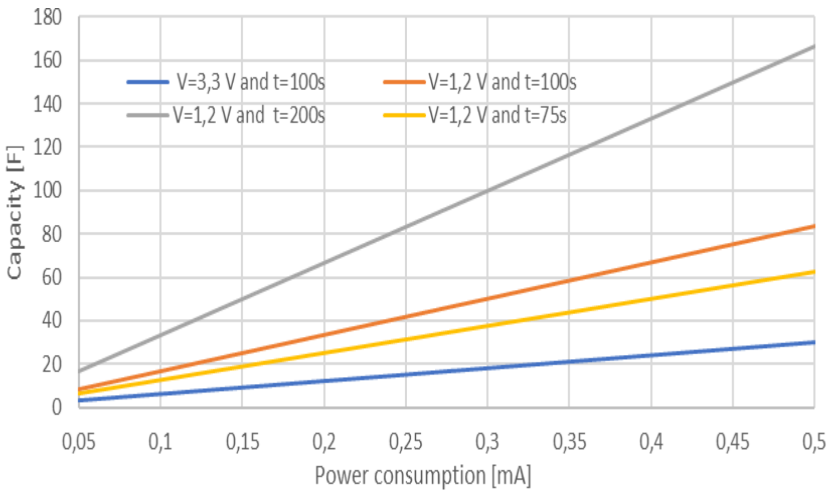
$$C = \frac{2 \cdot I \cdot t}{V} \qquad (4)$$

for the capacitance of the super capacitor and (5) for the current consumed

$$I = \frac{C \cdot V}{2 \cdot t} \qquad (5)$$

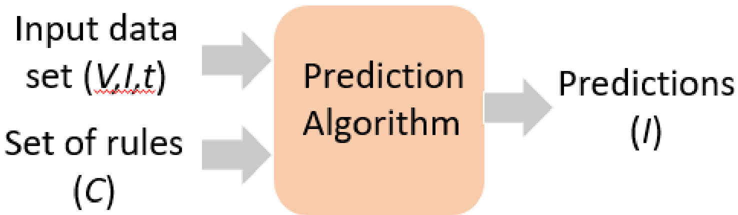
In the new architecture we use a super capacitor of 100F/2,7V and a DC-DC step-up converter to push voltage to 3,3V. According to calculus based on (4), the super capacitor value is near 50F (see Figure 9), we duplicate the value because the discharge curve have not a flat voltage curve during the time, is very roughly during the time, wecan lose 50% of the capacity.

**Figure 9.** Capacity vs Power consumption for the different cases tested




After this analysis (Figure 9), we created a prediction model based on a online tool TADA-Ed [6]. TADA-Ed stands for Tool for Advanced Data Analysis in Education. It is a Data Mining (DM) platform dedicated to teachers, allowing them to visualize and mine students on-line exercise work with the aim of discovering pedagogically relevant patterns. Most of the time, prior to mining, the data stored in a database needs some transformation. TADA-Ed contains pre-processing facilities so that users can transform the database tables to a format that, when used with a DM algorithm, can generate meaningful results for the easy and sample predictive models.

**Figure 10.** Predictive Model for Power Consumption




In Figure 10, it can be shown the predictive model developed and applied in TADA tool. The predicted results based on DM algorithm of TADA tool are: for 3,3V of power supply (new architecture proposed) and for a descent time of 100 seconds, the predicted current consumption is 235 mA; for a 1,2V of power supply (more integrated architecture – SoC, based on Complementary Metal-Oxide Semiconductor (CMOS) technology) and for a descent time of 100 seconds, the predicted current consumption is141 mA and finally for a descent time of 200 seconds and 1,2V power supply the predicted current consumption of the pico-satellite will be 97,5 mA.

The accelerating growth in wireless systems for sensing and monitoring applications has originated a high demand not only for low-power autonomous devices but also for ultra-low cost SoC combining single chip radio with baseband signal and digital data processing [7]. Target applications, such, high-density environmental sensing networks IoT, will be massively available if it is removed the requirement of explicit human action for energy recharge. A second concern for the deployment of large numbers wireless sensor networks is the cost of each individual remote device. Standard digital CMOS technology offers the best trade-off between cost versus performance and facilitates the integration of the digital and analog circuit blocks in the same wafer, whichis a fundamental characteristic to build SoC and/or single chip radio [7]. The parametric signal conversion technique [8], strongly develop during the fifties due to its low-noise performance, was progressively replaced by transistor in a transconductance operation mode. Most recently, due to the intrinsic gain degradation in nano-scale MOS transistor, the parametric approach was revisited and adapted to the CMOS technology.

## 6. CONCLUSION

With this work, we start from a real mission of a pico-satellite (using 5V power supply and more or less 523 mA current consumption) in Azores Island, we collect the data proposed by our mission. After we create a new approach of system architecture withlow-power, low-cost and with more integration of hardware system. We test also in a realscenario, using 3,3V power supply and we verify a reduction of 67% of current consumption (310 mA). Finally, we use DM algorithms to predicted current consumption for the future use in CMOS technology, with 1,2V power supply and DM algorithm predict 141 mA for a descent time of 100 seconds and 97,5 mA for 200 seconds. The descent time of 200 seconds maybe occurs because with this new approach using CMOStechnology, the system will be much lighter compared with traditional CANSAT (330 g of mass). The future work will be design a SoC that integrate sensors, microcontroller, RF and DC-DC step-up converter. The only part outside the SoC will be the cameras.

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