Resumen: DEIMOS-2 GS PRODUCT PROCESSORS ARCHITECTURAL DESIGN DOCUMENT

1. INTRODUCTION

The Product Processors is an element of the PDGS that is in charge of processing the payload raw data from the satellite to produce image products. The four, most important operations that the product processors perform on the input data are:

- A calibration, to convert the pixel elements from instrument digital counts into radiance units.
- A geometric correction, to eliminate distortions due to misalignments of the sensors in the focal plane geometry.
- A geolocation, to compute the geodetic coordinates of the input pixels.
- An ortho-rectification, to produce ortho-photos with vertical projection, free of distortions.

The previous steps also generate quality-related figures of merit that are made available in all the products. Moreover, the product processors generate metadata, in line with industry standards, to facilitate the cataloguing, filtering and browsing of the product image collection.

The output image products are classified into different levels, according to the degree of processing that they have been subjected to. In short:

- Level 0 products are unprocessed images, in digital count numbers.
- Level 1A products are calibrated products, in units of radiance.
- Level 1B products are calibrated and geometrically corrected products, blindly geolocated.
- Level 1C products are calibrated and geometrically corrected products, precisely geolocated using ground control points.

Within the L1B and L1C products, we make a distinction between resampled products in UTM projection (L1B-G and L1C-T), and products in the original raster format (L1B-R, L1C-R).

2. DESIGN OVERVIEW

The Product Processors Element is part of the DEIMOS-2 Ground Segment. The purpose of the DEIMOS-2 Ground Segment is to operate the DEIMOS-2 S/C, to process the generated payload image data and to archive the resulting image products, all according to the mission concept.

More specifically, the Product Processors Element is contained in the Payload Data Ground Segment (PDGS). The PDGS comprises the elements required to process and archive the payload data produced by the DEIMOS-2 on-board optical instrument.

The main functions of the PDGS can be summarized as follows:

- Payload data ingestion.
- Product processing. The main objective is the generation of up to L1 products of high-resolution multi-spectral and optical images.
- Product processing performance monitoring and calibration.
- Product archive and inventory. The main purpose of this subsystem is to provide catalogue and archive services for the products and external auxiliary data.

The PDGS of Deimos-2 architecture is based on the ESA Generic PDGS Specification. This specification defines a generic Processing Facility in terms of a Management Layer and a set of Instruments Processors. The Management Layer controls the processors operations and implements the interface to the other PDGS elements. The Instrument Processors encapsulates the algorithmic and computational part of the product generation process. All the interfaces between the Management Layer and Instrument Processors are file-based.

The objective of the Product Processors Element as part of the Deimos-2 Ground Segment is to transform the data received from the satellite into images and other auxiliary data, in a format suitable for the final user. The product images are corrected radiometrically and geometrically, and put in a cartographic projection. The auxiliary data includes mainly navigation/geolocation information, allowing the user to identify the area being depicted in the scene with precision. The auxiliary data also includes image quality information (for e.g. the percentage of saturated and invalid pixels), terrain type, cloud coverage, and more.

2.1. Concept of Operation

At the highest level the Product Processors have two modes of execution: automatic and manual.

In the automatic case, the Product Processors require no intervention from the operator once configured. The full Processing Chain is configured using the Automatic Processing Chain configuration files and the Processors Configuration files. The triggering mechanism is the ingestion of new raw data in the system. Upon this event, the PDGS Orchestrator directs the execution of the Level Processors following the correct sequence of execution as specified in the Automatic Processing Chain configuration file. The products generated during the execution of the processors are moved, catalogued and archived by the PDGS Orchestrator.

During execution the processors generate log messages that get monitored from the HCI. In case of a processor failure, the processor will clean up temporary and intermediate files and return a failure exit code. The PDGS Orchestrator will detect the failure and interrupt the Automatic Processing Chain. If there are files to be cleaned up in the shared area, the PDGS Orchestrator will take care of it. The failure will be reported properly.

It is important to note that the configuration files and the auxiliary data files used in the automatic chain are under strict configuration control. The operator is not able to change this configuration except through the established procedure.

2.2. Processing Levels

The execution of the different Level Processors in an organised manner is configured at the PDGS Orchestrator. The PDGS Orchestrator configuration contains the definition of the Automatic Processing Chain. Although the order of the algorithms is fixed, the configuration of the Automatic Processing Chain can be changed by the operator to switch on or off some of the algorithms, and to change their behaviour.

The Deimos-2 Processing Chain contains four Processing Levels and associated Products that are executed automatically upon ingestion of new satellite data. These are the following:

- Processing Level 0: Level 0 products contain un-processed raw data from the satellite. Two sub-levels are identified:
  - L0 product: the data is decoded, but not processed.
  - L0R product: the data is packed into square scenes and reformatted for the next levels of processing.
- Processing Level 1A: L1A data is radiometrically calibrated, and contains radiances in W.m-2.sr-1.um-1, but no other transformation is applied, not even band-registration. Some quality information is attached to the products, such as the number of invalid and saturated pixels, cloud coverage estimation, etc. L1A is an intermediate level that, in principle, is not intended for archiving.
- Processing Level 1B: These products contain calibrated radiances with some geometric corrections applied. Also, the images contain detailed quality annotations and crude geolocation grids. There are two types of L1B products:
  - L1B-R1: a calibrated, band-registered product, crudely geolocated (but not resampled). The PAN images (one for each sensor) are the reference bands and are unmodified from the L1A. The scenes from the two sensors (FPA1 and FPA2) are not merged. This product includes two crude geolocation grids (one for each PAN image) derived from the telemetry or from the Ground Segment orbit file. It is optional to use a Digital Elevation Model (DEM) to obtain an altitude grid.
  - L1B-G: this is the L1B-R1 product resampled to a UTM grid. During the resampling to UTM, the images from the two sensors are merged. Fill masks identify each of the pixels as “natural” or “filled”. Also orphan pixels are collected in a separate file. Orphan pixels are the pixels (radiance, sensor and detector information) that were discarded during the resampling. Most of the orphan pixels will be from the overlapping area of the two sensors. With the orphan information, it is possible to re-generate the L1B-R1 product from the L1B-G.
- Processing Level 1C: These products include precise geolocation information obtained by comparing the image to a reference image, using Ground Control Points (GCP). The following sub products are identified:
  - L1C-R2: a calibrated, registered product. The contents are the same as L1B-R1, except that it includes a precise geolocation grid obtained using GCP and a reference image at medium resolution (e.g. DMS-1 or Landsat).
  - L1C-T1: This is the L1C-R2 product resampled to a UTM grid. It is the equivalent of L1B-G.
  - L1C-R3: a calibrated, registered product in Focal Plane geometry. It includes a precise geolocation grid obtained using GCP and a reference image at medium resolution (e.g. DMS-1 or Landsat). The difference with L1C-R2 is that the GCP are identified manually by the operator.
  - L1C-T2: This is the L1C-R3 product resampled to a UTM grid.

DMS2	R	B	G	D	CP	Resamp.	Description
L0						None	None.

L0R						None	Scenes
L1A						None	Calibrated.
L1B-R1						FP	Registered + Crudely Geolocated
L1B-G						UTM	L1B-R1 Resampled
L1C-R2						FP	Precisely Geolocated
L1C-T1						UTM	L1C-R2 Resampled
L1C-R3						FP	Manually Geolocated
L1C-T2						UTM	L1C-R3 Resampled

R: Radiometric calibration.
B: Band and sensor registration.
G: Geolocated
D: Geolocated using Digital elevation model.
CP: Precise geolocation using ground-control points.
FP: Focal Plane.

2.3. Design Method

The PP architecture is presented from three independent points of view:

- The Functional Decomposition describes the functions that have to be performed by the PP. The functional decomposition is derived from the system requirements. It is a step prior to the actual system design.
- The Logical Architecture describes the software components that will carry out the work. The logical architecture can be identified with what is commonly known as the "software architecture".
- The Physical Architecture describes the SW units and the HW physical elements that will be deployed. This includes the actual SW binaries that will be built (executable files, scripts and libraries), the configuration files, the CFIs, the COTS, and the HW servers.

In summary, the functional decomposition answers what the PP does, the logical architecture answers who is doing it, and the physical analysis answers where they are going to do it.

The motivation for the above methodology is the traceability, which flows from the technical specification to the different architectural components. This works according to the following logic:

- System requirements are linked to functions. This identifies which functions fulfil which requirements.
- Functions are linked to logical components. This identifies which components provide each function.
- Logical components are linked to physical components. This identifies how the HW and the SW binaries will be built and deployed.

3. SOFTWARE LOGICAL DESIGN

The Deimos-2 product processor architecture is driven by the level of processing of the image products:

- At the lowest level, the L0 processor decodes the raw data from the satellite and packs it into square scenes.
- Then, the L1A processor performs the radiometric calibration of the instrument data.
- The L1B processor then performs some geometric corrections such as the band registration and a coarse geolocation.
- Finally, the L1C processor performs a precise geolocation and generates ortho-images.

The four processors are the main software modules of the Deimos-2 PP. They will be described in detail in the sub-sections that follow.

The high level architecture is shown in the following flow chart. The main logical components are aligned in the centre of the chart. The main products are aligned to the right of the chart. The main products were described in greater detail in section 2.2. Briefly:

- The L0 products are un-processed data.
- The L1A product contains calibrated images.
- The L1B product contains geolocated and registered images.
- The L1C product contains precisely geolocated images (ortho-rectified).

In the charts throughout this document, the L0 elements are painted in green, the L1A are in blue, the L1B in yellow, and the L1C in red.

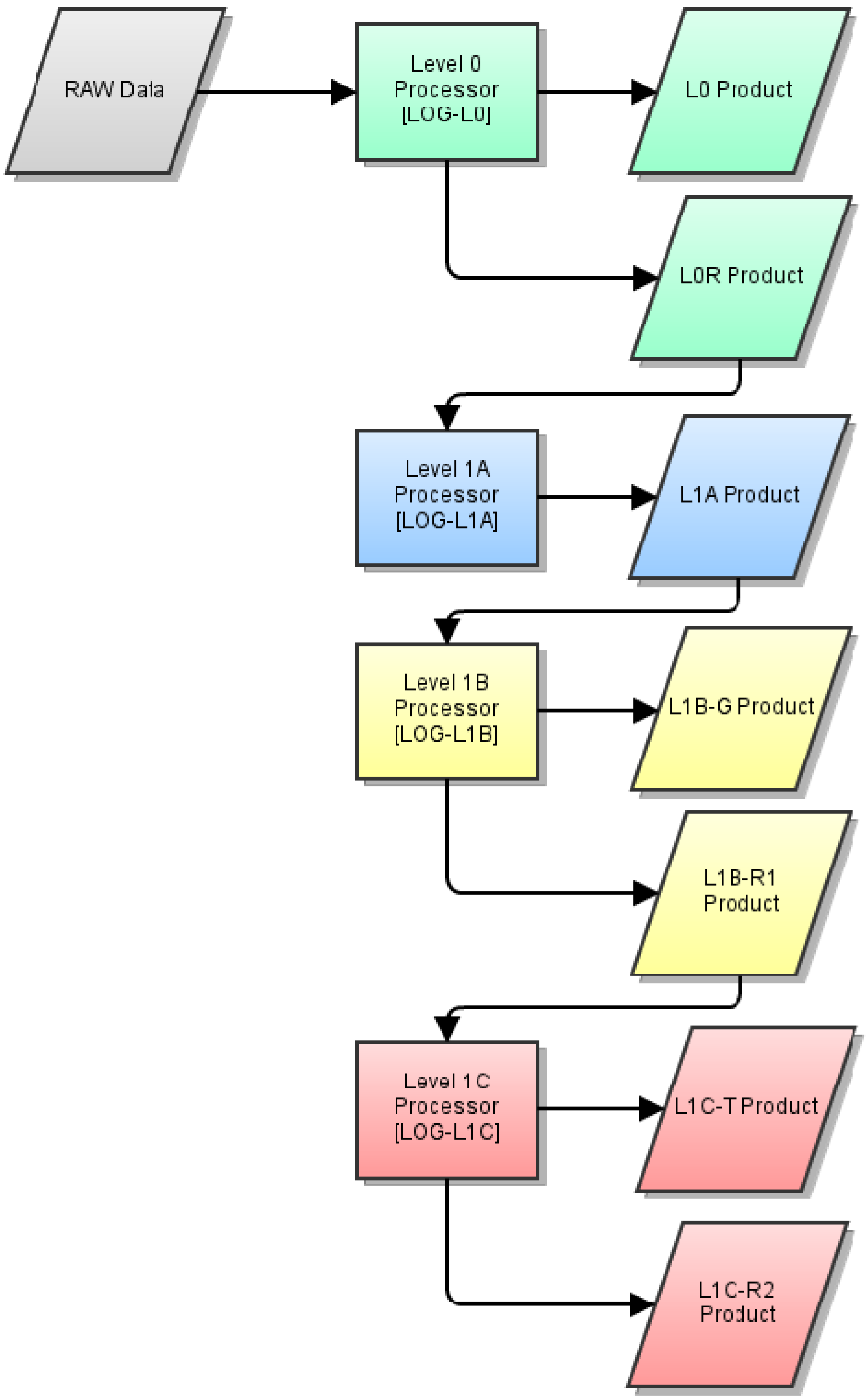

Figure 1. Logical Architecture (Flowchart)

3.1. Context

The data flow is depicted in a numbered sequence as follows:

1. Data Ingestion. Incoming data is ingested into the system. The main source for incoming data is from the payload. However, there can be other input sources, such as the calibration facility or the HMI in case of manual operation. Depending on the nature of the incoming data, some pre-processing might be required. In all cases,

the incoming data is incorporated to the Archive. This operation is directed by the Management Layer of the PDGS, also called PDGS Orchestrator.

2. The PDGS Orchestrator, driven by the event of new data ingested, follows a set of rules, or task tables, to initiate the execution of a Processor whenever all the inputs are available. When the input files are all available the PDGS Orchestrator circulates them to a shared storage area.
3. Once all the files are ready for processing in the shared storage area, the PDGS Orchestrator prepares a Job Order for the Product Processors. The Job Order contains all the information required by the Processing Facility to process incoming data. The PDGS Orchestrator starts and controls the execution of the Processor required to perform the Job Order.
4. The Processor retrieves data from the shared storage area and performs the required process on the input data, generating output data in the shared storage area. The execution of a Processor is specified in the Job Order. During the execution, the Processor logs the most significant events occurring during the processing.
5. Upon finalization, the PDGS Orchestrator moves the produced data into the Archive.

3.2. [LOG-L0] The L0 Processor

Property	Value
Component file names prefix	L0_*
Type	Level Processor
Purpose	Process RAW data to deliver the L0 products.
Development Type	New development
Pre-conditions	Raw data is available in input directory.
External interfaces	With PDGS orchestrator. With L0 packing component.

The L0 processor is a software component that reads the RAW data ingested by the orchestrator and generates two products:

- The L0 product: decrypted telemetry annotated with quality metadata.
- The L0R product: L0 cut into scenes and geolocated. Saturated and invalid pixels are found and identified. The L0R product also includes browse images.

The main objective of the Level 0 processor is to decode the data acquired from the satellite. The headers from the satellite transmission are removed and the error correction codification is processed.

The L0 product contains the raw data in unencrypted form, annotated with extra headers to make it compliant with the CCSDS standard (see [PP ICD] for details). At this level, the raw data is not processed in any way. The L0 product is then cut into scenes, converted to an internal format (TIFF+XML), and a crude geolocation is performed from the AOCS data included in the ancillary packets. Saturated and invalid pixels are found and identified with a well-known value so that subsequent levels are not contaminated by them. Saturated and invalid pixels values are different from any other pixel value and also different from no-data value used in resampling.

The result is the L0R ("Reformatted") product.

3.2.1. Interfaces

The inputs to this processor are described in the processor's ICD. These are:

- The Raw Data.
- The configuration database.
- The calibration database.

The outputs, described in the same document, are:

- The L0 product.
- The L0R product.

The acquired data is organized into image sectors of predefined size and structure. We will refer to these as L0 Sectors (sector files) and it is important to differentiate them from the L0R Scenes generated by level L0R. Scenes, as defined here, are used throughout the subsequent L1 levels. The size and configuration of the scene is not changed again in the processing chain, for this reason the scene definition is constant for all the L1 levels.

The L0 Sector contains 655 Image Units and 1 Ancillary Data Unit. Each one of these units is codified into a Source Packet. This definition, together with the configuration of the Image Units yields to L0 Sectors of size 12,000 x 2,620 pixels for the panchromatic band (including both sensors).

Images will be generated by packing consecutive L0 sectors. The image size for PAN band is user configurable, considering a default value of 22,000 PAN lines, so by default the scene size for PAN band is 12,000 x 22,000 pixels. On top of this, consecutive scenes can share one L0 Sector on each end, providing with some overlapping.

There are two configurable parameters to establish the scenes size: the nominal scene length and the minimal scene length. The last scene of the acquisition may be bigger or smaller depending on the scene size. If the acquisition does not contain enough sectors to compose the last scene (nominal scene size), but there are enough sectors to fulfil with the minimal scene size, a smaller scene is generated. If not, the last scene of smaller size is appended to the previous one, generating a bigger scene. This has to be taken into account in the L1 processing level.

3.3. [LOG-L1A] The L1A Processor

Table 1: L1A Design Sheet

Property	Value
Component file names prefix	L1A_ *
Type	Level Processor.
Purpose	Perform the radiometric calibration and corrections.
Development Type	New development.
Pre-conditions	L0R product is available.
External interfaces	L0R input directory. L1A product output directory.

This section describes the functionality of the processors included in the Level 1A of the Automatic Processing Chain. The goal of Level 1A is to calibrate the scenes. The resulting images are given in units of radiances.

The Level 1A Processor component contains the following modules:

- The calibration module: The pixel values are transformed using previous knowledge of the sensor radiometric characteristics, obtained during calibration. The goal of this processor is to obtain a uniform radiometric value for each pixel in the image, removing the effect of the differences between pixel sensors.
- The denoising module: removes high frequency noise using a wavelet filter. This module is disabled by default, but can be activated through the configuration file.
- The MTF deconvolution filter: The pixel values are transformed to compensate the low pass filtering or blurring that the optic system introduces in the image. MTF deconvolution uses Inverse, Pseudo-inverse and Wiener filtering. The MTF can be selected by configuration between a known kernel and a set of predefined degradation functions.

- The L1A packing module: in charge of generating the manifest and acquisition metadata files, and the product name. This module also collects statistics on invalid pixels, and computes an estimate of the cloud coverage. This estimate is crude because the bands are not registered at this point.

The L1A component works on the scenes that compound the L0R product (PAN, Red, Green, Blue and NIR images, one for each sensor), performing different transformations over pixel values to generate radiances.

3.3.1. Interfaces

The inputs to the L1A level are:

- One L0R scene.
- The configuration database.
- The calibration database.

The output is:

- The L1A product.

3.4. [LOG-L1B] The L1B Processor

Table 2: L1B Design Sheet

Property	Value
Component file names prefix	L1B_*
Type	Level Processor.
Purpose	Perform the geometric corrections.
Development Type	New development.
Pre-conditions	L1A product is available.
External interfaces	L1A input directory. L1B-R output directory. L1B-G output directory.

Level 1B implements the following processing steps:

- Blind geolocation: geolocation grid and sun angles, computed using the attitude information extracted from ancillary data and either precise orbit file estimated in the Ground Segment or the orbit information extracted from ancillary data depending on configuration.
- Band Registration: To compensate the possible difference in the position of sensors measuring different bands, the L1A multi-spectral images geometry is modified to match the panchromatic image.
- Pixel Classification: This step computes a pixel mask that classifies the pixels in one of the following categories: cloud, water, vegetation, land.
- Browse product generation. The browse product is a small snapshot of the scene in Focal Plane geometry (registered) in RGB.
- Merged product generation. The merged product is a combined version of both FPAs images of the scene in Focal Plane geometry (registered) in RGB.
- L1B-R packing: packs the L1B-R1 product, generates the Manifest file, the product name, and updates the quality metadata file and the acquisition metadata file. For example, it adds to the quality file the following information:
    - Updated percentage of cloud/water/vegetation/land.

- Thresholds used in the pixel classification masks.

- Resampling: Applies the geolocation grids previously calculated to provide resampled images, angle data and masks in UTM projection.
- L1B-G packing: packs the L1B-G product, updating the quality metadata file and the acquisition metadata file. The quality file is enhanced with the resampling statistics.

3.4.1. Intefaces

The inputs to the L1B level are:

- The L1A product.
- The configuration database.
- The calibration database.

The outputs are:

- The L1B-R1 product.
- The L1B-G product.

In short, the L1B-R1 product is a registered product with geolocation information, and the L1B-G product is the same information resampled to a UTM grid.

3.5. [LOG-L1C] The L1C Processor

Table 3: L1B Design Sheet

Property	Value
Component file names prefix	L1C_*
Type	Level Processor.
Purpose	Perform the automatic and manual ortho-rectifications.
Development Type	New development.
Pre-conditions	L1B-R1 product is available.
External interfaces	L1B-R1 directory (input). L1B-R2 / L1B-R3 output directory. L1B-T1 / L1B-T2 output directory. The operator (manual mode only).

The L1C processor performs the ortho-rectification of the L1B product using ground control points. It can be executed automatically, using medium-resolution images, or manually, using an external image provided by the operator.

3.5.1. Interfaces

The inputs to the L1C level are:

- The L1B-R1 product.
- The calibration database.
- The configuration database.

The output, when ran in the automatic mode, is:

- The L1C-R2 product.
- The L1C-T1 product.

The output, when ran in the manual mode, is:

- The L1C-R3 product.
- The L1C-T2 product.