Title

AIPC - Autonomous Image Processing Chain - Executive Summary

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Document type	Nb WBS	Keywords

NbCars 15908
NbWords 2983
FileName AIPC-ExecutiveSummary_v01r00.doc

SUMMARY

This document is the executive summary of the AIPC study, which took place between January 2008 and September 2009, in the frame of ESTEC contract 21251/07/NL/HE. The study was lead by Astrium, with a large contribution from Deimos.

In the frame of this study, a full autonomous image processing chain was designed and prototyped. After testing campaign, the performance of the developed tool reveals satisfying on the following points:

- Image quality performance is good for all individual modules
- Real satellite imagery data is successfully processed
- Computational time performance is in line with expectations
- Flexibility of the tool is demonstrated by handling of various processing and data levels in the frame of testing campaign
- Autonomy is ensured by the absence of human intervention during processing

The document synthesises the main elements of the study: context & objectives, industrial organization, main activities & results.

TABLE OF CONTENTS

1 INTRODUCTION

This document is the executive summary of the Autonomous Image Processing Chain (AIPC) study, which took place between January 2008 and September 2009, in the frame of ESTEC contract 21251/07/NL/HE. The study was lead by Astrium, with a large contribution from Deimos.

Part 2 of this document presents the study context and objectives, part 3 the industrial organisation of the project. The main activities performed during the project are presented in part 4.

2 CONTEXT / STUDY OBJECTIVES

The AIPC study takes place in the context of GMES (Global Monitoring for Environment and Security) satellite missions, where a large amount of data is to be produced and processed within short time intervals, in order to deliver services meeting users' requirements. The objective of the activity is to define and implement an autonomous image processing chain, able to deal with optical remote sensing missions at high spatial resolution (metric to decametric), with rectangular geometry (push-broom or whisk-broom). Processing ranges from level 0 to level 1c, including typical radiometric (equalization, restoration) and geometric (co-registration, ortho-rectification, mosaicking) steps.

The following high-level requirements have been identified as the basis for the definition of AIPC:

- **Image quality**, as required by the services to be provided.
- **Autonomy**, i.e. no human intervention shall be required for the actual processing of data.
- **Real-time processing**. Real-time means that products must be available in an acceptable delay with regard to the service to be provided.
- **Genericity**. The AIPC shall be able to process data from various present and future optical Earth observation missions, with rectangular geometry (i.e. push-broom or whisk-broom), with a resolution ranging from metric to decametric.
- **Flexibility**. The AIPC shall be able to provide data up to mosaicked level 1c, intended for various end-user level 2 or 3 specific products.
- **Standardization**. External and internal interfaces shall be standardized to ensure genericity and flexibility.
- **Opening** to growth potential and future missions.

3 INDUSTRIAL ORGANISATION

The team in charge of the activities is composed of Astrium SAS and DEIMOS Space. This is an experienced and complementary team where Astrium, as prime in earth observation, provides end-to-end system knowledge and space imagery expertise, and where DEIMOS, highly involved in many earth observation programs, provides valuable expertise in processor developments.

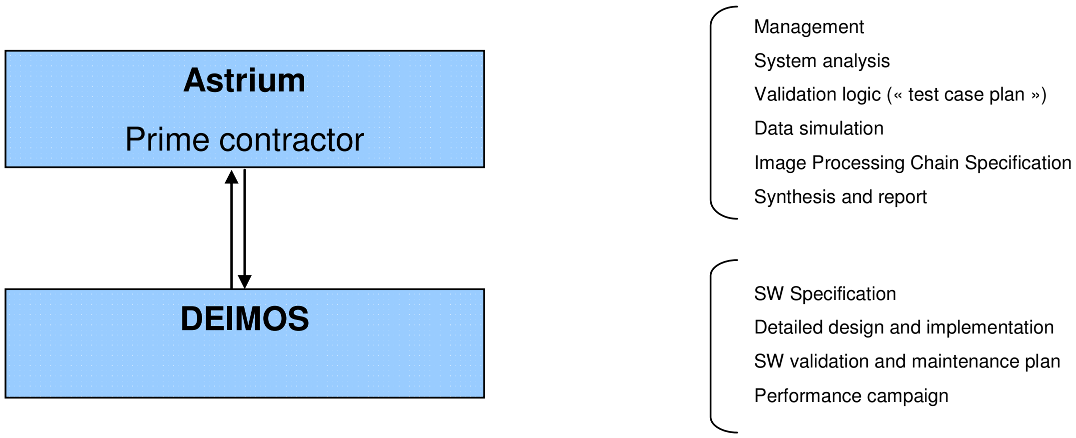

Figure 1: Industrial organization

The Work Breakdown Structure (WBS) of the study is presented on Figure 2. The main activities are organized in a number of Work Packages (WP), which took place at different phases of the study. WP1 activities took place before Preliminary Design Review (PDR), and consisted of design activities, ranging from system analysis to specification of the chain. WP2&3 took place between PDR and Qualification / Acceptance Review (QR/AR), and consisted in software development and validation. This was the biggest part of the project in terms of volume of activities. WP4 took place after QR/AR, and consisted in performance characterization based on simulated and real data processing by means of the developed software.

Responsibilities on the different WPs were shared between Astrium and Deimos as indicated on WBS (Figure 2).

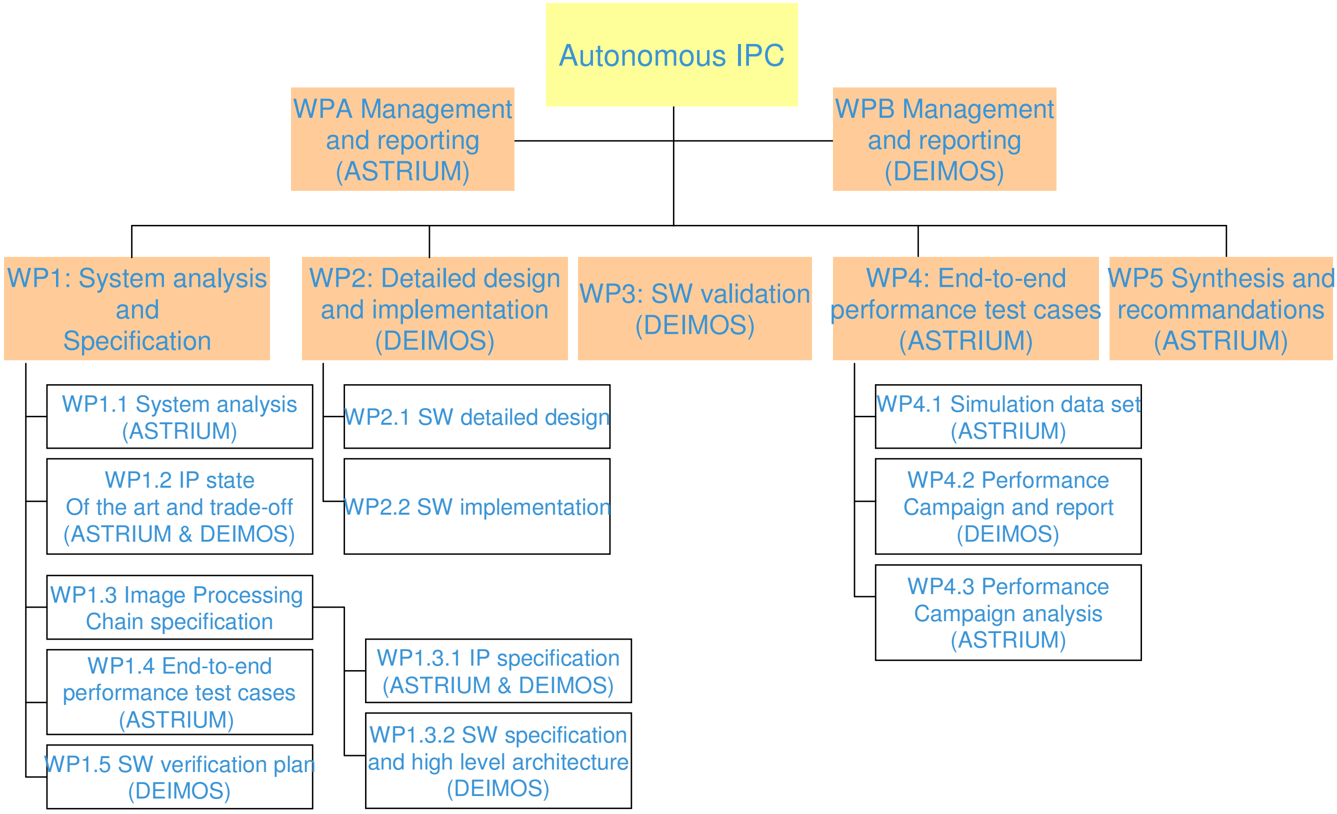

Figure 2: Work breakdown structure

4 MAIN ACTIVITIES

4.1 SYSTEM ANALYSIS

4.1.1 Overview

A number of satellite earth observation missions were reviewed, in order to establish the baseline system parameters to take into account in the frame of the study. Together with high level requirements expressed from the user side (image quality, autonomy, real-time processing, genericity, flexibility…), this was the basis for establishment of a set of criteria on which processing design was based.

4.1.2 Selected reference missions for the study

After reviewing GMES related missions, the following two missions were selected as specific reference use cases for the study. They were used as driver inputs at the design phase of the study, and corresponding data was used for performance characterization.

4.1.2.1 Sentinel-2

This mission is a superspectral (13 spectral bands) with medium resolution (10 to 60 m). The swath is very large (290 km) and thus the number of pixels in the focal plane is huge (31 104 pixels for each of the 10 m bands). This implies several detectors across track with overlapping areas. There is a need for a focal plane rearrangement just after the equalisation module.

The images used in the frame of the AIPC study will be ones simulated in the frame of the Sentinel2 program. The source data are hyperspectral images delivered by ESA. The simulations are representative in terms of image quality, focal plane geometry but not in terms of size and swath. It is indeed very difficult to acquire high resolution hyperspectral data on an area larger than a few kilometres.

The MTF is in the range of 0.15 to 0.45. The SNR is in the range of 100 to 1000 at reference radiance. The 10 m band images have to be deconvolved. The denoising is useful for some bands.

4.1.2.2 HR mission (Formosat2)

The second reference mission is a classical multispectral mission (PAN + 4 MS) with a high resolution (2 to 8 m). The swath is small (24 km). The number of pixels of the PAN band is 12 000. There is only one single detector per band in the focal plane. This means that there is no focal plane rearrangement needed.

The images used in the frame of the AIPC study will be real data acquired by the satellite in flight since June 2004. These images are property of NSPO and Astrium has the right to use it in the frame of internal projects but not to distribute it. The use of these images will thus be strictly restricted to the AIPC study.

The MTF is in the range of 0.13 to 0.40. The SNR is in the range of 140 to 220 at reference radiance. The PAN images have to be deconvolved. The denoising is not strictly mandatory due to the low level of noise.

4.1.3 Trade-off process

In order to define an adequate design for AIPC, the high-level requirements are converted to design criteria. These criteria are directly taken into account in the trade-off process leading to the actual design of the modules. They are briefly described here.

Image quality criteria

For each module image quality criteria are defined in accordance with functional objective of the module.

Computational cost criteria

These criteria applies for all modules but especially for the complex processing (denoising, registration, ortho-rectification,...).

Execution time is the best scale we can provide to evaluate an algorithm, since it is the effective measurement of the quality of the service to be provided. If possible, it is measured on a prototype implementation of the algorithm. This measure has to be interpreted, depending on the representativity of the tested implementation, compared to a potential operational implementation. The measurement is made on a typical target architecture, i.e. a PC adapted to scientific computing, running under Linux or Windows. The target size of the input image for execution time will be a square area of 12000 x 12000 pixels, which is representative for a typical situation. Execution time on a 31 104 x 31 104 pixels image shall also be evaluated. For practical reasons, tests can be made on smaller images and extrapolated for the nominal size.

Algorithmic complexity can complement or replace execution time criterion if needed. The task of evaluating an execution time starting only from algorithm properties is very uncertain, since many aspects of the algorithm efficiency rely on implantation hypothesis and unpredictable computer parameters (memory management, computing optimizations, etc). However, in order to compare some algorithms between them, some properties can be investigated:

- Number of arithmetic operations / multiplications per pixel
- Typical working area size
- Block processing

Additional criteria

A number of additional criteria are taken into account, among the following:

- *Autonomy*: autonomy means that no human intervention is required for the processing. Algorithms must be automated, without reference to human interpretation of images. However this does not refer to the potential need for auxiliary data for the setting of the parameters. Autonomy is strictly non negotiable in the frame of AIPC. Any algorithm requiring human intervention can not be selected.
- *Auxiliary data*: the need for auxiliary data, and the amount of such data, needed for a particular module can be a criterion for the trade-off. For a given image quality, a reduced need for auxiliary data can be an advantage, particularly if these data are subject to be unknown or to change with time.

- *Reference missions*: usage of an algorithmic solution implemented on an already flight proven mission is an important indicator of technical maturity, and shall be considered in the trade-off.
- *Robustness*: robustness is the ability for the algorithm to work well even if the conditions are not ideal (e.g. non optimal tuning, inputs out of the theoretical functional domain for some aspects, etc).
- *Complexity*: Complexity is here to be understood as the scientific complexity of models to handle in order to specify, implement and test the algorithm. This is an element to take in consideration for ensuring safe development of AIPC.
- *Testability*: testability estimates the amount of existing reliable tools or background available for proper testing of the developed products.

4.2 IMAGE PROCESSING CHAIN DESIGN

4.2.1 Overall architecture

Starting from the image chain as defined in the Statement of Work, a concurrent architecture has been proposed, taking in to account modularity and flexibility constraints as well as future missions specificities. The final architecture of the chain is presented here.

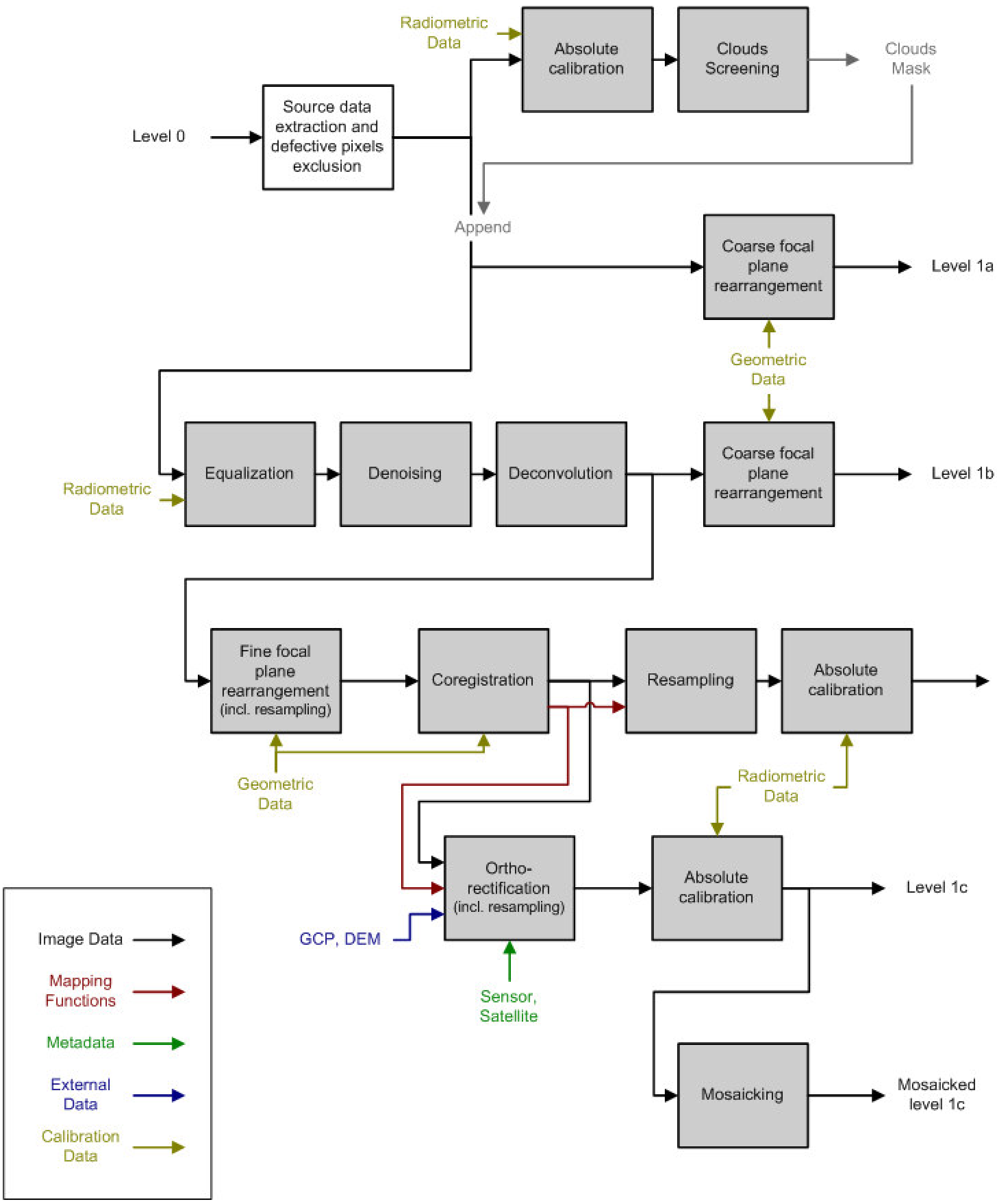

Figure 3: Block diagram of the Autonomous Image Processing Chain

4.2.2 Processing Modules

The functional overview for each module is briefly described here:

- Absolute calibration is required to convert the digital units into physical units ($W.m^{-2}.sr^{-1}.\mu m^{-1}$).
- Clouds screening module allows for detecting clouds on the image and producing a mask for further processing.
- Equalization handles the non-uniformity and the non-linearity correction.
- Denoising allows for noise reduction, and is required when deconvolution is applied and for raw image SNR lower than typically 150.
- Deconvolution allows for improving the MTF of the image, and is required for raw image MTF lower than typically 0.2.
- Coarse focal plane rearrangement allows for correcting roughly the column block shifts and the band misregistration. It is based on simple integer shifting.
- Fine focal plane rearrangement allows for all detectors, in staggered configuration, to be precisely set in the same geometry.
- Coregistration allows for all the spectral bands to be precisely set in the same geometry.
- Ortho-rectification allows for making the geometry of the image planimetric or map-accurate.
- Mosaicking allows for composing a single image from different overlapping scenes.
- Resampling module allows for final image rectification.

4.3 SOFTWARE IMPLEMENTATION & VALIDATION

4.3.1 System design

AIPC is composed of 11 modules. Each one is implemented as a standalone executable, which is triggered and monitored by the AIPC framework (openSF). The data flow between the modules is performed by means of the input and output files.

Each module is designed as a class that contains the processing performed by the module. The executable implementing the AIPC module just instantiates the module class, and execute its entry method.

Besides the module classes, there are a series of additional classes, needed by the modules during their processing. These classes model and manage the images in the system, the configuration of the system, the log system, etc.

4.3.2 Implementation

Software implementation was based on the detailed design previously defined. The different classes were developed, as well as additional modules, HMI, installer…

C/C++ was the preferred language for algorithm coding, due to the large in-house experience in the Consortium and the availability of internal libraries directly applicable to the AIPC project.

Java was the preferred programming language for the development of the Framework and GUI, due to extensive heritage from similar projects (ECSIM and GERSI).

The software is compatible and executable on a PC with both Linux and Windows operating systems, on both 32 bits and 64 bits architectures.

4.3.3 Validation

A set of software validation tests has been defined and implemented in order to assess conformity of the developed code to the requirements baseline.

4.4 PERFORMANCE TEST CASE PLAN

4.4.1 Overview

A performance test campaign took place in the last phase of the study. The main goal of the test plan was to characterize the performance of the chain in terms of:

- image performance
- execution time
- robustness to real imagery

In order to cover the various needs for each of the module of the chain, a number of test cases were defined. The test cases are based on the two defined reference missions for the study: Sentinel-2 and Formosat-2. The Sentinel-2 test cases are based on image simulation. They are mainly used for image performance characterization, up to resampled level 1b. The Formosat-2 test cases are based on real imagery. They are mainly used for execution time evaluation, and robustness to real data assessment. They are also used for image performance characterization for last geometric processing (ortho-rectification and mosaicking).

The following matrix details the covering of performance assessment needs by the various defined test cases (I stands for image performance, T for execution time evaluation and R for robustness to real imagery):

	EQ	RST	S2-1B	ABSC	FFP	CREG	RSMP	S2-1B-RES	F2-AV	F2-BY
Equalization	I								T R	
Denoising		I							T R	
Deconvolution		I							T R	
Coarse FP rearr.			I T							
Abs. calibration				I T						
Fine FP rearr.					I T			I		
Coregistration						I				T R
Orthorectification									I T R	I T R
Mosaicking										I T R
Resampling							I		T R	
Clouds screening										ITR

Table 1: covering of performance assessment needs by the various test cases.

The arrangement of modules is specific to each test case. The full performing of the test campaign thus also assesses for correct flexibility in the usage of the chain. An example test is presented on Figure 4.

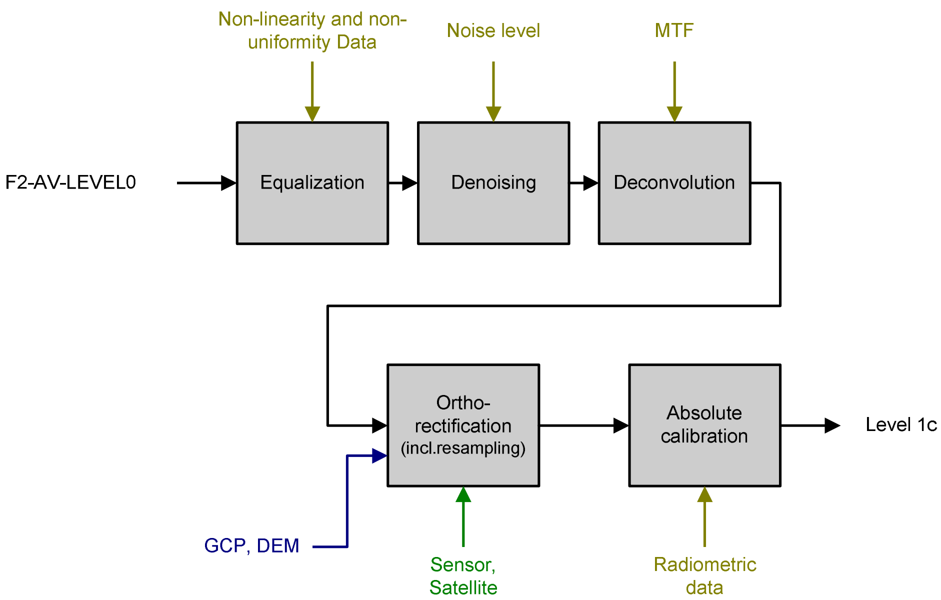

Figure 4: Example test case – F2-AV.

4.4.2 Test Dataset

The test dataset is composed of simulated Sentinel-2 data, and real Formosat-2 data.

Sentinel-2 simulations main characteristics are the following:

- Scene: North Toulouse, France (urban, mirrored along track)
- Spectral bands: B3, B4 (VIS), B8a (NIR)
- Resolution: 10m (B3&4), 20m, (B8a)
- 4 sets of images for each spectral band, corresponding to different levels of simulation.

Formosat-2 "AV" data main characteristics are the following:

- Scene: Avignon, France (urban + fields)
- Spectral bands: PAN
- Resolution: 2m
- Size: 12000 x 12000 pixels
- 1 image, level 0

Formosat-2 “BY” data main characteristics are the following:

- Scene: Berry, France (fields)
- Spectral bands: MS (3 VIS + 1 NIR)
- Resolution: 8m
- Size: 3000 x 3000 pixels
- 2 images for each spectral band, level 1a, with overlapping area, and different dates of acquisition.

Sentinel-2 data is mainly used for image performance characterization, while Formosat-2 data is used for most robustness tests and execution time evaluations.

4.4.3 Campaign results

According to the performance campaign, the AIPC performance is satisfying from different points of view. Image performance is good for all modules, in accordance with expectations at design phase of the project. Real satellite imagery data has been successfully processed in the frame of performance campaign, ensuring robustness for most part of the modules. Finally, execution times stay in a reasonable domain, with an approximate projection of about one or several hours for a S2 scene on a single standard PC.

An example result illustrating performance of equalization, denoising & deconvolution modules is presented on Figure 5.

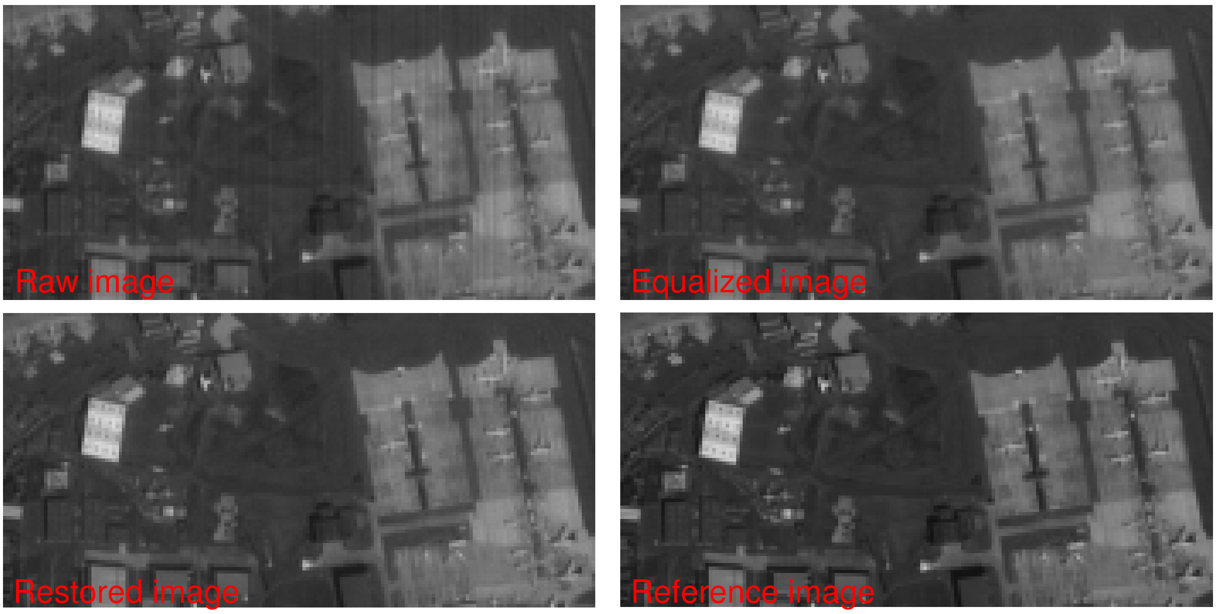

Figure 5: Example result on a Sentinel-2 simulation. Raw, equalized, and restored+equalized images, compared to the reference target.

5 SYNTHESIS

In the frame of this study, a full autonomous image processing chain was designed and prototyped. After testing campaign, the performance of the developed tool reveals satisfying on the following points:

- Image quality performance is good for all individual modules
- Real satellite imagery data is successfully processed
- Computational time performance is in line with expectations
- Flexibility of the tool is demonstrated by handling of various processing and data levels in the frame of testing campaign
- Autonomy is ensured by the absence of human intervention during processing

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