Definition and Prototyping of a Statistical End-To-End Performance Simulator for Optical Imaging Sensors

SEPSO

Executive Summary

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Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

1.1. Purpose

This document is the Executive Summary of the *Definition and Prototyping of a Statistical End-To-End Performance Simulator for Optical Imaging Sensors* project, known as SEPSO, and gives an overview of the project objectives and a description of the major outcomes of the project.

The objective of SEPSO is to define and prototype a generic Statistical End-to-end Performance Simulator for Optical imaging sensors for optical passive imaging sensors in the spectral range between 0.3 and 15 µm from Earth Observation and Space Science missions.

1.2. Reference Documents

The following table specifies the reference documents that shall be taken into account during project development.

Table 1: Reference documents

Reference	Code	Title	Issue
[RB]	SEPSO-DMS-TEC-URD01	Requirements Baseline	1.13
[SUM]	SEPSO-DMS-TEC-SUM	SEPSO System User's Manual	1.0
[SVTS]	SEPSO-DMS-TEC-SVTS	SEPSO Software Validation Testing Specification	1.9
[ICD]	SEPSO-DMS-TEC-ICD	SEPSO Interface Control Document	2.2
[ADD]	SEPSO-DMS-TEC-ADD	SEPSO High Level Architecture Document	3.0
[ATBD-A]	SEPSO-DMS-ATBD-A	SEPSO Algorithms Theoretical Baseline for module A	1.7
[ATBD-BC]	SEPSO-DMS-ATBD-B	SEPSO Algorithms Theoretical Baseline for module B and C	1.10
[ATBD-DE]	SEPSO-DMI-TEC-TNOATBD	SEPSO Algorithms Theoretical Baseline for module D and E	2.7

2. SEPSO SIMULATOR

The SEPSO simulator is constituted by the executable files corresponding to Models A, B, C, D and E and the openSF infrastructure. Models are integrated into the framework, and from there on, operators are able to define and run the simulations, providing before the necessary input and configuration data required during the execution (Figure 2-1)

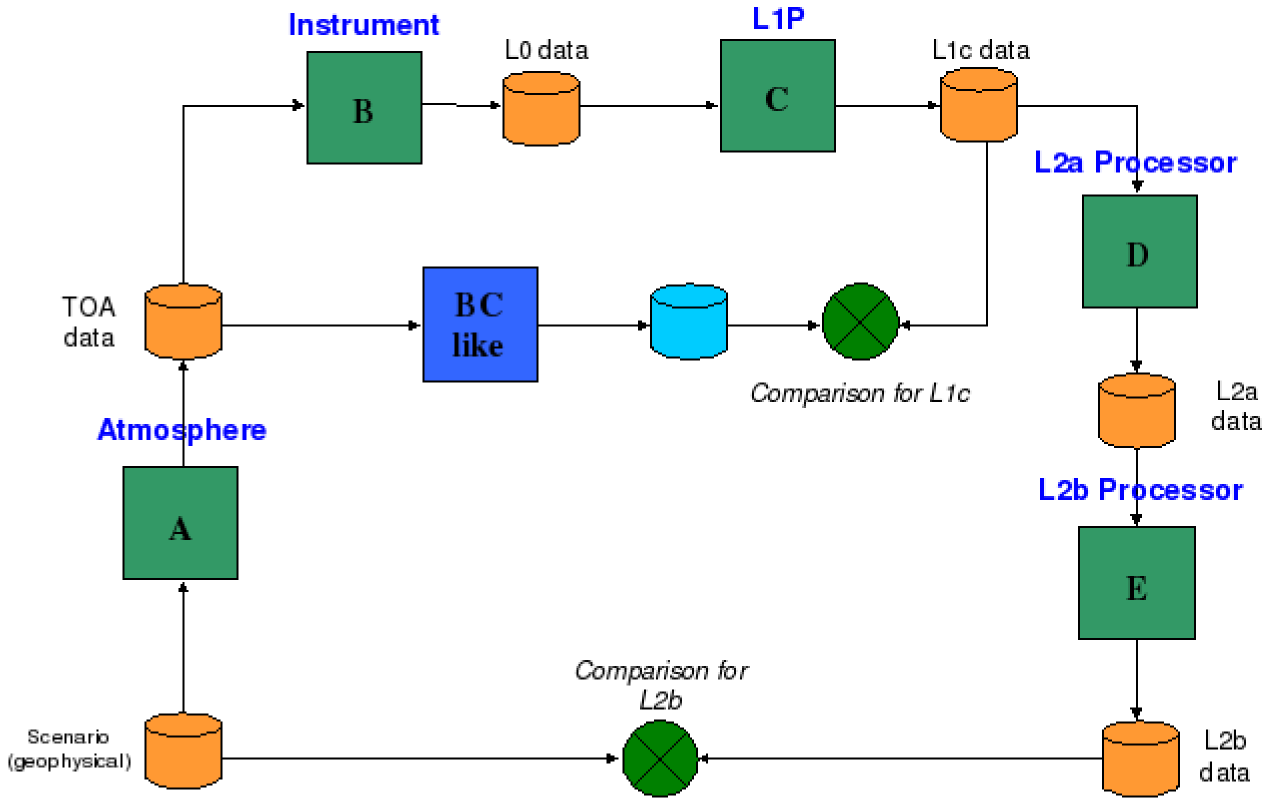

Figure 2-1: SEPSO high-level processing chain architecture

This figure shows the following elements:

- ❑ Products, depicted as cylinders, as input/output data being the subject of the process.
- ❑ Models as squares, the executable entities that will perform transformations to data.
- ❑ Tools as crossed-circles, for comparing some data products.

The core part of the SEPSO tool is the models. Here is a brief description of their objectives:

- Model A. Generate the radiance at top of atmosphere level, from a geophysical scenario.
- Model B. Simulate the effects of instrument from the Top-Of-Atmosphere (TOA) Radiance to Level 0 Data.
- Model C. Simulate effects of image processing Chain from Level 0 Data to Level 1c.
- Model D. Generate de Level 2a data, i.e. the BOA (Bottom-Of-Atmosphere) values.
- Model E. Retrieve of geophysical variable products, going from Level 2a to Level 2b data products.

SEPSO used a COTS product for the simulation infrastructure the **open Simulation Framework** (openSF) tool designed and developed by DEIMOS Space, widely used in ESA contracts.

2.1. openSF Adaptation to SEPSO

SEPSO can be run in 2 different modes, Full and Reduced.

- **Full mode** means that multiple runs are executed for the same model, each run corresponding to a different set of configuration parameters drawn statistically according user set up of the probability distributions (this is configured using openSF). The result of the multiple runs is averaged to come up with a mean and a sigma values, that is, there is a XML product with the mean values, another with the standard deviation ones.
- **Reduced mode** requires only one execution for a given set of configuration parameters. Then no average is performed and there is at end only one instance of the products (an XML output file).

This had important considerations for SEPSO as it had impact not only on those models were both running modes are possible, but also on openSF as, for Full mode execution, the framework is in charge of:

- setting the iterations by selecting the configuration parameters susceptible to be perturbed during the simulation;
- calling the models in a loop as many times as the combination of parameters has derived;
- passing the output files to the next model in the simulation

2.2. Models

2.2.1. Pre-processing Unit (PPU)

The PPU (aka pre-processing unit) is an off-line tool intended to be run before a SEPSO execution. Its usage is *recommended* because it will provide with significant information to improve the consistency of the whole runs. In SEPSO there are different systems to relate even if the simulator does not show this explicitly in the codes. On one side there is an on-board instrument with a given pixel size (pixel pitch). On the other, a ground observed from the instrument. The former is represented by Module B, the latter by module A. Being the instrument orbiting according some orbital parameters, there is a logical relation between the pointing direction from the instrument and the viewing angle of the satellite from on-ground.

2.2.2. Model A

The main task of Module A is to generate the radiance at top of atmosphere level from a geophysical scenario. The module is flexible in terms of type of input information at BOA level, configuration possibilities and type of output information. This flexibility is achieved by means of two radiative transfer codes:

- libRadtran. libRadtran software package is a suite of tools for radiative transfer calculations in the Earth’s atmosphere that has been integrated into SEPSO. It is used to compute radiance, irradiance and actinic flux in the solar and terrestrial part of the spectrum..
- PROSAILH (PROSPECT+SAILH). PROSPECT computes spectra of the reflectance and transmittance of single leaves from chlorophyll concentration, water content, and a structural leaf

mesophyll parameter. In a more recent version, dry matter and brown pigment have been added as biochemical substances. SAILH simulates canopy reflectance from the output of the PROSPECT model (leaf reflectance and transmittance) plus a set of variables affecting the canopy.

Conceptually, SEPSO Module A is formed by two components:

- **Surface module (SRF)**: In charge of generating BOA radiance using as input a set of geophysical parameters. It relies on libRadtran or PROSAILH radiative transfer models, depending on the type of approach selected for BOA signal simulation.
- **Atmospheric module (ATM)**: Based on libRadtran and using the BOA from SRF, it generates the TOA radiance according to the scenario defined by the configuration parameters.

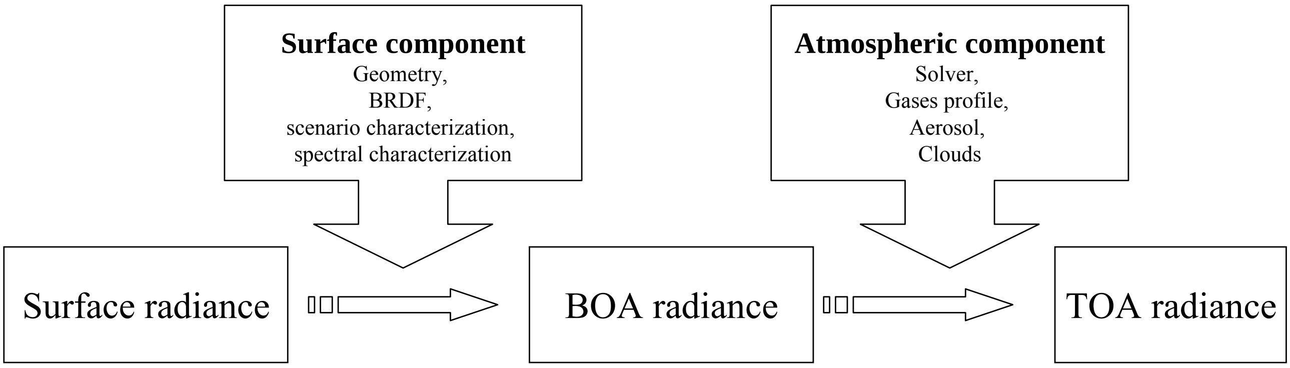

Figure 2-2: Flowchart of Module A showing the two components

2.2.3. Model B

This module was designed to be generic enough to be able to simulate any kind of optical imager like Panchromatic imagers, multi-spectral imagers, and spectro-imagers that covers the domain of wavelength between 0.3µm to 20µm. The hierarchical system of file used to define the payload parameters allows to consider a payload containing several spectral regions, several detectors and even to define some differences between pixels of a same detector as the aberration factor or stray-light parameters for example (what can be particularly useful to simulate a spectro-imager).

Module B is able to work in FULL or REDUCED modes. This module has been implemented with different algorithmic branches for both modes. This way, in FULL mode, instead of being called several times, it is called only once but including the specific treatment for FULL mode . Consequently, the user can study the statistics of repartition of the payload output. In REDUCED mode, some classical summation rules are used in order to compute directly the expected standard deviation of the output, and some additional data that allows computing the absolute radiometric accuracy in the module C.

More than the payload signal output, the model also computes other measurements that are necessary for the module C as the output signal of the calibration scene or the expected noise standard deviation what insures consistency between module B and module C, and allows module C to auto-calibrate Module B without any need of external information.

This module is sub-divided into three main sub-modules:

- **Optics**, that deals with the calculation of the amount of incoming light onto the detector,
- **Detector**, that simulates the conversion of the light signal into electronic signal at the output of the detector by the way of two possible models: Quantum Detector or Micro-Bolometer dedicated to thermal infrared, and

- **Video Chain**, that simulates the amplification and quantization of the electronic signal.

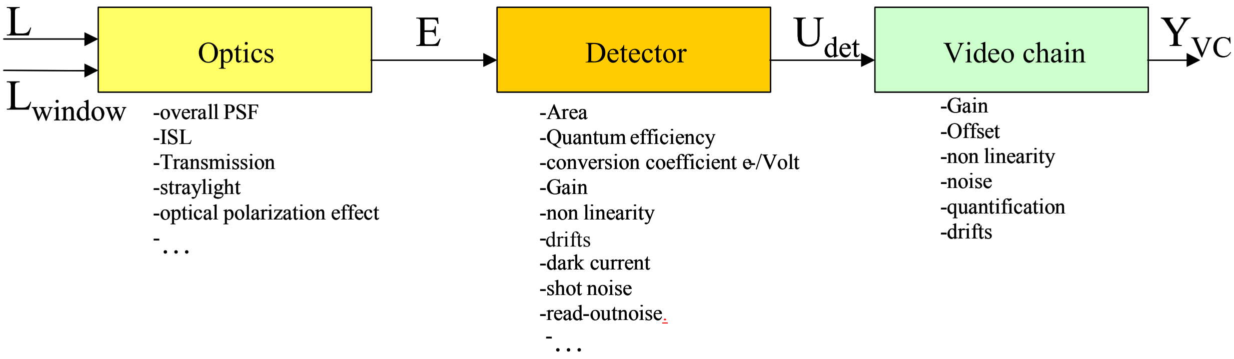

Figure 2-3: Sub-division of Model B components

2.2.4. Model C

Model C aims at simulating the effects of image processing from Level0 product to Level1c, including radiometric calibration, compression, restoration and re-sampling.

As told in the module B description, a particular effort has been made in order to insure the consistency between module B and module C and forces to include in the output of Module B, not only the Level0 signal but also some ancillary data as the signal simulated for the calibration scene simulation, the estimated PSF, and the part of signal due to noise.

Model B is divided into two main blocks, the first one deals with **Radiometric Calibration** aspect, and the other is dedicated to the **Image Processing** effects. Additionally, a special mode has been implemented in response to a special request of ESA in order to fit to the particular design of Sentinel-2 mission.

Figure 2-4: Sub-division of Module C components

2.2.5. Model D

Module D generates Level 2a data, i.e. the BOA (Bottom-Of-Atmosphere) reflectances. Module D comprises two main procedures, the atmospheric and the topography corrections (the latter is optional). It shall be able to use as inputs both Level 1b (radiometry preserved information) or Level 1c (ortho-rectified) TOA radiances/reflectances, although default input product is Level 1c.

Module D is composed of two components:

- **D-ATM**, in charge of the atmospheric correction. This component is based on the *libRadtran* transfer code, which is subject to inversion by means of a LUT approach. The procedure has been tailored to Sentinel-2 spectral resolution and performs three consecutive steps.
  - Estimation of the aerosol optical thickness at 550nm.
  - Estimation of the water vapour content.
  - Estimation of the BOA signal according to the input TOA value and the outcomes of the two previous steps..
- **D-TOP**, in charge of the topographic correction. This component is based on the SCS correction method that is equivalent to projecting the sunlit canopy from the sloped surface to the horizontal, in the direction of the illumination.

The block diagram in Figure 2-5 details the system design, data flow and the base algorithms for each component of Module D.

Figure 2-5: SEPSO Module D design

2.2.6. Model E

Module E includes the retrieval of geophysical variables, obtaining Level 2b data products from Level 2a BOA reflectances. The retrieved values for the geophysical variables (LAI, leaf chlorophyll content and leaf water content) can be compared with the input scenario used in Module A for the generation of BOA data, thus allowing an end-to-end performance appraisal. Module E is composed of the following components (Figure 2-6):

- **E-LAND**, which performs a supervised classification. It assigns to the target pixel one of the predefined land cover classes considered by the GSE Land project by comparing the input spectrum with reference spectra by means of the spectral angle mapper classifier.
- **E-BIO**, which retrieves three biophysical properties of the vegetation (Leaf Area Index, Leaf chlorophyll content and leaf water content). This component is based on the inversion of the PROSAILH radiative model.

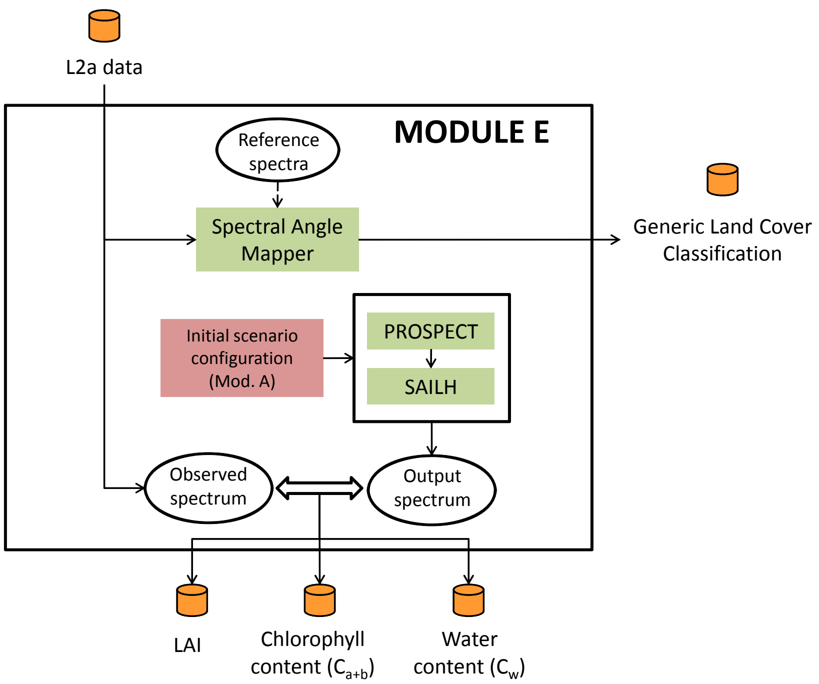

Figure 2-6: SEPSO Module E design