Feasibility of Nano-Satellites Constellations for AIS Decoding and Fire detection

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1. Introduction

Fire fractional cover and Automatic identification system (AIS) are of potential value for emergency and management services. Fire detection solutions provide information about burnt areas and help activating the proper response from fire departments to reduce the risk to people, flora, fauna and environment. On the other hand, the AIS measurements are used to identifying and locating vessels (position, course and speed) to mitigate risks and improve marine safety.

This paper assesses the possibility of using nano-satellites constellation for AIS decoding and fire detection for global monitoring. Firstly provides a global look on the state of the art of existing satellite systems for fire detection and AIS decoding, and then discusses the possibility of extending the solution to space for global coverage with revisit time near to real time for improved Land Monitoring and Emergency Management Services. In order to cope with the demanding requirements of these applications, it is presented the $3CAT^3$ (6U nanosat, 9 kg mass, 10° pointing accuracy, transmission data rate in the order of 1 Mbps in S-band and T&T at UHF band), an earth observation platform based on the cubesat standard which includes two payloads: an optical sensor in the 475 to 870 nm region of the spectrum based on a CMOS active-pixel sensor with spatial resolution between 7 to 9 m and AIS decoder. A 3-CAT3 constellation is also presented in order to fulfill with the demanding requirements of these applications both in terms of spatial and temporal resolutions and global coverage.

2. Fire Detection

Nowadays different satellites provides fire measurements, such as MODIS [1], [2] (AQUA and TERRA missions, spatial resolution of 1 km and revisit time of 12 h), AVHRR [3]–[5] (NOAA/ Metop, revisit time of 12 hours at 1 km of spatial resolution), OLI [6] and ETM+ [7], [8] (LandSat, revisit time of 16 days at 60 m spatial resolution), NAOMI [8] (SPOT, revisit time of 3 days at 8 m of spatial resolution, global coverage in 1 month), MSS (KANOPUS-V, daily revisit time at 12 m spatial resolution, global coverage in 4 month) with different capabilities in terms of spatial resolution and frequencies of overpasses of these satellite data is not enough for emergency management, applications in which a near-real time response is required. Geostationary satellites programs capable to measure fire are: SEVIRI/MSG [9] [10], Imager/GOES, Imager/INSAT, with revisit time of 15 minutes, however, with a moderate spatial resolution on the ground of 1 km.
Several future programs missions planned (horizon 2020-2030) to provide fire monitoring capabilities have been proposed by NASA and ESA agencies. Future instruments (e.g. GOES/ABI [11], MTG/FCI) with high temporal resolution present coarse resolution (1 km), and small fires will be not frequently detected. Other future sensors capable to measure fire area are: HSI [12] (EnMAP, instrument mas 300 kg, 250 W of power, and 30 m of spatial resolution), HYC (PRISMA, instrument mass of 90 kg, 110 W of power, and 30 m of spatial resolution), NAOMI [8], [12] (SPOT, instrument mass of 18.5 kg, revisit time of 3 days for specific areas at 8 m spatial resolution, global coverage in 1 month), AVHRR/3 (Metop-C, instrument mass of 33 kg, 27 W of power and 1 Km of spatial resolution), MSI (Sentinel-2, instrument mass of 275 kg, 266 of power, and 10 to 60 m spatial resolution), SLSTR [13] (Sentinel-3, instrument mass of 140 kg, 100 W of power, and 500 to 1000 m spatial resolution), VIIRS [14] (JPSS, instrument mass of 275 kg, 240 of power, and 250 m of spatial resolution) [13], OLI [6] (LandSAT, instrument mass of 450 kg, 375 W of power and 30 m of spatial resolution) will provide moderate and high spatial resolution for fire measuring but they will not satisfy the revisit time for nowcasting. Fire detection for agriculture meteorology require 60 minutes of revisit time at 10 m spatial resolution, but for emergencies need 15 minutes of revisit time [15]. In response to these problems, this work will explore nano-satellites constellation in LEO orbit (geostationary orbit, this make unfeasible of small platform, coarse resolution and raises costs) to improve the spatial and temporal resolutions.

3. AIS Decoding

AIS works on two channels in the maritime VHF band. The possibility of AIS decoding from space was first presented in [16]. These signals can be detected from space for altitudes up to 1000 km [17], using small omni-directional antenna. The first AIS concept demonstration satellite was developed by ORBCOMM in 2004 [18] (Vesselsat1 weighs 28 kg). Several countries and institutions, such as Italy, Germany [19], Norway [20], Canada, , China, and the European Space Agency (ESA) [21] [22] have launched their own satellites with AIS systems. To improve the security and surveillance services, satellites constellation plans have been deployed. A Constellation of 17 satellites in 2012 was launched by ORBCOMM. A constellation of 30 nano-satellites by US Naval Laboratory has plans to develop GLADIS (Global Awareness Data Extraction International Satellite). Near real-time and global surveillance with AIS decoding has become feasible. However, Space-borne with optical sensor and AIS can be considered to be complementary, using an integrated combination. This paper presented the design of a constellation of nano-satellites to improve the fire and AIS measurements.

4. 6U Earth observation platform

The growing requirements of these applications both in terms of spatial and temporal resolution and the advent of nano-satellites constellations, inter-satellite communications capabilities and the need of cutting-edge technology equipped in the satellites places small satellites in the top picked solutions to confront these observables.

3Cat3 Initiative3Cat3

The 3Cat3 initiative starts as a feasibility study in order to equip a 6U CubeSat with an optical system capable of acquiring images with a resolution of less than 10 m in 5 different bands (from visible to VNIR). It is both a technological demonstrator and a survival test for a small platform with heavy restrictions in terms of power consumption, thermal tolerances and data downlink capabilities. At the same time, the nature of the mission pushes all subsystems to the limit in order to acquire as many images as possible and decode AIS signal along the orbit.

Budgets analysis

The vulnerability of nano-satellites in contrast to larger platforms is observable not only in terms of radiation resistance but also in energy capitation and temperature management which menace the survival of the satellite and therefore of the whole mission. Thus, it is mandatory to simulate as many scenarios as possible concerning power gathering and consumption and temperature drops and rises due to eclipse periods. The following figures show a power budget, a thermal budget and a data budget of a 3Cat^3 platform with two payloads (CMOS optical sensor in the visible+VNIR bands and AIS decoder), EPS and two sets of batteries providing up to 6-8 W, 14 1U solar panels, ADCS subsystem, S-band transmission card for data download, UHF-band transmission card for T&T and battery heaters to maintain the satellite between 5 °C and 45 °C.

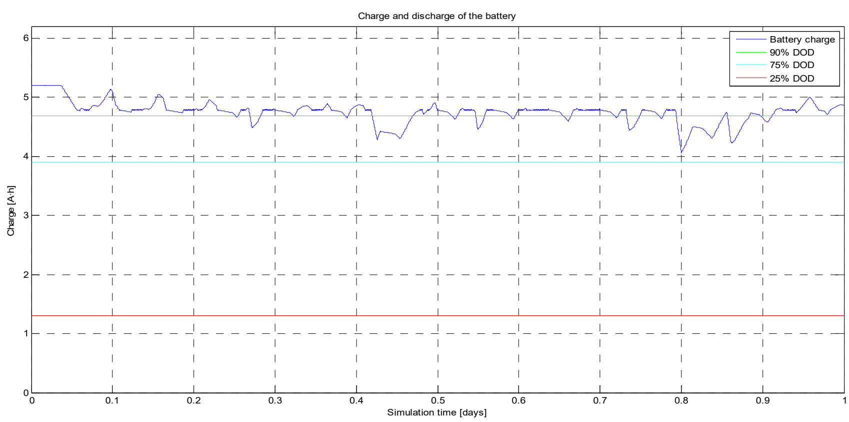

Figure 1: Power Budget for a 24 hours simulation in an inclined 55° orbit. The simulation considers 2 ground stations to download data where the S-band and the UHF links are active and three 1000 km radius target areas where both payloads are acquiring data.

The importance of designing a precise scheduler for a mission of this type is crucial for the survival of the satellite. The batteries are delicate in terms of temperature tolerance (2 °C up to 65 °C). Other components resist lower temperatures but due to the chemical processes inside the batteries, the temperature cannot drop under 2 °C. It is also decisive not to discharge the batteries excessively. The deeper DoD (Depth of Discharge) is reached, the more is reduces the lifespan of the batteries and it can even be over if a complete discharge were to happen. The scheduler limits the energy drain of all satellite's subsystems to protect the discharge of the batteries, but allows the heaters to consume as much as needed to keep the batteries away from the temperature limit.
The following figure shows a thermal budget corresponding to the same simulation of the power budget. Especially critical are the eclipse periods when the temperatures drop and, first the batteries, but also all other equipment on bard are endangered.

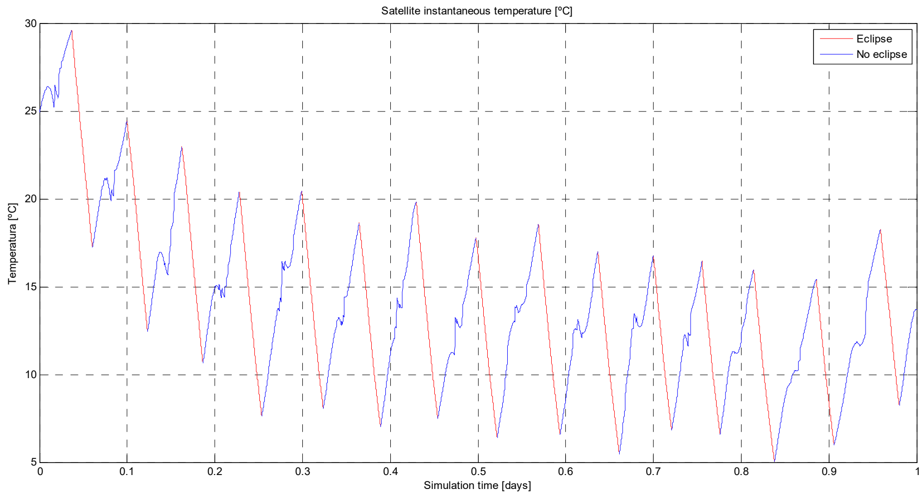

Figure 2: Thermal Budget for a 24 hours simulation in an inclined 55° orbit. The simulation considers 2 ground stations to download data where the S-band and the UHF links are active and three 1000 km radius target areas where both payloads are acquiring data. The figure explicitly shows eclipse phases during the orbit and the consequent drop of the satellite's temperature. The figure is timely connected with the Power budget shown above.

The power and thermal budgets provide necessary information to assess the feasibility of the mission and to design the scheduler in order to ensure the survival of the mission. The data budget exposes the conceptual success of the mission. The data acquired by both payloads must be downloaded and it is one of the bottlenecks small satellites missions. Low transmission rates (usually below 1 Mbps), little power available for transmission purposes and little contact time with ground stations are common scenarios. The following figure shows the memory capacity of the onboard storage through a data budget linked to the power and the thermal budgets showed previously. The scheduler does not allow the payloads to acquire data unless the conditions of power (battery charge over 90% of the DoD) and temperature (between 2 °C and 65 °C) and met. The S-band card has a relax power condition of 75% of the DoD due to the importance of downloading data.

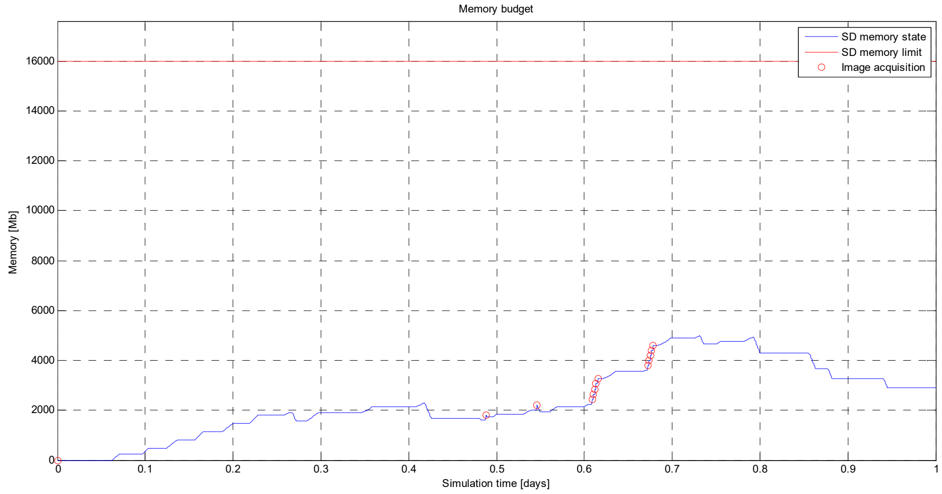

Figure 3: Data Budget for a 24 hours simulation in an inclined 55° orbit. The simulation considers 2 ground stations to download data where the S-band and the UHF links are active and three 1000 km radius target areas where both payloads are acquiring data. The figure shows the state of the memory onboard (2GB). When the satellite flies over target area 1 (TA1) only the AIS is active. When it passes over TA2 the camera is acquiring images. The S-band card transmits always that the scheduler's conditions are met.

5. Constellation configuration for the reduction of the revisit time

Perhaps the biggest advantage of small satellites for Earth Observation over larger platforms apart from the obvious cost reduction is the possibility of forming huge constellations of satellites which reduce the revisit time and global coverage time.

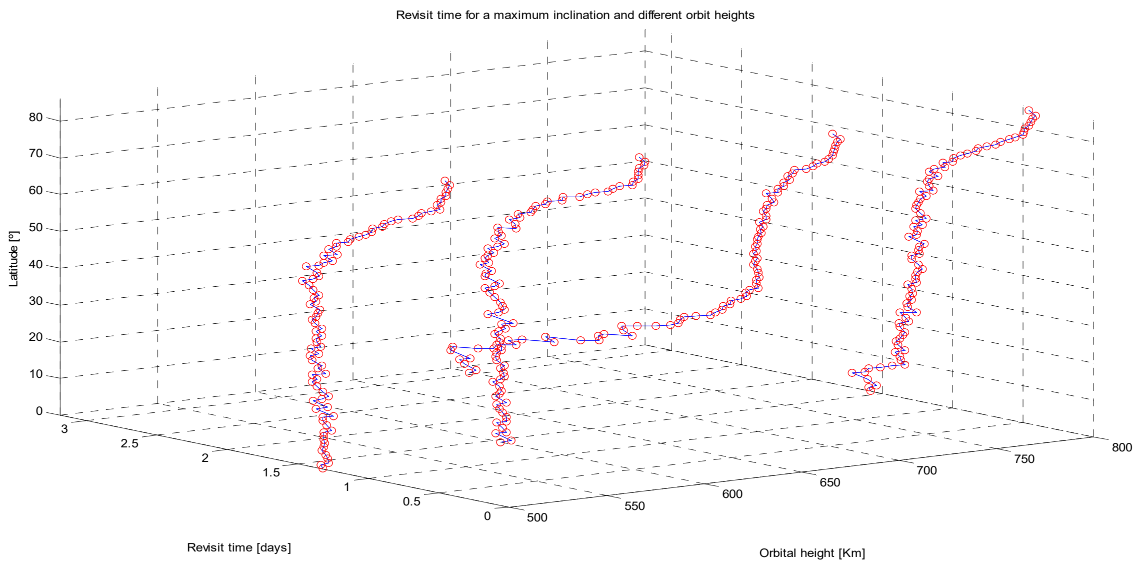

Figure 4: The figure above shows the revisit time for a 80° inclination satellite targeting a random target area with a cross-track swath of 80 Km and an along-track swath of 50 Km. The figure also shows the same experiment for different orbital altitudes and inclinations.

The revisit time can be reduced using a constellation of satellites located in the same and different orbital planes. The average revisit time for inclinations above 30° is around 36 hours. The formation of a constellation of 6 satellites in the same orbital plane would already reduce this revisit time below the 6 hours. The combinations with other orbital planes reduce even more that revisit time (in the order of the hour) given a crescent number of satellites shaping the constellation.

6. Conclusion

The 3CAT[3] constellation is an excellent candidate to improve the spatial and temporal resolution for fire and AIS measurements, with low-cost hardware concept. This work will be used as a basis for discussion and critique to define and deploy a global coverage for fire and AIS measurements. In the conference, the improvement of spatial and temporal resolution is presented with respect to various nano satellite constellation.

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