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Recent Developments on a RaioSat Optical Detection Prototype for Lightning Events On-Board a Nanosatellite

Sebastian Thaut [1], Lazaro A. P. Camargo [2], Kleber P. Nacaratto [2], Walter A. Dos Santos [2]

[1]EAH Jena University of Applied Scienes, Jena, Germany

Internship Student from Jena - INPE Technical Partnership - CSE.

[2]Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brasil

Sebastian.Thaut@stud.eah-jena.de

Abstract. *Due to climate changes, there is a rising frequency of extreme weather events. Lightning flash occurrences have a link to these phenomena and its monitoring holds significant importance in aiding the study and development of meteorological forecast models. Use of big satellites to monitor these events have been employed but using smallsats to do so have some benefits. One of the challenges to realize them involves using effective VHF and optical detection payloads to nanosatellites. Collaboratively, the Atmospheric Electricity (ELAT) group within the Earth System Science Center (CCST) and the Small Satellite Division (DIPST) have conceptualized the RaioSat mission. This initiative aims to augment the existing ground network by enhancing the monitoring capabilities for lightning occurrences. This work is focused into a RaioSat optical detection prototype, its recent developments and future works.*

Keywords: RaioSat; Lightning Flash Detection; Smallsats; Climate Change.

1. Introduction

The quest to understand and monitor natural phenomena from space has ushered in groundbreaking technological advancements. Among these, the development of an optical detection prototype for lightning flash events on-board a nanosatellite, here named RaioSat [Carretero & Naccarato, 2014] [Naccarato et al., 2016] [Moura, 2017] [Naccarato et al., 2017] [Julio Filho et al., 2020], stands at the forefront, marking a pivotal milestone in satellite-based research. Lightning, a captivating yet elusive natural occurrence, has long fascinated scientists, prompting innovative approaches to capture and comprehend its dynamics [Goodman et al., 2012].

The RaioSat mission will serve as a valuable complement to the BrasilDat network, enriching the capacity for monitoring atmospheric electrical discharges. Its integration will play a pivotal role in improving Brazil's civil defense mechanisms and enhancing the country's risk and disaster management system. This mission's significance lies in its profound impact on short-term weather forecasting, particularly in preemptive measures against storms and electrical discharges. By providing critical data insights, RaioSat aims to fortify disaster prevention strategies and contribute significantly to the efficiency of risk management, civil defense, and disaster response initiatives.

This prototype harnesses the capabilities of nanosatellite technology to observe and detect lightning events through optical means, paving the way for a new era of real-time, high-resolution data acquisition. In this work, we introduce the intricacies and significance of this cutting-edge technology, exploring its potential to revolutionize our understanding of atmospheric phenomena from the vantage point of space.

This paper is organized as follows: section 2 mentions about the RaioSat project, section 3 presents the key methodological points, section 4 shows some preliminary results and discussions, section 5 briefly points to future work and finally section 6 concludes the work.

2. The RaioSat Project

Hundreds of fatalities and billions of dollars in damages worldwide annually caused by severe weather phenomena. Unlike other predictable hydrometeorological events, severe atmospheric events in Brazil occur randomly, lacking a clear socio-spatial pattern [Naccarato and Pinto Junior, 2012a]. Consequently, there exists a pressing need to enhance prediction techniques for such events, leveraging high-resolution numerical models. The acquisition of a substantial volume of high-quality observational data is essential, particularly lightning data in extremely short-range scenarios.

Moreover, the detection of lightning flashes generated by storms holds significant importance across diverse applications and within specific domains of scientific inquiry. These applications encompass the comprehension of human influence on climate dynamics and the potential impact of climate change on long-range storm behavior [Fierro, et al., 2012].

The optical detection of lightning from space involves measuring the emitted light radiation from the hot lightning channel as it propagates through the atmosphere and clouds, primarily scattered by the latter, eventually reaching an observer positioned above the clouds. One effective approach for monitoring lightning flashes is through the integration of sensors aboard satellites to gather pertinent data.

This integration is the target for a payload proposal tailored for the RaioSat nanosatellite [Camargo, L.A.P et al, 2022] as shown in Figure 1, comprising a specialized optical camera developed externally, a VHF radio, and a data fusion processing unit designed to integrate data from both aforementioned sensors.

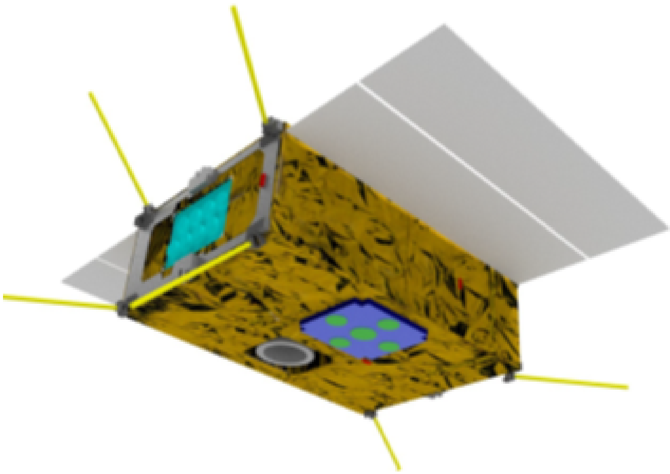

Figure 1. RaioSat artistic view for lightning monitoring. [Camargo, L.A.P et al, 2022]

The RaioSat mission will be carried out by a 6U-cubesat, weighing 10 kg, serving as the space segment. This nanosatellite will be equipped with an onboard computer and an attitude control system designed to fulfill the requisites for capturing lightning flash images.

3. Methodology

This work is part of the proposed RaioSat lighting detection scheme [[Camargo, L.A.P et al, 2022 that uses a VHF-triggered camera as shown in Figure 2. This paper addresses only the camera and the payload OBC portion.

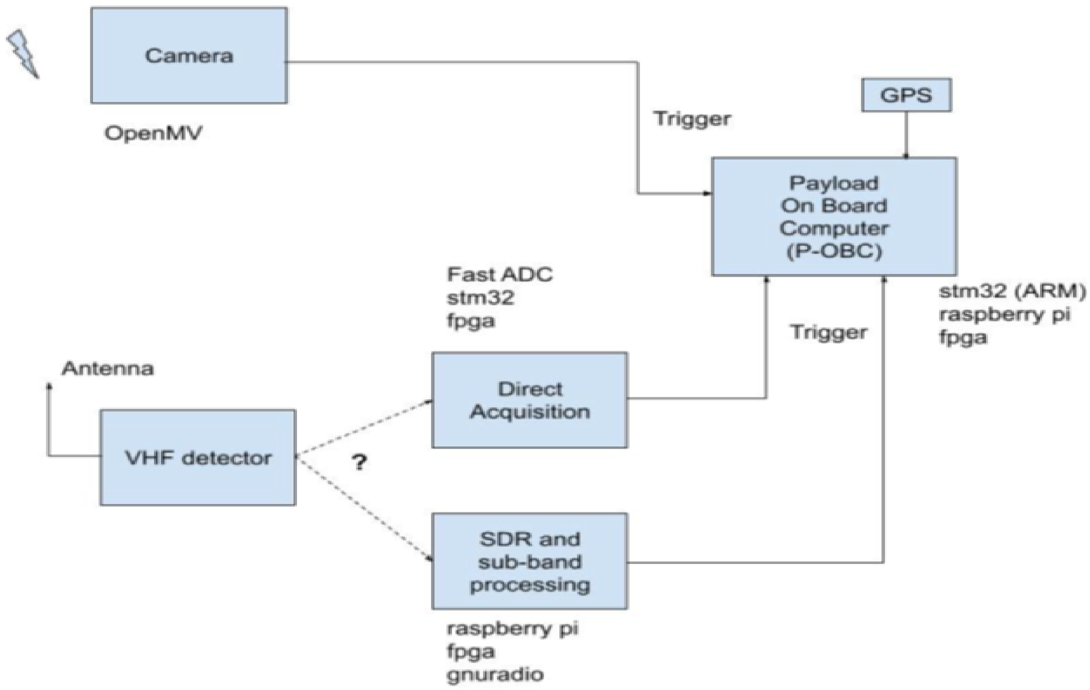

Figure 2. Proposed RaioSat lighting detection scheme [Camargo et al, 202].

The RaioSat payload includes a high-performance camera operating in the infrared (IR) spectrum, featuring specialized sensors and optical filters. Additionally, the satellite will incorporate a Global Positioning System (GPS) optimized for low-orbit applications. Complementing these features, the satellite will house a VHF Software Defined Radio (SDR) receiver, designed to operate within the 30 - 100 MHz band. This radio system is dedicated to capturing and recording the electromagnetic signatures associated with lightning events, thereby corroborating and validating the lightning detections acquired by the IR camera.

In order to realize a RaioSat optical detection prototype for lightning events, this project uses COTS (Commercial Off-the-Shelf) components, as depicted in Figure 3, are basically:

- STM32 Core-144 development board - works like a dummy OBC to trigger the camera by two options: (1) Changing pin state or (2) I2C (work still in progress).
- OpenMV Cam H7 - with a OV7725 camera sensor and STM32H743VI MCU (1MB SRAM & 2MB flash) this provides 640x480px maximum resolution in a speed range of 75-150 fps for an image resolution of 320x240px furthermore an OpenCV like MicroPython library is available to increase coding efficiency. Internal limiting RAM size constitutes a real bottleneck.

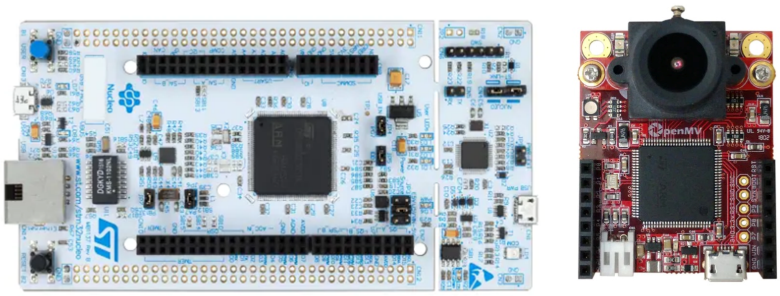

Figure 3. Used components in the prototype realization

For image processing a special event detection process by background subtraction is employed, see [Voss, B.; Zecherle, J, 2022] for details.

4. Preliminary Results and Discussions

As a case study, two sets of images retrieved from previous space missions from ESA and ISS were used to simulate a scene viewed from space. This scene was acquired by the OpenMV Cam H7 and the image was preprocessed and then sent to the STM32 board for final processing using the background subtraction technique mentioned earlier. Examples of a captured image, background and event mask are shown in Figure 4 where basically the captured image minus background results in the mask/event.

Figure 4. Slow dynamics case study scenario and resulting background removal.

Applying a simple histogram technique, it was possible to fine-tuning the threshold for lightning event detection. Selecting this number of pixels threshold, one may detect a real event which is saved and then listed for prospective telemetry download.

For the second set of images which works in a high dynamic scene seen from ISS that is depicted in Figure 5. The major challenge is to deal with the light that is also collected from the presence of big cities on the ground. Some initial results have been obtained but it's still necessary to improve the algorithmic approach to handle these features.

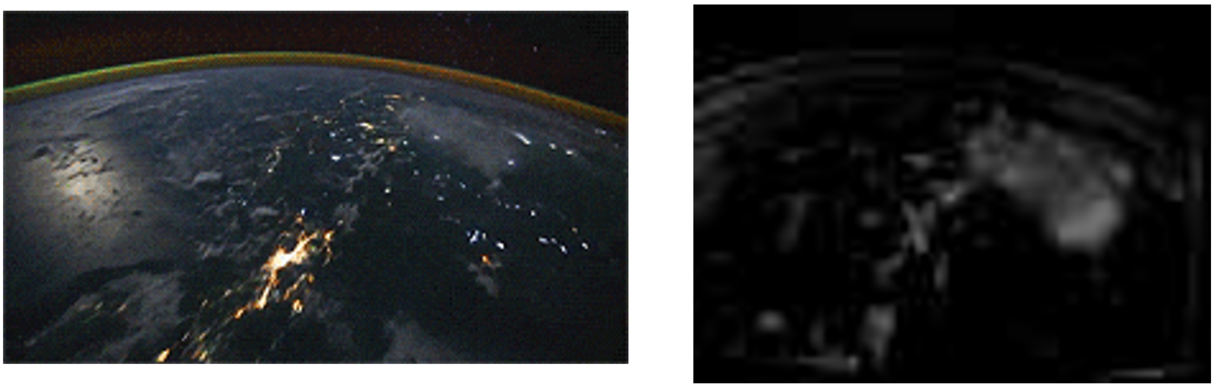

Figure 5. Fast dynamics case study scenario and partial background removal.

5. Future Work

The planned steps to a follow-on of this work are listed below:

- Improve lighting detection algorithms using techniques applied to correlated domains.
- Finalize a prototype of a RaioSat photometer payload similar to the one used in VITF payload in the JEMS GLIMS Mission.
- Implement I2C communication protocol between camera and OBC.
- Development and testing plan: (1) Payload and Camera Design and Science Targets, (2) Observational Planning and Constraints and (3) Photometric Modeling.

- Choose a suitable photodiode and add it to the STM32 loop.
- Suggest ground-support equipment for VV&T (verification, validation and testing) of future nanosatellites candidates with these payload capabilities.
- Plan for a Balloon flight if time allows.

6. Conclusions

Climate changes and their effects driving extreme weather events, have a close correlation between lightning occurrences. The lightning event monitoring serves as a crucial information in advancing our understanding and refining meteorological forecast models. While conventional use of larger satellites has been the norm, the shift towards smallsats presents several inherent advantages. However, realizing this potential necessitates overcoming challenges, notably in the effective integration of VHF and optical detection payloads into nanosatellites, such as the RaioSat proposal to fortify and expand the existing ground network, RaioSat holds the promise of significantly enhancing lightning occurrence monitoring capabilities and this paper tackled the optical approach.

Using a prototype that employs COTS components such as STM32 Core-144 development board and an OpenMV Cam H7, this paper presented some background subtraction technique into a two-scenario case study of imagens subjected to a slow and fast dynamics. As the OpenMV camera has a limited RAM volume the algorithmic approach has to be efficient to meet detection requirements. Furthermore, the fast running image challenges as acquired scenery from satellites could sometimes generate false-positive lightning events due to large cities background could be misleading in the lightning occurrences. Future work was also presented which will contribute to a plan for a Balloon flight if time allows.

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