# Methodology for the selection of an optimal optical sensor for a 6U CubeSat constellation

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**ABSTRACT**

The payload, in defining the central objective of a satellite mission, plays a critical role in determining the overall efficiency of the satellite. Consequently, the satellite's effectiveness is strongly influenced by both the payload itself and its configuration. Given the essential importance of choosing an optimal payload and aware of the direct impact it has on the success of a space mission, this article presents a methodology for selecting an optical sensor intended for the 6U CubeSat constellation of the FACSAT-3 mission and future space missions of the Colombian Aerospace Force (FAC). The methodology includes the definition of mission objectives, definition of key parameters, performance modeling, risk and reliability assessment, and other critical aspects that influence mission efficiency and success.



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## 1. INTRODUCTION

The Colombian Aerospace Force (FAC) has determined the adoption of reduced-size satellite platforms with the purpose of obtaining images of the Earth's surface. Currently, the FAC has launched two satellites into space, named FACSAT-1 and FACSAT-2 (Chiribiquete), which have been deployed as an integral part of the FACSAT program. These CubeSats, designed and configured specifically for Earth observation, have been equipped with optical capture technology that covers both the RGB spectrum and various spectral bands. Thanks to this advanced technology, it has been possible to obtain highly detailed and diverse images of the national territory, thus providing a valuable source of information for various applications and analyses.

Given the critical importance of selecting optical sensors for future FAC space missions, it is imperative to have a methodology that facilitates the selection of the most suitable payload. This is because the quality of the sensor has a direct impact on obtaining the data necessary to achieve the mission's objectives. Previous research related to payload selection [1], has focused on identifying fundamental parameters such as spatial resolution, swath and coverage, as well as spectral aspects such as bandwidth and number of bands, and radiometric aspects such as quantization and dynamic range. However, this study highlights the lack of studies on evaluations of the efficiency of the image acquisition system, which could be valuable for evaluating a system and comparing its performance with others. These evaluations could provide considerable value by allowing the evaluation of a system and the comparison of its performance with others available on the market.

On the other hand, other studies conducted by researchers have addressed essential characteristics for selecting an optical payload [2], emphasizing the importance of spatial resolution and spectral range as determining factors in the quality and usefulness of the data obtained. These investigations serve as valuable foundations for developing a comprehensive methodology that considers both traditionally highlighted parameters and those that may go unnoticed but are crucial for a complete and effective evaluation of image acquisition systems in the context of space missions. The primary objective of this study is to develop a methodology for selecting the most suitable optical sensor to be integrated as a payload in future FAC satellite missions. This methodology addresses a variety of critical factors and aspects that influence the effectiveness and success of the mission, including the simulation of images obtained with these sensors, which allows anticipating the quality of the data that would be obtained with the selected sensor.

## 2. METHOD

The payload defines the mission purpose of the satellite. Therefore, the satellite's efficiency depends significantly on the payload and its configuration [1]. Specifically, in the field of electro-optical payloads, the detection of light signals emitted or reflected by an object is carried out using various types of sensors. Subsequently, this signal is processed and transformed into digital format [3]. The considerations to weigh when choosing an optical payload are diverse, as discussed in previous research, with references such as [1], [2] standing out. In this context, not only these variables have been considered but also others that are crucially relevant in the process of selecting an optimal optical sensor for the configuration of the CubeSat constellation addressed in this study. Figure 1 presents the methodology developed based on the experience accumulated in the first two missions of the FACSAT program, which will be of great value in selecting the optimal optical sensor for the FACSAT-3 constellation.

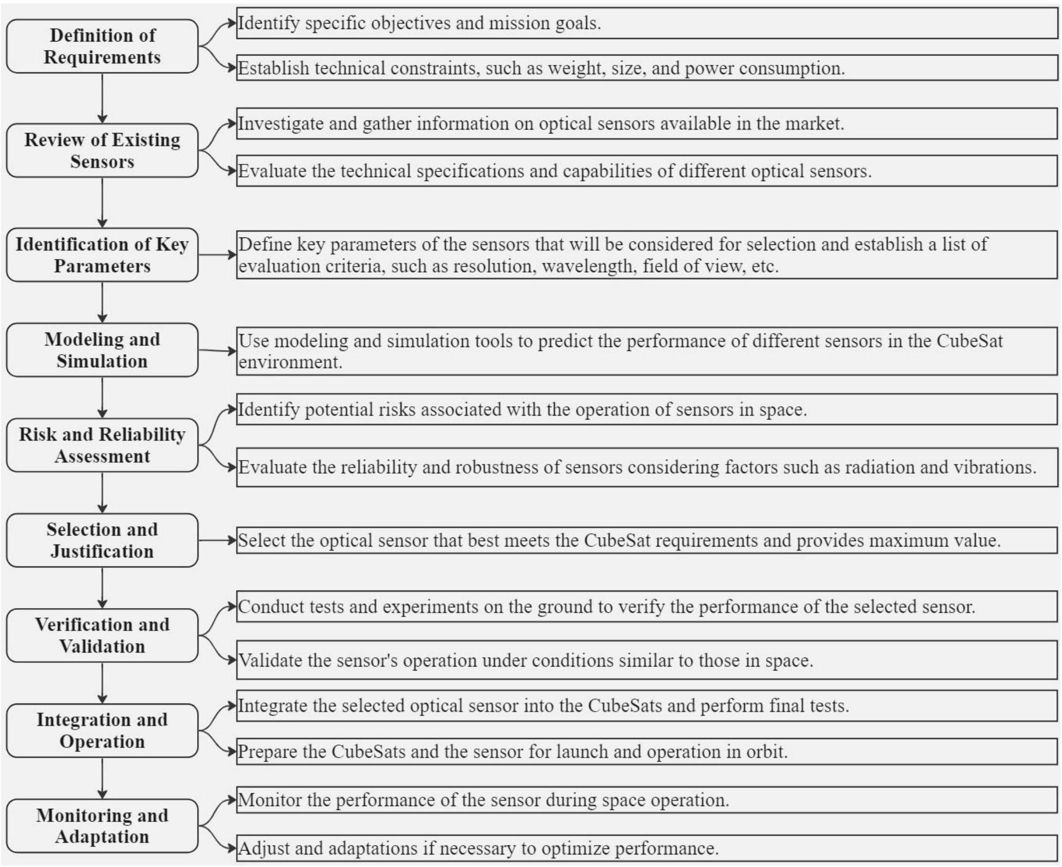



Figure 1. Methodology for selecting an optimal optical sensor

This methodology establishes a structured framework for the precise selection of a suitable optical sensor for a CubeSat, ensuring a comprehensive evaluation of a wide range of relevant factors. In the initial phase of the FACSAT-3 mission, the selection of the optical sensor is in its early stages and is exclusively focused on the four initial factors of the methodology mentioned earlier. These four factors are the central focus of this study, and the following is a detailed definition of each of them.

## 2.1. Definition of requirements

### 2.1.1. Identifying specific objectives and mission

The objectives and missions of CubeSats, miniaturized satellites with a standardized format, are as diverse as the needs and priorities of each project [4]. These versatile devices, with significant potential, can address a wide range of applications, from Earth observation and environmental monitoring to deep space scientific research. The choice of mission depends not only on scientific or commercial interests but also on factors such as available technology and allocated financial resources, influencing the complexity and scope of the objectives.

Table 1 provides an overview of some specific missions that could be implemented by a CubeSat constellation. These missions include, but are not limited to, climate and environmental monitoring, tracking natural disasters such as hurricanes and earthquakes, maritime and terrestrial surveillance for security and defense, as well as astronomical research and deep space exploration. Each of these missions has its own unique requirements and technical challenges, and the selection of these missions will depend on the specific objectives of the project and the capabilities of the available CubeSats:

Table 1. Specific CubeSat missions

| Mission | Description |
|---|---|
| Earth observation | A CubeSat constellation can be designed to observe Earth from space and collect data on vegetation, air quality, natural disasters, and other terrestrial phenomena [5], [6]. |
| Communications | A CubeSat constellation can implement a communication network that provides global connectivity services, especially in remote or poorly connected areas [7]. |
| Climatological studies | CubeSats can be used to conduct measurements and detailed studies on climate change [8], ocean temperature, atmospheric circulation patterns, and other phenomena related to global climate [9]. |
| Interplanetary missions | CubeSats are considered by NASA for interplanetary missions due to their small size and reduced cost. The option to launch multiple CubeSats increases precision and redundancy. NASA is testing CubeSats for interplanetary exploration, demonstrating promising potential in this field [10]. |

### 2.1.2. Establishing requirements and constraints

Establishing requirements and constraints is a crucial aspect in the design and selection of an optical sensor for a 6U CubeSat. These CubeSats, characterized by their compact size and low weight, impose certain limitations that must be considered when choosing the appropriate optical equipment. A 6U CubeSat [11] consists of six-unit modules, resulting in approximate dimensions of 10×20×30 cm and a maximum mass of up to 15 kg [12]. These compact dimensions and limited weight impose significant restrictions on the size, weight, and power consumption of the optical sensor that can be integrated into the satellite. These specific limitations have been the subject of study in previous research, where various aspects to consider have been identified [13]. Some of the key aspects that influence the optical sensor selection process include:
- Given its current state of standardization, the need for adherence to basic requirements and limitations is imposed, with a particular focus on aspects related to dimensions and configuration.
- Specifications and limitations are established concerning the deployment subsystem, covering aspects such as the maximum allowed mass, packaging configuration, and precise arrangement of access openings to the CubeSat, among others.
- Requirements concerning the launch platform that will host the deployment devices.
- Requirements and limitations related to the launch phase, which are linked to the use of high-risk components such as fuel and propulsion systems.
- Regulatory guidelines and limitations that pertain to compliance with legislation and international agreements related to space utilization.
- Inherent requirements and limitations in the design, development approach, and payload specifications, among other interrelated aspects.

## 2.2. Identification of key parameters

The assessment of optical sensors for satellites is of paramount importance to ensure their suitability in the accurate and reliable achievement of data acquisition objectives. In this context, Table 2 outlines critical parameters whose evaluation is imperative in both the selection process and the design of optical sensors intended for implementation in satellites:

Table 2. Critical parameters for the selection of an optimal optical sensor [14], [15]

| Parameter | Description |
|---|---|
| Spatial resolution | Spatial resolution indicates the sensor's ability to accurately detect objects and details on the Earth's surface, measured in meters per pixel [16]. |
| Spectral resolution | The spectral resolution of the sensor involves discerning between various wavelengths in the Electromagnetic spectrum, capturing information in multiple spectral bands such as visible, near-infrared, and thermal infrared. |
| Radiometric Quality | Radiometric quality is related to the accuracy in measuring the intensity of the electromagnetic radiation reflected or emitted by the Earth [17]. |
| Bandwidth | The bandwidth is the range of wavelengths capturable by the sensor. Surfaces and objects emit radiation at various wavelengths. A larger bandwidth provides more detailed information about the composition and properties of the Earth. |

When evaluating optical sensors for satellites, it is essential to find a balance between these parameters to meet the mission objectives. The required specifications will vary depending on the specific application of the satellite, whether it is for environmental monitoring, agriculture, mapping, or other applications.

### 2.3. Review of existing sensors

The comprehensive review of commercially available optical sensors is a crucial process in the development of a CubeSat, but also one that demands a considerable investment of time and resources. This stage is essential to ensure the selection of the sensor that best fits the technical and budgetary requirements of the mission. To optimize this search, it is essential to consider various factors, from the sensor's technical specifications, such as resolution and sensitivity, to its compatibility with the CubeSat's system and its performance history in similar missions:

- Investigate commercial optical sensors available: This process can be time-consuming, and it is important to dedicate sufficient time to research and analysis to find the most suitable optical sensor for specific needs. The following are essential considerations to guide the search:
- Define requirements: Clearly establish the specific requirements of the optical sensor, considering key parameters.
- Research suppliers: Investigate multiple commercial suppliers of optical sensors for CubeSats, either online, through specialized catalogs, or by directly contacting suppliers.
- Compare features: Carefully compare the technical features of optical sensors offered by suppliers with the previously defined requirements.
- Evaluate quality and reliability: In addition to technical specifications, assess the quality and reliability of the sensors. Investigate the reputation of suppliers and seek opinions from other users.
- Consult experts: Seek advice from experts in space technology or engineers with experience in CubeSats to obtain recommendations based on their knowledge.
- Make an informed decision: After researching, comparing, and evaluating, make an informed decision about the most suitable optical sensor, considering technical aspects, quality, reliability, and cost.

### 2.4. Simulation of images to anticipate and evaluate the data quality to be obtained

Despite the diversity of approaches available for image simulation, to date, we lack a framework that organizes them systematically. Addressing this need, a structure is presented. Table 3 is designed for the purpose of categorizing the various methods proposed in this field.

Table 3. Proposed methods for image simulation [17]–[19]

| Classification | | Description |
|---|---|---|
| Analog-based | Diorama/Model | Analog approaches simulate images using controlled physical platforms, replicating solar illumination, and adjusting optical parameters. By varying camera and solar angles, they generate simulated images. |
| Hybrids | Diorama + Computer | A hybrid method for simulating multispectral scenarios combines physical models, lighting, and computer vision. It allows for the integration of variations and materials but may require manual editing due to its complexity. |
| Computer-based | Based on Existing images | Satellite image simulation creates images like those captured by satellites using existing images from other sensors to reproduce situations, atmospheric conditions, lighting, and other relevant factors. |
| | Fully synthetic | Fully synthetic satellite images are computationally generated without real captures. They use mathematical models and simulated data to emulate the appearance of images obtained by real satellite sensors. |

## 3. RESULTS AND DISCUSSION

Through the previously established methodology, the selection of an optimal optical sensor for the CubeSats 6U constellation is to be achieved. Since the mission planning phase is in its initial stages, this project focuses exclusively on the first four criteria of the process: requirements definition, identification of key parameters, comprehensive review of existing sensors, modeling, and simulation. A detailed description of each of these criteria is presented below.

### 3.1. Definition of requirements

#### 3.1.1. Identify the objectives and specific mission

The implementation of highly accurate and efficient agricultural approaches [20], together with forestry management aimed at natural disaster reduction [21], sustainable urban planning [22], and global surveillance in defense fields, have significantly strengthened the relevance of earth observation satellites [23]. Taking into account the above and considering the transcendental relevance that the availability of an earth observation satellite implies for our country, especially in the context of the space applications proposed by the Colombian Space Commission and that can be observed in Figure 2. The National Government has expressed the need to acquire earth observation satellites [24] with the purpose of correcting the insufficiency in the access to images of the national territory, as evidenced in the CONPES 3683 and 3983 reports [25], [26].

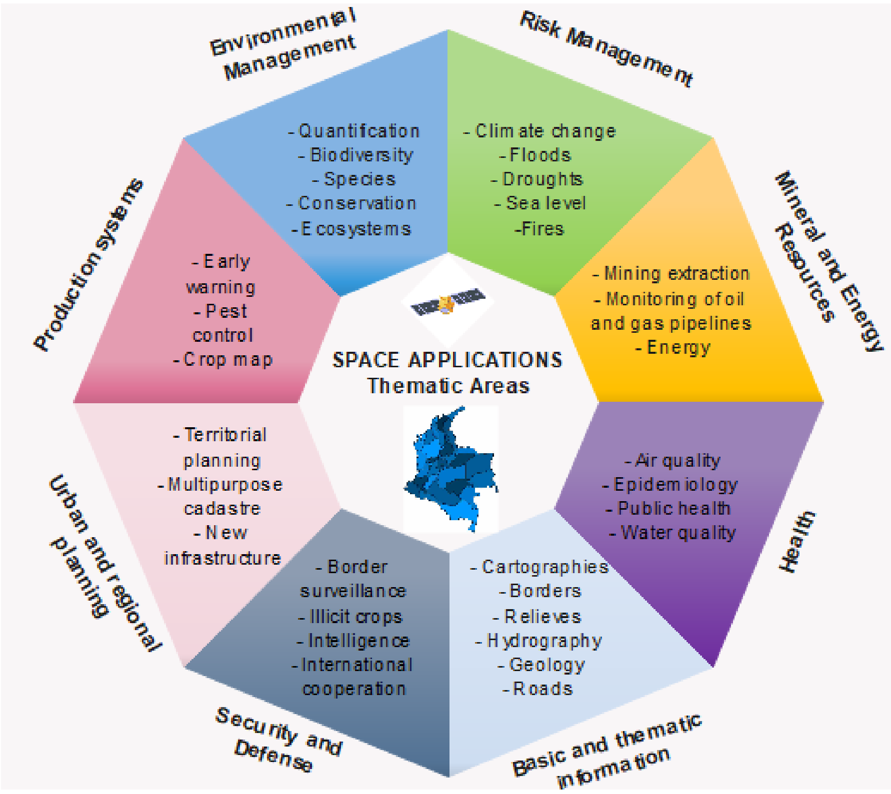



Figure 2. Space applications proposed by the Colombian Space Commission

In accordance with what was previously mentioned, in November 2018, the FAC successfully achieved the deployment of its first earth observation satellite, the FACSAT-1. This satellite allowed the acquisition of images in the red, green, and blue (RGB) spectrum of the national territory and culminated its operational life cycle in June 2023. Subsequently, as an integral part of the second phase of the space project, the successful launch of FACSAT-2, also known as Sat Chiribiquete, was carried out. This satellite has two payloads, with the presence of a sophisticated multispectral optical sensor being a significant highlight. The technical specifications of both CubeSats are detailed shown in Table 4.

The third phase of the FACSAT project will remain focused on Earth observation, with the central objective of addressing a challenge previously identified in the initial phases: the reduction of the revisit period as much as possible. To achieve this goal, three CubeSats are planned to be launched, which will coexist in the same orbit, but will be deployed at different times. In parallel, the integration of a higher quality optical sensor and improved capabilities to optimize data acquisition is being pursued.

#### 3.1.2. 6U CubeSat requirements and constraints

Given the advantages previously recognized in 6U CubeSats during the FACSAT-2 mission, the FAC has determined that the FACSAT-3 constellation will be composed of three 6U CubeSats. Therefore, the requirements and limitations inherent to CubeSats in these technical specifications are considered.

– Size and volume: A 6U CubeSat has a standard configuration of 30×20×10 cm, which is equivalent to six 1U units. This results in a total volume of 12 liters.
– Mass: The maximum recommended mass for a 6U CubeSat is generally in the range of 10 to 15 kilograms.
– Power: 6U CubeSats typically have a limited power generation capability, generally ranging from 10 to 40 watts.
– Mission lifetime: Due to its limited resources and compact size, the typical lifetime of a 6U CubeSat is usually relatively short, although this can vary depending on the design and mission objectives.

Table 4. FACSAT-1 and FACSAT-2 technical characteristics

| Characteristic | FACSAT-1 | FACSAT-2 |
|---|---|---|
| Orbit type | LEO | LEO |
| Format | CubeSat 3U | CubeSat 6U |
| Mass | Mass 4 kg | Mass 10 kg |
| Communication system | UHF | Band X, S |
| Orbital inclination | 12° | 16° |
| Height | 500 km | 500 km |
| Optical sensor | Gom X3 | Simera MultiScape100 CIS |
| IFOV | 30 mts | 4,75 mts |
| FOV | 30 km | 30 km |
| Spectral resolution | RGB | 08 bands |
| Radiometric resolution | 12 bits | 16 bits |
| Status | End of useful life | In orbit |

### 3.2. Review of commercially available optical sensors for CubeSats 6U and classification of their characteristics based on previously identified key parameters

After defining that the FACSAT-3 mission would be oriented towards Earth observation and establishing the specific parameters and limitations inherent to a 6U CubeSat, the next step involved a meticulous investigation of the optical sensors available on the market. In this process, priority attention was given to the adaptability of these sensors to the intrinsic constraints of the 6U CubeSats, in line with the critical parameters previously defined. The fundamental purpose of this inquiry was to select a triad of the most suitable optical sensors for incorporation into the satellite constellation. Table 5 lists the optical sensors identified as available on the market:

After performing this categorization of the characteristics of the CubeSats available on the market, two optical sensors emerged as the standouts: the MultiScape100 CIS optical sensor and the DF CAIMAN. These sensors have been shortlisted for further analysis to determine which of the two is more appropriate. It should be noted, however, that this detailed study will not be addressed in the context of this paper.

### 3.3. MultiScape 100 CIS simulation with EO-1 Hyperion data

After the selection of the two previously mentioned sensors, we moved on to the modeling and simulation stage. In this context, we carried out a spectral simulation exclusively for the images generated by the MultiScape100 CIS sensor. The spectral simulation of the DF CAIMAN sensor was not performed due to the lack of information on the spectral range covered by each captured band of this sensor, essential information to carry out an accurate simulation. For the simulation of the data to be obtained from the Multiscape100 CIS sensor, a computational method based on existing images was used. It is important to note that there are more sophisticated approaches that can generate fully synthetic data, such as digital imaging and remote sensing image generation (DIRSIG) software, developed by NASA and the Rochester Institute. DIRSIG is an advanced tool specifically designed for generating synthetic images with a high level of realism and accuracy. This software is versatile and is used in a variety of applications, with a prominent focus on space mission planning and design. This software has been employed in high-profile missions, such as NASA's Landsat mission, underscoring its importance and reliability in data simulation for critical applications in remote sensing and remote sensing.

Table 5. Commercially available optical sensors that can be integrated into a 6U CubeSat

| Optical sensor | (GSD) 500 km | (Swath) 500 km | Mass | Spectral bands | Physical size | Satellite options (CubeSat types) | Radiometric resolution | Flight assets |
|---|---|---|---|---|---|---|---|---|
| DF GECKO | 39 m | 80 km | 0.4 kg | RGB (Bayer Pattern) | 1U (10×10×6.5 cm) | Compatible with 1U or 2U | 8 o 12 bit | 12 releases, 7 launches between 2018-2022 4 space missions |
| DF MANTIS | 32 m, PAN 16 m, HS 32 | 32 km | 0.5 kg | 6 MS, 150 HS | 1U (10×10×6.5 cm) | Compatible with 1U or 2U | 8 o 12 bit | 1 Launched 2021 |
| DF CHAMALEON | 20 m, PAN 10 m, HS 20 m | MS 40 km, HS 20 km. | 1.6 kg | 6 MS, 150 HS | 2U (10×10×20 cm excluding electronics) (10×10×21.5 cm with CCU incorporated) | Compatible with 3U or 6U | 8 o 12 bit | 2 launches in 2022 |
| DF CAIMAN | PAN 3.25 m MS 6.25 m | 13 km | 1.8 kg | 7 MS | 2.5U (10×10×25 cm excluding electronics) (10×10×26.5 cm with CCU incorporated) | Compatible with 6U | 8 o 12 bits | NA |
| KAIROS | 5 m Mult, 3 PAN | 9.95 km | 1.4 kg | 7 bands (RGB, Red Edge, NIR, PAN) | 101×243 (±1) mm | Designed to fit CubeSat platforms | 14 bits | Validation in space |
| HYPERSCAPE100 | 4.75 m | 19.4 km | 1.2 kg | 32 bands (487 – 810 nm) | 98×98×176 mm | Designed to fit CubeSat platforms | 16 bits | Not registered |
| HYPERSCOUT S | 19 m | 80 km | 1.6 kg | 16 bands (450-950) | 1.6 liters | Designed to fit CubeSat platforms | 12 bits | Validation in space |
| SOP 120 | 5 m | 20 km | 1.8 kg | 3 (RGB) or 1 (PAN/NIR) | 250×150×150 mm | Designed to fit CubeSat platforms | 12 bits | Not registered |
| SOP 3U | 4.46 m | 18 km | 0.6 kg | 3 (RGB) or 1 (PAN/NIR) | 105×105×315 mm | Designed to fit CubeSat platforms | 12 bits | Not registered |

The method based on existing images, as its name indicates, its main input are already existing images that are subjected to transformations or modeling to obtain the simulated image in which one or some of its resolutions (spatial, spectral, radiometric) or aspects related to them change. It can be applied both to simulate new products, for example: images from a new sensor as in this case, and to analyze certain behaviors of remote sensing in specific applications. Spectral simulation is feasible when the source sensor has a higher spectral resolution than the sensor to be emulated. The simulation process involves the estimation of the Gaussian spectral response function (SRF) for each channel, using the corresponding center and bandwidth (full width at half maximum (FWHM)). The SRF is defined as (1):

$$R_i(\lambda) = \frac{1}{\sigma\sqrt{2\pi}} e^{-0,5(\lambda-\mu)^2/\sigma^2} \quad (1)$$

where $Ri(\lambda)$ represents the spectral response, μ denotes the band center, σ indicates the standard deviation (equivalent to the FWHM) of the channel, and λ refers to the wavelength relative to μ. The integral over the SRF equals 1. Subsequently, the channels with the highest spectral resolution in the image (in this case, Hyperion) that are within the selected wavelength range of the image to be simulated (MultiScape100 CIS) are combined using (2):

$$\rho_{res}(\lambda_i) = \frac{\int_{\lambda_1}^{\lambda_2} \rho(\lambda) R_i(\lambda) \mathrm{d}\lambda}{\int_{\lambda_1}^{\lambda_2} R_i(\lambda) \mathrm{d}\lambda} \quad (2)$$

where $\rho_{res}(\lambda_i)$ is the resampled spectrum using the continuous spectrum in the integration interval $\rho(\lambda)$ and the SRF function of $R_i(\lambda)$. This mathematical operation, called deconvolution, is achieved by integration between the lower $(\lambda_1)$ and upper $(\lambda_2)$ wavelengths of the image channel to be simulated. In this study, Hyperion hyperspectral bands will be combined for the purpose of simulating the multispectral bands of the MultiScape100 CIS sensor. The general procedure involves performing a weighted sum of the Hyperion bands spanning each of the bands of the MultiScape100 CIS sensor. An image of Hyperion observed in Figure 3, has 242 hyperspectral bands spanning the range of 400 to 2,500 nm, with a spatial resolution of about 30×30 m and a spectral resolution of about 10 nm. A complete scene captured by this sensor spans an area of 256 pixels (7.7 km wide) by 6,072 scanning swaths (185 km long) as can be seen in Table 6. The MultiScape100 sensor incorporates a 7-band multispectral filter with the characteristics detailed in Table 7.

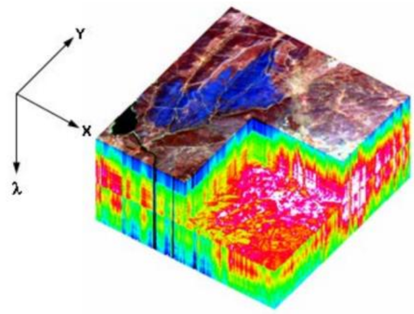



Figure 3. Data cube of a hyperspectral image from the EO-1 Hyperion sensor [27]

Table 6. Calibrated and uncalibrated bands of EO-1 Hyperion. Adapted from: [28]

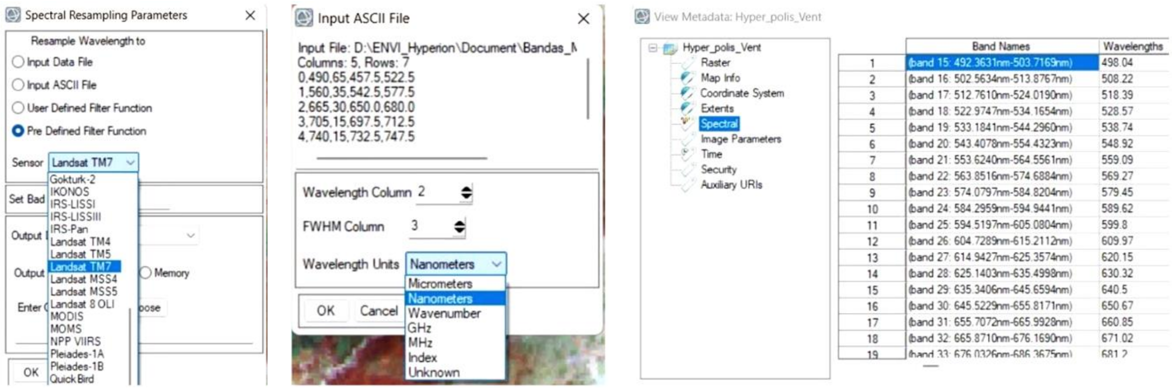
| Bands | No. Band | Bandwidth (nm) | Status |
|---|---|---|---|
| Bands VIS - IRC | 1-7 | 356 - 417 | Non-calibrated |
| | 8 - 55 | 426 - 895 | Calibrated |
| | 56 - 57 | 913 - 926 | Calibrated (overlap with SWIR) |
| | 58 - 70 | 936 - 1058 | Non-calibrated |
| Bands SWIR | 71 - 76 | 852 - 902 | Non-calibrated |
| | 77 - 78 | 912 - 923 | Calibrated (overlap with VIS – IRC 56 – 57) |
| | 79 - 224 | 933 - 2396 | Calibrated |
| | 225 - 242 | 2406 - 2578 | Non-calibrated |

Table 7. Filter specifications. Adapted from: [29]

| Bands | Central wavelength (nm) | Bandwidth (nm) | Initial cut (nm) | Final cut (nm) |
|---|---|---|---|---|
| 0 | 490 | 65 | 457,5 | 522,5 |
| 1 | 560 | 35 | 542,5 | 577,5 |
| 2 | 665 | 30 | 650,0 | 680,0 |
| 3 | 705 | 15 | 597,5 | 712,5 |
| 4 | 740 | 15 | 732,5 | 747,5 |
| 5 | 783 | 20 | 773,0 | 793,0 |
| 6 | 842 | 115 | 784,5 | 899,5 |

The spectral simulation process based on pre-existing images is incorporated in the ENVI digital image processing software, using the spectral resampling algorithm. This algorithm has predefined filter functions for various sensors, such as TM, ETM+, SPOT, ASTER, MODIS, SPOT, AVHRR, among others, as illustrated in Figure 4(a).

As shown in Figure 4(a), the predefined filter function for the MultiScape100 CIS sensor is not available. Therefore, it is imperative to establish it using one of the remaining three methods. In this instance, we will use the input ASCII file method, which requires the creation of a text file with two columns: center wavelength and FWHM (spectral width). It is essential to have knowledge about their units of measurement, which in this case are nanometers, as shown in Figure 4(b). To carry out the spectral resampling process, it is essential that the reference image data file (in this case, Hyperion) includes in its metadata the values corresponding to the centers of the wavelength bands, as well as their respective values of spectral width (FWHM), as illustrated in Figure 4(c). Figure 5 shows the result of the spectral simulation of the bands of the multispectral sensor MultiScape100 CIS, obtained from the bands of the image captured by the hyperspectral sensor Hyperion.



(a) (b) (c)

Figure 4. Spectral simulation process: (a) Initially, the spectral resampling parameters option is selected in ENVI to apply the spectral resampling algorithm, (b) then the input ASCII file of spectral resampling option is selected including the unit of measurement in millimeters, (c) verification of the metadata with spectral information of the Hyperion bands

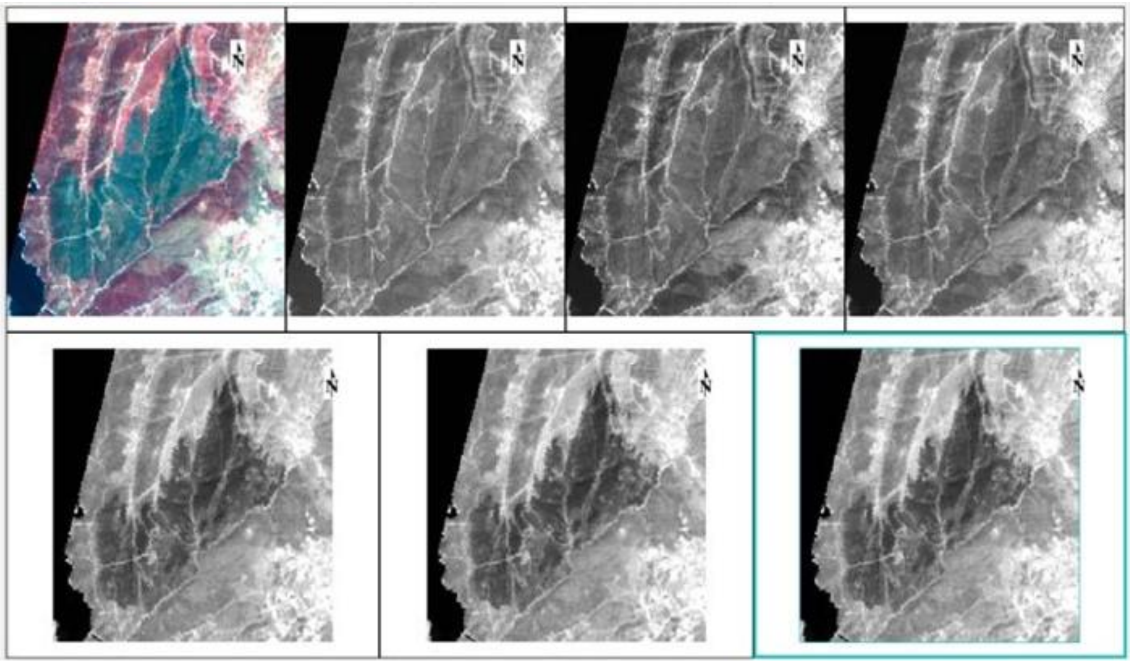


Figure 5. ENVI spectral simulation results

## 4. CONCLUSION

The creation of a robust and efficient methodology for the selection of a suitable optical sensor for a constellation of 6U CubeSats of the FACSAT-3 mission is of significant relevance in today's space exploration landscape. Throughout this research study, this task was approached with a meticulous and comprehensive approach. Initially, the specific requirements of the CubeSats constellation were precisely identified, recognizing the diversity of missions and objectives that can be pursued with these small spacecrafts. Next, a wide range of commercially available optical sensor options were evaluated, taking into account both their technical capabilities and limitations.

Progress was made in the initial phase to select the optimal optical sensor best suited to the requirements of the FACSAT-3 CubeSats constellation, ensuring that it can provide the data quality needed to achieve our scientific and technological objectives. Ultimately, it is worth noting that this methodology provides a robust and systematic guide to address one of the key challenges in designing space missions with CubeSats. By following this approach, the CAF can make informed decisions that contribute to the success of its projects and the continued advancement of space exploration.

## REFERENCES


[1] D. R. M. Samudraiah, M. Saxena, S. Paul, P. Narayanababu, S. Kuriakose, and A. S. Kiran Kumar, "Payload configurations for efficient image acquisition – Indian perspective," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XL–8, pp. 1201–1206, Nov. 2014, doi: 10.5194/isprsarchives-XL-8-1201-2014.

[2] B. Baran, B. O. Martinez, and M. Baran, "Multi-objective optimization in the selection of a CubeSat PayLoad," in *2021 IEEE International Conference on Aerospace and Signal Processing (INCAS)*, 2021, pp. 1–4, doi: 10.1109/INCAS53599.2021.9666919.

[3] R. G. Congalton, "Remote sensing and image interpretation. 7th edition," *Photogrammetric Engineering & Remote Sensing*, vol. 81, no. 8, pp. 615–616, Aug. 2015, doi: 10.14358/PERS.81.8.615.

[4] D. Jhunjhunwalla, D. P. Mishra, J. K. Sahu, D. Hembram, and S. R. Salkuti, "Satellite mission to study the Van Allen belts," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 31, no. 3, pp. 1400–1407, Sep. 2023, doi: 10.11591/ijeecs.v31.i3.pp1400-1407.

[5] J. Crusan and C. Galica, "NASA's CubeSat launch initiative: enabling broad access to space," *Acta Astronautica*, vol. 157, pp. 51–60, Apr. 2019, doi: 10.1016/j.actaastro.2018.08.048.

[6] D. P. Roy, H. Huang, R. Houborg, and V. S. Martins, "A global analysis of the temporal availability of PlanetScope high spatial resolution multi-spectral imagery," *Remote Sensing of Environment*, vol. 264, Oct. 2021, doi: 10.1016/j.rse.2021.112586.

[7] A. J. Camps, J. A. Ruiz-de-Azua, A. Perez-Portero, L. Fernandez, and J. F. Munoz-Martin, "Evolving capabilities and limitations of future CubeSat missions," in *Next Generation CubeSats and SmallSats*, Elsevier, 2023, pp. 79–120.

[8] C. Kok Yang, F. Pei Shan, and T. Lea Tien, "Climate change detection in Penang Island using deterministic interpolation methods," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 1, pp. 412–419, Jul. 2020, doi: 10.11591/ijeecs.v19.i1.pp412-419.

[9] J. Loisel, "CubeSat technology and periglacial landscape analysis," in *Treatise on Geomorphology*, Elsevier, 2022, pp. 18–29.

[10] G. Benedetti *et al.*, "Interplanetary CubeSats for asteroid exploration: mission analysis and design," *Acta Astronautica*, vol. 154, pp. 238–255, Jan. 2019, doi: 10.1016/j.actaastro.2018.05.011.

[11] S. F. Sabri, N. A. Ahmad, S. Sahibuddin, and R. Dziyauddin, "Dynamic frequency scheduling for CubeSat's on-board and data handling subsystem," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 22, no. 3, pp. 1672–1678, Jun. 2021, doi: 10.11591/ijeecs.v22.i3.pp1672-1678.

[12] C. Cappelletti and D. Robson, "CubeSat missions and applications," in *CubeSat Handbook*, Elsevier, 2021, pp. 53–65.

[13] C. Nieto-Peroy and M. R. Emami, "CubeSat mission: from design to operation," *Applied Sciences*, vol. 9, no. 15, Aug. 2019, doi: 10.3390/app9153110.

[14] "CubeSat information," *ISISPACE*. https://www.isispace.nl/cubesat-information/#requirements-constraints (accessed Aug. 08, 2023).

[15] K. Merry, P. Bettinger, M. Crosby, and K. Boston, "Remote sensing," in *Geographic Information System Skills for Foresters and Natural Resource Managers*, Elsevier, 2023, pp. 269–301.

[16] A. Valenzuela, K. Reinke, and S. Jones, "A new metric for the assessment of spatial resolution in satellite imagers," *International Journal of Applied Earth Observation and Geoinformation*, vol. 114, Nov. 2022, doi: 10.1016/j.jag.2022.103051.

[17] M. T. Razzak, G. Mateo-García, G. Lecuyer, L. Gómez-Chova, Y. Gal, and F. Kalaitzis, "Multi-spectral multi-image super-resolution of Sentinel-2 with radiometric consistency losses and its effect on building delineation," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 195, pp. 1–13, Jan. 2023, doi: 10.1016/j.isprsjprs.2022.10.019.

[18] C. A. Stelle, F. J. A. López, and M. A. U. Cámara, "Simulation of synthetic images using free software (Blender)," (in Spanish) *Academic Journal*, vol. 27, no. 191, pp. 22–29, 2018.

[19] C. T. Judianto and E. N. Nasser, "The analysis of LAPAN-A3/IPB satellite image data simulation using high data rate modem," *Procedia Environmental Sciences*, vol. 24, pp. 285–296, 2015, doi: 10.1016/j.proenv.2015.03.037.

[20] B. Edwin *et al.*, "Smart agriculture monitoring system for outdoor and hydroponic environments," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 25, no. 3, pp. 1679–1687, Mar. 2022, doi: 10.11591/ijeecs.v25.i3.pp1679-1687.

[21] M. Aitimov *et al.*, "Predicting and detecting fires on multispectral images using machine learning methods," *International Journal of Electrical and Computer Engineering*, vol. 14, no. 2, pp. 1842–1850, Apr. 2024, doi: 10.11591/ijece.v14i2.pp1842-1850.

[22] M. Alansaari *et al.*, "Sharjah-sat-2: an earth observing satellite for sustainable urban development," in *2024 International Conference on Global Aeronautical Engineering and Satellite Technology (GAST)*, Apr. 2024, pp. 1–4, doi: 10.1109/GAST60528.2024.10520756.

[23] "Satellite-based earth observation market report by solution (data, value added services), end user (defense and intelligence, infrastructure and engineering, agriculture, energy and power, and others), and region 2024-2032," *imarcgroup.com*, 2023. https://www.imarcgroup.com/satellite-based-earth-observation-market (accessed Aug. 25, 2023).

[24] C. Li, Q. Wang, C. Cao, and L. Ma, "An efficient imaging strategy for single pixel camera in earth observation," *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 12, no. 6, Jun. 2014, doi: 10.11591/telkomnika.v12i6.5524.

[25] "2010. CONPES 3683. Programa Nacional de Observación de la Tierra | Infraestructura Colombiana de Datos Espaciales," *Infraestructura Colombiana de Datos Espaciales-ICDE*, 2010. https://www.icde.gov.co/node/4402 (accessed Jan. 31, 2024).

[26] "Spatial development policy: enabling conditions for promoting national competitiveness," (in Spanish) *National Council of Economic and Social Policy, Republic of Colombia, National Planning Department*, 2020. https://santandercompetitivo.org/biblioteca-de-documentos/competitividad-en-colombia/conpes-3983-poltica-de-desarrollo-espacialpdf/ (accessed Aug. 25, 2023).

[27] I. Aneece and P. Thenkabail, "Accuracies achieved in classifying five leading world crop types and their growth stages using optimal earth observing-1 hyperion hyperspectral narrowbands on Google Earth Engine," *Remote Sensing*, vol. 10, no. 12, Dec. 2018, doi: 10.3390/rs10122027.

[28] E. M. F. da R. de Souza, R. S. Vicens, and C. B. M. Cruz, "Stripe Removal and Atmospheric Correction of EO-1/Hyperion Image, in the State of Rio de Janeiro," (in Portuguese), Biblioteca Digital da Memória Científica do INPE, 2011, Accessed: Jul. 09, 2024. [Online]. Available: https://www.mysciencework.com/publication/show/remoção-de-stripes-e-correção-atmosférica-de-imagem-eo1hyperion-estado-do-rio-de-janeiro-17d9dc11.

[29] "MultiScape100 CIS product," *Simera Sense*. https://www.simera-sense.com/products/multiscape100-cis/ (accessed Aug. 25, 2023).

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