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ISIS SCC : a french generic control center product line approach

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Abstract

The French Space Agency (CNES) generic Spacecraft Control Center, ISIS SCC, is currently a mature system. Indeed, its development started in 2013, based on the ISIS initiative of mission interfaces & operational concepts standardization. It is designed as a set of modular and reusable components plugged on an actor framework derived from the CCSDS MO standards. It covers all of a SCC functions, except Flight Dynamics, for which it can interface with CNES FDS product line (SIRIUS) or any other FDS. It's being used to operate several missions at CNES since 2021 (CERES, SWOT, N3SS, KINEIS).

It's still being improved to cope with future CNES mission's needs (MMX, YODA, C3IEL, …etc) and operations feedback, but also to facilitate its usage by any company of the space ecosystem (associated with a license agreement).

It can address various mission's typology and orbits, for both civilian and military missions and all phases of a space project. It can also be used in more reduced environments, typically for functional chains validation or Assembly, Integration and Tests (AIT) activities.

The purpose of this manuscript is to give an overview of the current status of the LP ISIS, w.r.t. current & future uses, main coming improvements, and gains of using a generic control center as a base to build any mission control center (in terms of costs, delays, human resources).

Keywords: spacecraft control center, operations, genericity, modularity, scalability, securization

Acronyms/Abbreviations

Airbus Defence & Space (ADS)
Assembly, Integration and Tests (AIT)
Base de Données (BD)
CapacitÉ de Renseignement Électromagnétique Spatiale (CERES)
Centre d'Orbitographie Opérationnelle (COO)
Centre National d'Etudes Spatiales (CNES)
Centre Opérationnel du Réseau (COR)
Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)
Cluster for Cloud evolution, ClimatE and Lightning (C3IEL)
Consultative Committee on Satellite Data Standard, Mission Operations (CCSDS MO)
Convection, Rotations et Transits planétaires (CoRoT)
Electronic Ground System Equipment (EGSE)
European Cooperation for Space Standardization (ECSS)
Flight Dynamics System (FDS)
Housekeeping Telemetry (HKTM)
Initiative for Space Innovative Standard (ISIS)
Launch and Early Operations (LEOP)
Low Earth Orbit (LEO)
Martian Moons eXploration (MMX)
Mission Ground System (MGS)
Nanosat 3U pour la Surveillance du Spectre civil (N3SS)
Packet Utilization Standard (PUS)
PROTEUS
PULP is the Unified Layer Package (PULP)
Soil Moisture and Ocean Salinity (SMOS)
Spacecraft Control Center (SCC)

Surface Water Ocean Topography (SWOT)
TeleCommand (TC)
TeleMesure (TM)
Thales Alenia Space (TAS)
Training Operation and Maintenance Simulator (TOMS)
Yeux en Orbite pour un Démonstrateur Agile (YODA)

1. Introduction

In the current evolution of space activities, being able to benefit of existing solutions, which can cope with various types of spacecraft or mission typology is an attractive solution.

At the Centre National d'Etudes Spatiales (CNES), the French space agency, this brainstorming took place in the early 2000's. Rich of more than thirty years of spacecraft operations, it led to the decision to develop a generic control center solution. Developments began in the 2010's and it took nearly ten years to reach a fully operational solution that meets all functions of a spacecraft control center. This solution is now fully mature and used for CNES missions. It's still being improved to cope with internal needs, as well as external possible usages.

2. Genesis

As detailed in [1], at the beginning of CNES spacecraft missions, each project had to develop, integrate and qualify its dedicated Spacecraft Control Center (SCC). In the 1990s, the question of cost optimization raised and led to the development of a mini satellites product line called PROTEUS. This system was made of:

- A platform and its interfaces, designed for multipurpose use,
- A command control ground segment and its interfaces, compliant with the platform, including small TM/TC stations.

Each mission had then to design only its payload and payload programming & processing centers, to be compliant with the PROTEUS resources and interfaces. The platform command control ground segment was fully reused from one mission to another, or with only slight modifications. Having designed a reusable system was a major contributor to the low cost objectives of the missions using PROTEUS. This product line has been used for 6 CNES missions (Jason-1, CALIPSO, CoRot, Jason-2, SMOS, Jason-3).

Then, in the beginning of the 2000s, CNES studied the follow up of PROTEUS product line. Brainstorming based on PROTEUS experience and cost reduction objectives led to the decision of defining a CNES internal standard, which would be more cost effective than having a new platform product line, with nevertheless the objective to recycle those of PROTEUS concepts having proven their efficiency. This standard was named ISIS, for Initiative for Space Innovative Standard and was defined in partnership with the 2 main French space companies, Airbus Defence & Space (ADS) and Thales Alenia Space (TAS). It offers both a standard and a document tree with:

- all aspects of the platform and command control ground segment,
- all interfaces within ISIS components and with external entities.

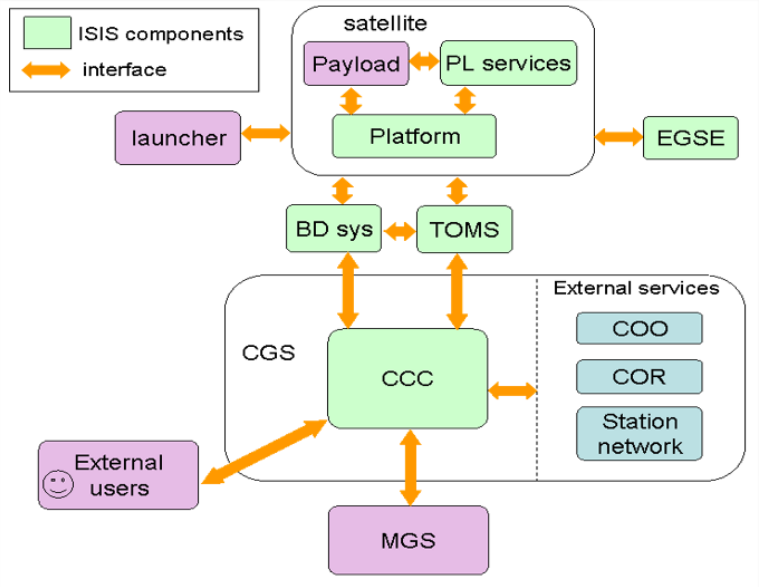

Fig 1. ISIS components among system overview

ISIS standard is derived from international CCSDS, ECSS, PUS standards, to which it is then compliant

Its scope is the same than PROTEUS, except for TMTC stations, as ISIS uses the existing CNES multi-mission stations network instead of a dedicated stations network as defined for PROTEUS. The objective was to apply the standard to all CNES new missions with the advantages of:

- cost savings by reusing products compliant to the standard from one mission to another,
- flexible human resources thanks to common operation concepts, which allow operators to switch easily from a mission to another.

In the mid-2000s, SCC roadmap discussions went further with the decision that CNES had to develop a single reusable control center product line, compliant with main international standards. It was thus fully natural that this generic SCC be developed in the frame of ISIS standard. The objective was to reinforce ISIS standard advantages of cost savings through a single SCC solution for all missions, and flexible human resources through common operation concepts.

This is how ISIS SCC came to birth (see CCC block on Fig 1), with its development beginning in 2012.

3. Main characteristics

ISS SCC covers the whole functional scope of a spacecraft control center except Flight Dynamics (FDS), which is out of its scope. At CNES, flight dynamic systems are developed in a separate department, with a dedicated product line called SIRIUS [4].

As detailed in [2], ISIS SCC is then covering the following functions:

- Platform monitoring & control:
  - TeleCommand (TC) sending
  - Housekeeping Telemetry (HKTM) reception and processing
  - Alarm management
- Satellite configuration management:
  - On-board software patch and upgrade
- Automation:
  - Management of the rules for tasks planning
  - Tasks automatic execution
- Services to satellite experts:
  - Event storage
  - Storage and access to the TM and operational data

  - Data visualization in real and deferred time
  - Reports production, post-pass analysis
- Services to the mission:
  - Payload monitoring (via HKTM)
  - Mission plan upload
  - Transmission of the data relative to the satellite and its orbit to the mission center

ISS SCC also includes the main functions to control and manage configuration:

- Administration:
  - Authentication and access verification
  - Traceability and imputation
  - Software monitoring
- Operations preparation:
  - Operational documentation
  - Means for operations development
  - Configuration management
  - Non-regression tests
- Availability:
  - Operational data backup
  - Reproducible deployments
  - Nominal to backup center switch

ISIS SCC has been thought and is still being improved to cope with maintainability and scalability requirements with a modular architecture, up to date technologies, and service oriented components.

Fig 2. ISIS SCC high level functional architecture

It packs the best of more than 30 years of CNES spacecraft operations experience, with as much as possible automation to reduce operations costs.

As military missions are operated with this solution, ISIS SCC benefits of a high security level, with up to date COTS and capability to interface to a cyphering solution to secure the TMTC link.

4. MIG/ PULP

Observing that ISS SCC on its own wasn't so easy to handle, was one of the reason that made CNES engineers defining an overlay of the software. This overlay is called PULP, for "PULP is the Unified Layer Package". It gathers all mission's generic configurations, basic flight and ground procedures, automation rules and definitions, generic operational documentation, deployment scripts and then helps engineers to integrate the SCC on a new mission, reducing again the associated time.

Facilitation of a new mission integration is also helped by a fictive mission called MIG, which also provide a system level validation of ISIS SCC.

To integrate ISIS SCC on a new mission only consists in MIG duplication and taking into account the mission specificities:

Fig 3. Stacking layers to reach a full operational control center

The previous figure shows the different steps from the historic status when each mission used to developing its own SCC, to the current status where a new mission has only to focus on its specific features. The intermediate block shows the ISIS SCC generic part of each mission full SCC development, still with a consequent part dedicated to missionisation, even if ISIS SCC already brings a significant reduction in a new mission development time. The right block highlights the additional gain brought by the PULP overlay and the part remaining for mission features, with a ~4-fold reduction in mission development time.

More details can be found in [3]

5. Targets

ISIS SCC can fully address a whole Spacecraft Control Center, which is its most complex use, but it can also cope with simpler targets:

- Main control room, which is used during the LEOP phase,
- On board equipment test bench for AIT activities,
- Monitoring and control for onboard functional validation,
- Simulator test bench for flight procedures execution and telemetry monitoring.

These various targets allow the use of a same SCC solution all along development phases, with a continuity between all phases and with operational phases. This brings cost reduction thanks to common facilities and already trained teams when operation phases begin.

6. Current operational status

ISIS SCC is being used on missions operated by CNES since 2021. The first one was CERES, a military demonstrator with 3 satellites on a low orbit, launched in December 2021. Then came SWOT in December 2022, a new altimetry mission with a LEO satellite. It was followed by N3SS in October 2023, which was the first nanosatellite to be operated at CNES. More recently, ISIS SCC showed its ability to operate a constellation, with the 25 satellites of KINEIS constellation, launched between June 2024 and March 2025.

It will then be used at geostationary orbit for the 2 satellites of the YODA military mission, for an interplanetary mission with MMX rover which will be launched in 2026 for Martian Moons eXploration, and then for other spacecraft projects currently in definition phases, as C3IEL for instance, which is a two synchronized nano-satellites train for convective clouds study in low earth orbit.

Fig 4. ISIS SCC current operational status

This whole panel shows how ISIS SCC can be used for a wide range of missions (from LEO to exploration, from one to 25 satellites, from nanosatellite to bigger spacecraft, from scientific to military domain), with a long service life since future missions SCC will have to be maintained for many years.

7. Current feedback of ISIS SCC generic solution

Having ISIS SCC used on operational missions since 2021 gives CNES enough perspective for several feedbacks restitution.

One of the main feedback refers to the scope of the ISIS software: at the beginning, the requirements covered all a SCC functions, such as common services (e.g. infrastructure monitoring). Several years of experience have proven that only components with operational added-value were better to be kept in the ISIS product perimeter.

Although this evolution has been forced by the complexity of the initial scope effective maintenance, it appears today to be the most efficient distribution. Indeed, the 2 scopes evolve with different rhythms: common services may evolve quite quickly compared to functions. It also brings the advantage of diversifying industrial contracts.

Another feedback is related to the PULP layer: since it is maintained on CNES side, it can be used as a laboratory to experiment different ways to work for end-users. When an agreed solution is reached, related developments can be integrated in ISIS product by the manufacturer in charge of ISIS product maintenance. This flexibility helps to reach some needs that are often hard to precisely specify, or that can require maturation.

Agile methods of development, which have been introduced with the last maintenance contract in 2022, also demonstrated that the associated flexibility to cope with evolving or non-mature requirements helped to better answer final users needs, and helped their satisfaction. It also brings some flexibility in prioritizations, helping having new urgent topics dealt in priority.

From what CNES experienced and analyzed, a generic solution brings to a new mission the advantages of a tried-and-tested product. Integration period is reduced because just the missionisation part has to be implemented, which also brings cost reduction.

In a counterpart, a generic solution, to actually reduce time & cost and be efficient, requires that all the using projects have common operational concepts. They also have to agree on priority developments that will be onboard the generic product, maybe sometimes at the expense of their own priority needs. This requires a dedicated organization to arbitrate needs coming from all missions. At CNES, it's managed through dedicated boards.

Another point is that ISIS SCC was initially defined excluding telecom and interplanetary missions, just as it was limited to a maximum constellation of six satellites. It has evolved to cope with missions as MMX (Martian Moons eXploration) or KINEIS constellation (25 satellites). Going further the product was initially designed raised new issues, mainly related to performances, but whose fixing benefits to all the current and coming missions.

8. The new ecosystem deal

For the past 2 years, some demands have been coming from the space ecosystem to be able to benefit from existing solutions. As ISIS SCC was initially thought and designed for CNES internal missions, a specific roadmap was decided to be able to meet this new demand. It mainly consists in removing adhesions to CNES infrastructure and deployment resources, removing CNES dedicated operations concepts (libraries), improving installation and user documentation, helping a new company with getting started, preparing a future training center for new comers, and licensing the product.

This external package has already been tested through a first ISIS SCC solution evaluation by a new comer, at the end of 2024.

And even if ISIS SCC has been developed in the frame of ISIS standard, it can be adapted to interface with SCC solutions based on other standards.

9. A product still being improved

As previously introduced, ISIS SCC product line improvement is ongoing, with a roadmap based on 3 mains axis:

- Improve user experience: operation needs are collected and the dedicated boards decide to focus on those that benefit the whole community; it addresses new functionalities, ergonomy or performances
- Maintain high security level: it addresses OS & COTS updates but also ground/ board link securisation through external cyphering solution
- Make the product line easily usable by external entities

Here are then some examples of evolutions are currently being studied:

- Automation component disadherence: it will have this core component made be usable on its own and outside a SCC, which answers external and internal needs
- Make ISIS SCC compatible to the PUS-C requirements, with a progressive approach driven by the services required by the coming new missions
- Low-performance components redesign
- TMTC flow rates increase
- Ergonomy for better operability
- Containerization

And news studies are beginning, to cope with an agency objectives of endorsing risks of emerging concepts. It's, for instance, related to new protocols like IP on board, or swarm satellites operations.

10. Conclusion

ISS SCC product line is a mature product, whose efficiency has been experimented from 4 years of spacecrafts operations at CNES, the French space agency.

It's still being improved to cope with the needs of the current CNES internal projects being operated (CERES, SWOT, N3SS, KINEIS), the coming ones in development phases, but also with an external space ecosystem interested in this solution, as well as emerging concepts.

Integrating this SCC generic product for a new project is eased thanks to the PULP layer and an experimented CNES team assistance with getting started. Building a full control center based on this generic solution brings then savings in time and cost. And transferring the solution to a new project will be all the easier, provided that the operational concepts be similar.

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