ESA STUDY CONTRACT REPORT

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ABSTRACT
This document is an executive summary report summarizing briefly the most important results achieved in the CHIEM-c project. CHIEM-c answers essential questions about the usability of the hyperspectral image sensor chips developed in the CHIEM project for a small hyperspectral mission. Reliability testing revealed only a resolvable delamination issue of external rejection filters. The MTF of the BSI detectors was found to be too low. System performance analysis showed that it is important to apply digital TDI to increase SNR, which is supported by the read out electronics. FSI detectors with hybrid external rejection filters are chosen as baseline. Preliminary designs were proposed for the opto-mechanics, system and platform accommodation. An absolute geolocation accuracy < 40 m was found possible by systematically using GCPs. A preliminary mission definition was made which allows repeated monitoring of agricultural sites, in line with the mission objectives. The results obtained pave the way for a successful IOD mission.

Names of authors:

B. Delauré, S. Livens

NAME OF ESA STUDY MANAGER: L. Maresi DIV: TEC-MM DIRECTORATE: D/TEC	ESA BUDGET HEADING:

CHIEM-c ESR Executive Summary Report

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Circulation / distribution list

Name	Address	P/E	Name	Address	P/E
Joris Blommaert	VITO	E	Luca Maresi	ESTEC	E
Stefan Livens	VITO	E	Helene Strese	ESTEC	E
Dirk Nuyts	VITO	E	Alessandro Zuccaro Marchi	ESTEC	E
Bavo Delauré	VITO	E			
Tom Van Roey	VITO	E			
Iskander Benhadj	VITO	E			

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1. OVERVIEW

1.1 CHIEM-c Project Goal

This document summarizes the most important results as achieved within the CHIEM-c project., As its name implies, CHIEM-c intends to continue the work of the earlier CHIEM project and achieve results beyond those obtained within CHIEM. Essentially, the goal is to answer the question whether the hyperspectral image sensor chips developed in the CHIEM project are usable as the key parts of the hyperspectral instrument of a small hyperspectral mission. This includes:

- a choice between the three detector variant
- a preliminary optomechanical design of a compact hyperspectral instrument which can be embarked on a 12U CubeSat
- to evaluate and confirm this payload-platform compatibility by means of an accommodation study
- to modify the design of the ROE, in order to support processing to increase the overall performance of the compact hyperspectral imager
- to model the system performance of the compact hyperspectral instrument
- to execute a preliminary definition of an in orbit demonstration mission and definition of a concept of operation of the overall system to support the specific mission objectives

After briefly recalling the status at the end of the CHIEM project, we will summarize the main findings on aspects covered within CHIEM-c in the following sections.

1.2 CHIEM starting point

In the CHIEM project, an engineering model of a hyperspectral imager was successfully designed and built. The core of the imager is formed by a set of hyperspectral interference filters deposited on a large CMOS detector. The system is completed by a read-out electronics, capable of high speed operation, which allows postprocessing techniques to improve SNR. The system also includes the design of a compact high quality optical system. The largest effort was spent on the design and production of detectors with hyperspectral filters. These were successfully created in three variants:

- Front side illuminated (FSI) detectors with hybrid external rejection filters (FSI hybrid)
- Back side illuminated (BSI) detectors with hybrid external rejection filters (BSI hybrid)
- Front side illuminated (FSI) detectors with monolithically integrated rejection filters (FSI mono)

2. CHARACTERISATION

2.1 MTF

The Modulation Transfer Function (MTF), a good measure of per pixel spatial detail, was measured by CNES on the different detector variants. Good performance was found for the FSI sensors, with MTF > 0.3 at Nyquist freq. For the BSI sensors, very low MTF values were obtained, due to the thick EPI layer used for the BSI sensors.

2.2 Reliability Tests

Reliability tests were carried out on the different sensors, including a vacuum test, humidity test, thermal cycling test and vibration test. All sensors passed all tests successfully, only for the sensors with external rejection filters a delamination issue occurred under humid conditions. Meanwhile imec has developed a novel approach for integrating rejection filters to resolve this problem.

2.3 Detector Choice.

The MTF performance rules out the use of the BSI sensor. Taking into account the solution for the delamination issue, and also the known difference in optical performance between the hybrid and monolithical rejection filters (with hybrid filters offering better rejection), the FSI hybrid detectors as proposed as baseline, with the FSI monolithical as backup solution.

3. SYSTEM PERFORMANCE ANALYSIS

3.1 Signal to Noise Ratio

The SNR of single acquisitions was found to be rather low (average SNR 33 to 55). By using Digital TDI, in which multiple acquisitions of the same position and spectral bands are averaged, the SNR can be significantly increased. The sensor and read out electronics support digital TDI with up to 12 stages, which leads to an important overall increase in SNR with a factor SQRT(12). Further increases can be obtained by spectral binning and spatial binning to lower spatial resolutions.

3.2 Stray Light

The contributions to in-field straylight were assessed by analysis and shown to be well under control. The dominant effect comes from the grating effect, as the 1nm roughness effect was found to be very small.

3.3 Geolocation accuracy

Geolocation accuracy, the error between the real target location on earth and the estimated target location after on-ground post-processing, is of key importance for many applications. To estimate it, a geolocation budget was has compiled with all contributing effects. The results are a total geolocation error of **47.5 m** for a system without platform tilt, and **61.5 m** for a system with platform tilt. By systematically using GCPs to update the interior and exterior camera parameters and refining the attitude and position data, bias and periodic errors can be eliminated. This lead to a reduction in geolocation error to **less than 24m**, which than complies with the absolute geolocation requirement was set at 40m.

4. PRELIMINARY SYSTEM DESIGN

4.1 Read Out Electronics: (ROE)

The demanding requirements for the ROE could not be fulfilled using existing space qualified technologies. Therefore, instead of using full space qualified solutions, a hybrid approach was followed , in which COTS components are used for the data processing requiring high speed processing reso The missions lifetime urces, while simpler radiation hard-devices are used to monitor and manage the COTS devices, and fault tolerant mechanisms are added.

The ROE supports powerful image processing algorithms, including TDI processing with up to 12 stages, correction of sensor pixel offset (FPN) and gain (PRNU) variations, image accumulation, pixel Binning, with binning factors up to 6x6, image cropping in 32 pixel steps.

4.2 Optomechanical design

The optical design of the instrument consists of three mirrors: the primary and tertiary are aspherical concave off-axis mirrors, while secondary is a spherical convex mirror. A sensitivity and tolerance analysis have been conducted as input to the preferred manufacturing. The mirrors will be made of RSA 6061 aluminium alloy, a well-known space qualified material with good long-term stability. Additional nickel plating of the mirror is not foreseen.

The mirrors will be complemented with a set of baffles, designed following the results of the optical analysis. Additional baffling at focal plane level will be considered based on final straylight analysis. The focal plane mechanical assembly is the other main item in the design, its base plate is also aluminium.
All the elements and their proposed assembly are depicted in Figure 1

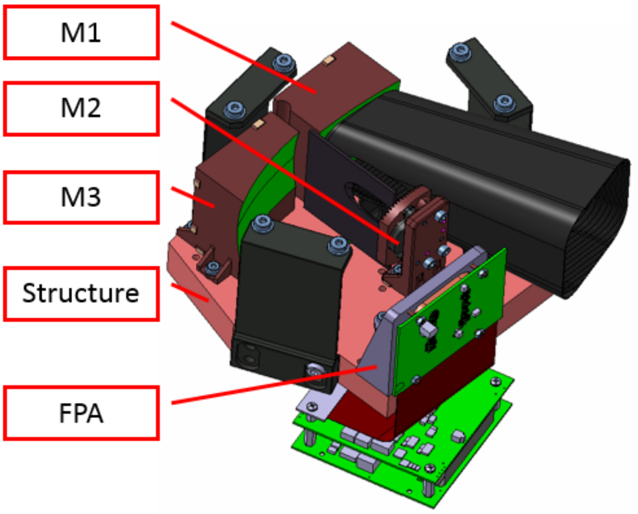

Figure 1: CSIMBA instrument preliminary design (axonometric view)

5. ACCOMODATION STUDY

The proposed satellite design relies on the **12U platform** developed by Aerospacelab. Similar to the platform baselined for the PROBA-V Companion Cubesat, it has a more optimized volume allocation. It is equipped with S- and X-band radios, deployable (4) solar arrays, a Power Conditioning and Distribution Unit, GNSS receivers, battery packs and a 3 axis attitude control stack. The proposed internal layout is shown in Figure 2.

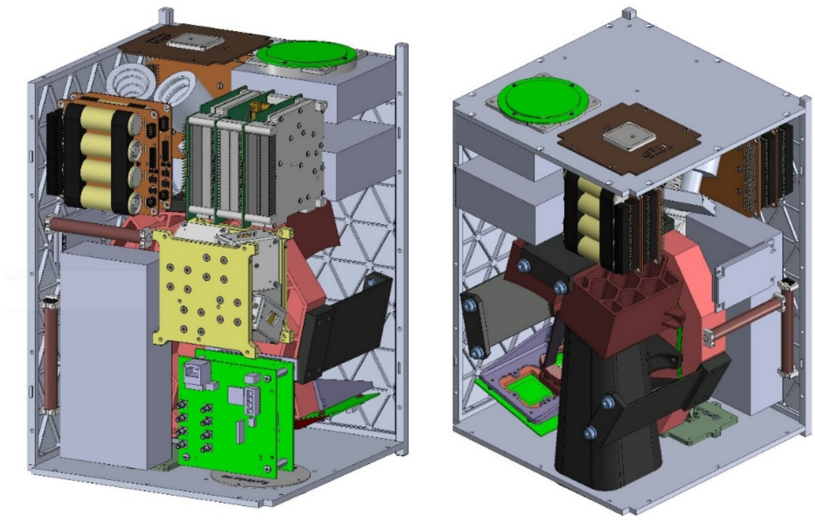

Figure 2: Proposed internal layout of the 12U CubeSat

6. PRELIMINARY MISSION DEFINITION

Orbit A sun-synchronous orbit with 500km altitude, 10:30 overpass time and a 1 year lifetime was proposed in the preliminary mission definition. With suitable data reduction, the data budget allows repeated monitoring of agricultural sites, in line with the mission objectives. The results obtained pave the way for a successful IOD mission.

The missions lifetime will be divided into following phases:

- Launch and early orbit (LEOP)
- Commissioning
- Operations: image acquisition for various purposes
- Experiments: evaluation of imaging modes and orbit maintenance approaches
- End of life: passivation of energetic subsystems, deorbit by natural orbit decay

Data generation and budget is summarized in Table 1**.**

Table 1: Data budget

data volume/day	5700	MB
data volume per sq km	0.5	MB
data volume for a 25kmx25km ROI:	312.5	MB
number of 25x25 ROIS per day	18	MB
with compression ratio 2.5:	45	MB
area per covered/week	80000	sq km
with compression ratio 2.5:	200000	sq km

7. CONCLUSION

CHIEM-c answers essential questions about the usability of the hyperspectral image sensor chips developed in the CHIEM project for a small hyperspectral mission. The results obtained pave the way for a successful IOD mission.

8. PROJECT PARTNERS

The CHIEM-c project has been carried out by a consortium of 5 companies. VITO, as prime, was responsible for the system performance analysis and preliminary mission definition. Aerospacelab carried out the accommodation study and contributed to the mission definition from the platform perspective. Amos performed the Optomechanical design and Deltatec the ROE design. Imec was responsible for the HSI chip characterisation and packaging evaluation.

9. SCIENTIFIC OUTPUT

ESRIN 2019	S. Livens, B. Delauré, J. Blommaert and B. Paijmans: *CSIMBA hyperspectral CubeSat in orbit demonstration mission*, Proc Worskshop 'Imaging spectroscopy - Cooperation in Space, Frascati, Italy, July 2019
IGARRS 2019	J. Blommaert, B. Delauré, S. Livens, D. Nuyts, K. Tack, A. Lambrechts, Imec, R. Di Paola, V. Moreau, E. Callut, G. Habay, L. Maresi, H. Strese, A. Zuccaro Marchi, B. Deper and M. Viitala, *CSIMBA: towards a smart-spectral CubeSat costellation*, Proc. IGARRS 2019, YoKohama, Japan, July 2019.
WHISPERS 2019	S. Livens, B. Delauré, J. Blommaert and B. Paijmans: *CSIMBA: Contributing to global monitoring with a small hyperspectral mission*. Proc. WHISPERS Conf, Amsterdam, Netherlands, Sept 2019.