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OUFTI-NEXT: THE SECOND CUBESAT OF THE UNIVERSITY OF LIÈGE

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In light of this experience, in the fall of 2016, the University of Liège (ULiège) assembled a panel of experts in a unique ideation session aiming at systematically and quickly identifying innovative scientific missions for nanosatellites/CubeSats. Among the many ideas that emerged from this process, the ULiège selected the concept of an earth observation 3U CubeSat and corresponding ground segment to produce images in the mid-wave infrared (MWIR) with a resolution of at least 50 m, dedicated to measure the hydric stress of vegetation. This monitoring would allow farmers to provide optimal irrigation to their crops and thus will lead to spare drinkable water. Performing useful MWIR imaging from a 3U CubeSat would be a World's first. Ultimately, a constellation would be required to provide the necessary daily re-visit rate. In order to prove the concept a demonstrator, called OUFTI-Next, will first be produced.

INTRODUCTION

The first University of Liège (ULiège) nanosatellite was the 1-unit (1U) CubeSat called OUFTI-1. Its primary mission was to bring a D-STAR repeater to low earth orbit. OUFTI-1 was successfully launched on 25th April 2016 from "Centre Spatial Guyanais" in Kourou, French Guyana, aboard Soyuz Flight VS14 in the frame of ESA's "Fly Your Satellite!" program. In order to continue space adventure with students at ULiège, an ideation session which gathered professors from different faculties and industrial partners was hold with the result of a new ambitious mission of earth observation.

In the world, one quarter of farmlands are irrigated. These irrigated farmlands produce one third of the world food production and are also 3.5 times more efficient than non-irrigated crops. Hence, irrigation is essential in arid regions and necessary to obtain high yields. At the world scale, agriculture is the biggest freshwater consumer (70%) followed by industry (20%) and eventually domestic consumption (10%). Nevertheless, nowadays the irrigation mean efficiency is inferior to 40% which leads to an enormous waste of freshwater. The detection of hydric stress linked to a lack of water is thus of paramount importance for increasing the crops yields and decreasing the waste of freshwater. Hydric stress detection in arid regions can help local farmers to

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manage more efficiently their crops. Satellites are particularly well suited for this task. The use of drones is far too expensive due to maintenance and cannot stand the comparison in terms of covered area.

The OUFTI-Next mission wants to offer farmers a solution for monitoring their fields by observing the Earth in an infra-red wavelength band.

MISSION REQUIREMENTS

Hydric stress detection is possible thanks to MWIR measurements. A plant without enough water closes its stomas which are small apertures at the leaves surface. These stomas are used to exchange water vapor with the atmosphere which leads to the transpiration of the plants. Transpiration is essential to conserve an ideal temperature for growing. When stomas are closed, plants heat up and it is a sign of hydric stress. Finally, thanks to MWIR measurements, it is possible to evaluate this level of stress by analyzing the temperature difference between the plants and ground surface. This difference in temperature is not negligible and can go up to 10°C.

Middle Wave Infra-Red (MWIR)

The MWIR band is the 3-5 μm portion of the electromagnetic spectrum. Usually, small satellites observe the Earth in visible or near infrared wavelengths while big satellites can also observe in the thermal infrared. Thanks to the developments in infrared detectors and the miniaturization of cryocooler technology, MWIR instruments can now be embedded in CubeSats. In the past, MWIR measurements were widely used for military applications such as heat-seeking missiles for instance.

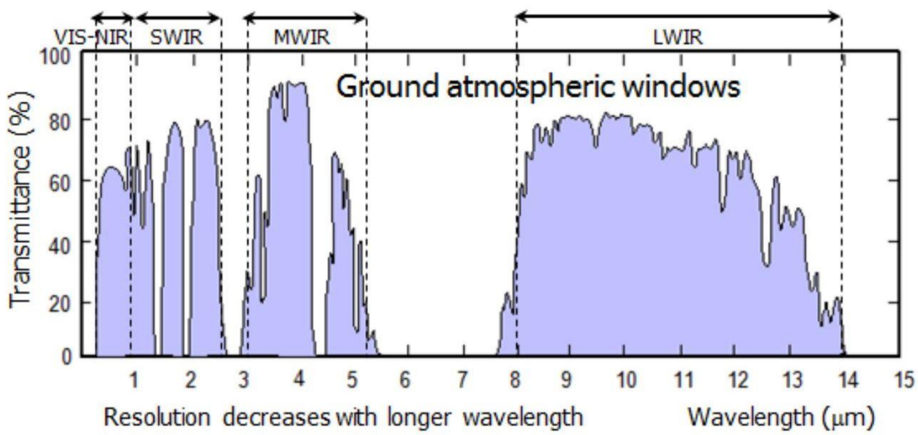

Figure 1. Definition of IR spectral band*.

Compared to the common LWIR band, MWIR measurements offer several advantages. The MWIR signal is composed of reflected light as well as thermal emissive signal as can be seen in Figure 2. This double composition offers the possibility of imaging at night when it is easy to detect the thermal emissive signal from the ground and during the day to obtain information from the reflected light. Furthermore, it is less subject to diffraction and less disturbed by radiations produced by its own instrument. It means that the detector must less be cooled compared to a LWIR detector which is a serious advantage in the frame of this mission. Nowadays, there are even uncooled MWIR detectors with a moderate sensitivity.

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*"Optoelectronics - Advanced Materials and Devices", Nibir K. Dhar, Ravi Dat and Ashok K. Sood, January 16, 2013.

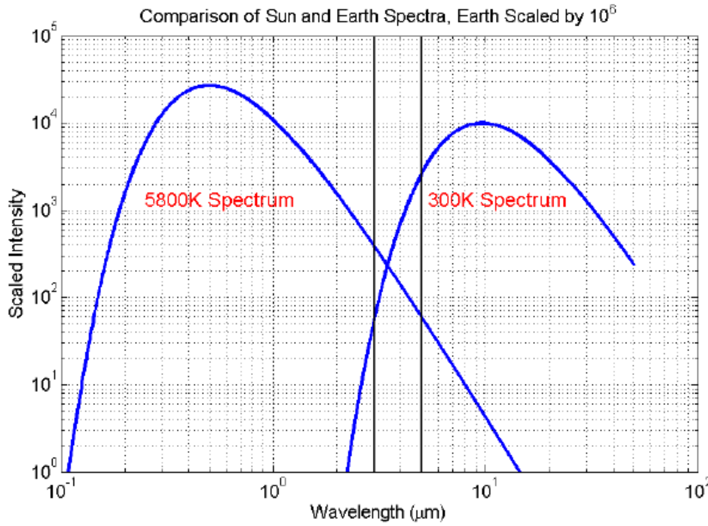

Figure 2. Earth and Sun spectra in the MWIR[*].

Revisit rate

To achieve the mission and provide a good detection of lack of water, a high revisit rate is needed. It is assumed that one picture per day is a good enough input for an irrigation strategy and is valuable information to farmers. Obviously, one satellite in LEO region is not able to offer a daily revisit rate. In theory, it is possible to reach a daily coverage with a constellation of 8 satellites in SSO at 800 km. But in practice, it depends on the satellite performances, e.g., if the payload can be use permanently or not.

Spatial resolution

The ideal spatial resolution needed to achieve the mission was defined at 50m according to the specialists. This value is not immutable because the maximum acceptable resolution will depend a lot on the field size.

THE OUFTI-NEXT DEMONSTRATOR

Before launching a constellation of satellites in space, one must ensure that mid-wave infrared images can be taken and sent back to the ground station. It is the purpose of the OUFTI-Next 3U CubeSat. The aim is to take MWIR images of the Earth and detect hydric stress in agricultural fields. Performing MWIR measurements with such a small satellite would be a world premiere!

Integer a MWIR camera in a 3U CubeSat is quite challenging in terms of volume, power consumption, etc. But it is also a challenge in terms of performance.

The goal of the demonstrator is to validate the concept of the mission: to take MWIR pictures of agriculture field and send it to the ground. A processing will be implemented on ground to use these picture and try to decide if irrigation is needed or not. The measurements taken will also be compared to onsite measurements in order to evaluate the performances.

[*] "Asteroids to agriculture: carving a niche in earth observation using asteroids prospecting instruments on a earth-orbiting CubeSat constellation", Hannah R. Goldberg, Planetary Resources, 2016.

The requirements for this demonstrator will obviously be a bit different than the ones needed for the complete mission but the detector used has to be the same. The spatial resolution will be doubled because the optics will differ due to the platform size. Moreover a daily revisit rate can't be achieve with only one satellite. However an SSO orbit could be preferred to offer a planet's surface coverage at the same local solar time.

PRELIMINARY STUDIES

The preliminary studies aim to determine if it is possible to observe the earth in MWIR with quite good performances from a 3U CubeSat.

Payload

In order to evaluate the feasibility of the mission, a parametric preliminary study is necessary to know how orbit altitude, sensor, and optic systems specifications influence the ground observation. Successively, it will be possible to select the appropriate instrument.

To achieve this objective, a parametric study has been performed to evaluate how all the variables of the problem are linked. In particular, the ground sample distance (GSD) and the signal to noise ratio (SNR) exhibit two opposite trends and then, the study become a research of the best compromise.

The first step has been to modelize the reflected and emitted radiances that compound the radiometric budget. After that, individualize what characterizes the optical system and the detector and apply some constraints. These constraints are substantially given by the instruments availability on the market (e.g. optics dimension, sensor array size etc..), since all the hardware components will be bought and are space qualified.

Obviously, the market offers several solutions. Hence, some variables are not strictly fixed but it is possible to limit them only to a few values (e.g. pixel size).

The problem has been modeled in separate sections:

- Radiometric budget (MWIR window, sun light, thermal emission etc...)
- Optical system (Pupil diameter, diffraction limit etc...)
- Detector system (Array dimension, Dark Current etc...)

The second step has been to develop a code that combines all the ground, optics, detector and orbital parameters to join all the different equations to perform parametric studies for the GSD and the SNR. Then, after evaluating their trends, simulations to predict the instrument requirements have been performed looking for a good balance between GSD and SNR. The input variables were set in order to have realistic values, usually extracted from supplier's datasheet or based on user's reasoning's.

In view of the performed parametric studies and the preliminary simulations, two instruments have been selected as possible candidates to be mounted on the 3U CubeSat (Figure 3).

Figure 3. MWIR camera: Kinglet* (left) and Neutrino† (Right).

The first and most promising is the SemiConductor Devices (SCD) Kinglet. Kinglet is based on SCD's state-of-the-art XBn (InAsSb) technology which demonstrates high performance at 150K FPA operating temperature. The product was developed in response to market demand for reduced SWaP (Size, Weight, and Power) and for increased reliability.

The second one is Neutrino from FLIR. The Neutrino is the ideal solution when SWaP design constraints, cost, and performance are needed. Featuring the latest technological advancements, the Neutrino is FLIR's smallest and lightest cooled camera core and incorporates the industry's most advanced image processing at the lowest cost and with the easiest integration of any MWIR System.

For more details, please refer to the complete analysis[1].

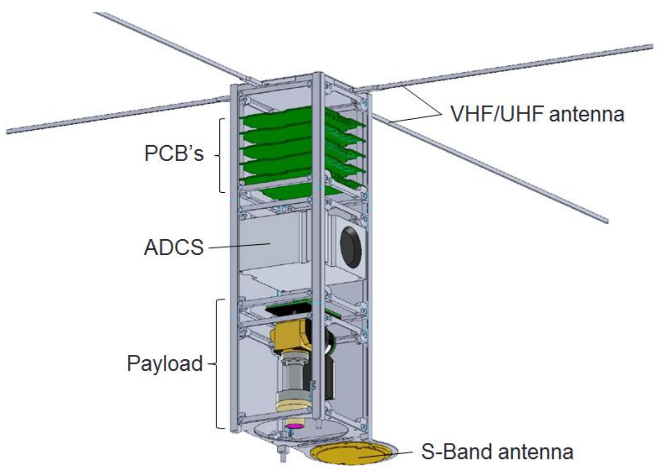

Figure 4. OUFTI-Next preliminary design.

* SemiConductor Devices. Kinglet 640, 15μm. http://www.scd.co.il/KINGLET-640-15.
† FLIR. Flir neutrino. http://www.flir.com/cores/display/?id=60562.

Platform

OUFTI-Next platform design depends on the mission analysis and several budgets have to be performed to assess the feasibility of the mission. The combination of these budgets (power budget, mass budget, volume budget, link budget and data budget) leads to the preliminary design of the satellite with 1.5U available for the payload as shown on Figure 4.

The preliminary study performed wants to give the highlight of the platform, and wants to detect potential problem sources. It lead to some restrictions about orbits fitting with the mission, in terms of lifetime, debris mitigation, power generated and telecommunication capability.

The study results give for example the minimal size of the battery capacity according to different orbits (for an assumed payload consumption). Moreover, it gives the necessity of downloading the payload data with an S-band channel to increase the communication baud rate.

For more details, please refer to the complete analysis[2].

CONCLUSION

The main goal of this project is to spare some drinkable water by helping the farmer to smart irrigate their fields. It was decided to reach this goal by observing the earth in the middle wave infra-red.

The first work was to study the physical parameters in the field of optics, detectors and radiometrics. The resulting simulations are very promising for the future of the mission.

In order to demonstrate the mission's in orbit capabilities and validate the concept, a demonstrator has to be build. This demonstrator is planned to be a 3U CubeSat with 1.5U available for the MWIR payload. The complete design is currently under study at the University of Liège by several students doing their Master Thesis.

OUFTI-Next is expected to be ready for launch by Q4 2019.

REFERENCES

[1] "Feasibility of Earth Observation in the MWIR Window with Cubesats for Agriculture Monitoring OUFTI-Next", E. Ghidoli, Master Thesis 2016-2017.

[2] "OUFTI-Next Nanosatellite: Feasibility Study and Mission Assessment", D. Schklar, Master Thesis 2016-2017.