SAC-D Mission Automated Plan Generation and Execution Validation

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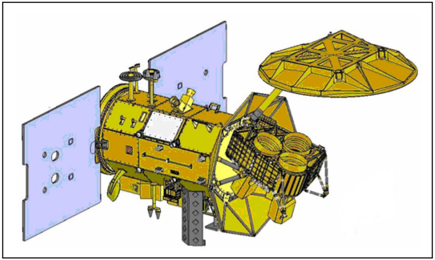
SAC-D/Aquarius is a low-orbit earth-observing science satellite in a sun-synchronous quasi-polar orbit at 657 km altitude.



The satellite includes eight instruments and the primary science objective of the mission is to contribute to the understanding of the whole Earth system (the water cycle, the climate, and the ocean).

Introduction

- All science operations commands plus some satellite maintenance commands are generated and upload from ground.
- The planning system is based on *state variables/timelines* concepts, and has been operational since launch on June 10, 2011.
- The satellite operations plan is made in a distributed way from three contributions:
  - Aquarius Instrument Operations Team.
  - SAC-D Instruments Operations Team.
  - Flight Operations Team.
- Due to project time constraints two functionalities were not included in the first deployed version:
  - Automated goal generation.
  - Plan post-execution validation.

SAC-D/Aquarius Mission Planning

Aquarius/SAC-D Instruments Overview

INSTRUMENT	OBJECTIVES	SPECIFICATIONS	RESOLUTION	AGENCY
Aquarius Radiometer & Scaterometer	Sea Surface Salinity Soil Moisture	Integrated L- Band radiometer (1.413 Ghz) & scaterometer (1.26 Ghz) swath: 390 km	Three beams:76 x 94, 84 x 120, 96 x 156 km	NASA
MWR Microwave Radiometer	Precipitable water, winds speed, sea ice concentration, water vapour, cloud liquid water	Bands: 23.8 Ghz V Pol. and 36.5 Ghz H and V Pol. Band widht: 0.5 and 1 Ghz swath: 380 km	Sixteen beams < 54 km	CONAE
* **NIRST** New Infrared Sensor Technology	Hot spot events, sea surface temperature measurements	Bands: 4, 11 y 12 um Instantaneous swath 182 Km extended swath 1000Km Pointing: ±30°	Space resolution: 350 m in temperature: 0.5°C smallest burning detectable area 200 m²	CONAE CSA
* **HSC** High Sensitivity Camera	Urban lights, electric storms, polar regions, snow cover, ships detection	Pancromatic: 450-900 nm Swath: 700 Km	200-300 meters	CONAE
* **DCS** Data Collection System	Data Collection System	401.55 Mhz uplink	2 contacts per day with 200 platforms	CONAE
ROSA Radio Occultation Sounder for Atmosphere	Atmospheric properties	GPS Occultation Techniques	Horiz: 300 Km Vert: 300m	ASI
CARMEN I ICARE & SODAD	Effects of cosmic radiation in electronic devices, distribution of micro-particles and space debris	I: three Si detectors, Si/Li S: four MOS sensors	I: 256 channels spectra S: Sensitivity: 0.5 u part. at 10Kkm/sec	CNES
TDP Tech. Demostration Package	Position, velocity and time inertial angular velocity determination	GPS receiver Inertial Unit Reference	Position: 20m, velocity:1m/sec Angular Random Walk: 0.008 deg/sqrt h	CONAE

*Acquisitions of these three instruments need to be planned, the rest of the instruments acquire data continuously.

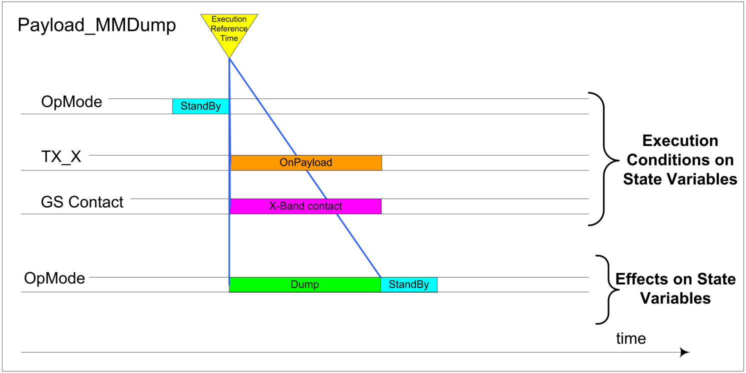
Plan Representation

- The representation is based on the usual state variable and timeline concepts.
- *State Variables* Are used to model the state of the system and operational modes. Represent the controllable part of the system.
- *None Controllable State Variables* Their values are externally propagated. Represents none controllable conditions, such as an Eclipse period, ground stations contacts, etc.

Formally, a *State Variable* is an identifier together with a domain (enum, integer, float, etc) indicating the possible values for the state variable.

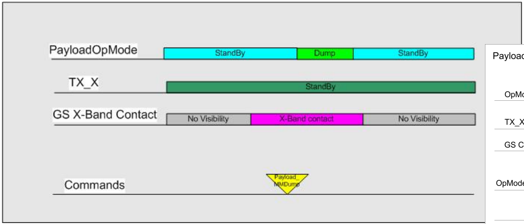
A *Basic Action* is a data set containing:

- One command from the CONAE SCL Basic Command Library.
- One reference execution time point (moment of execution).
- Specifications of its Execution Conditions.
- Specification of its Effects.

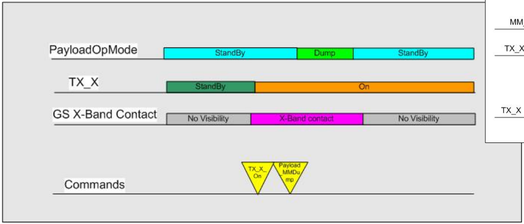


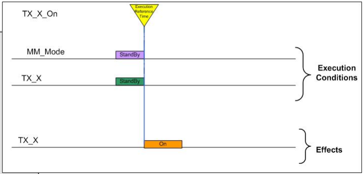
The propagation of state variables is done deterministically with the basic actions.

After Adding Payload_MMDump (conflict with TX_X)



After Adding TX_X_On (conflict is solved)

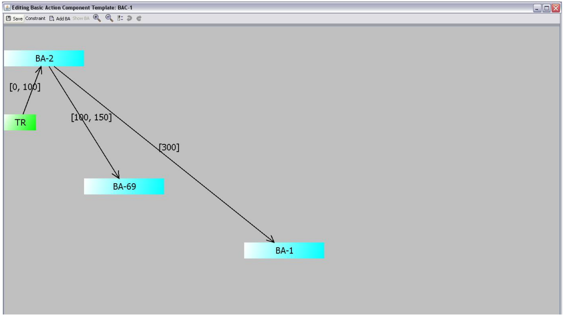




A Basic Action Component is composed by:

- A list of Basic Actions.
- One reference time point.
- Binary time constraints between the basic actions.

BA components allow the encapsulation of *command sequences* to be reused for operations.



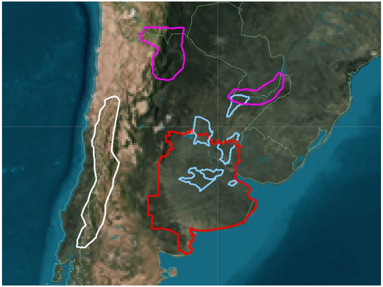
Due to project time constraints, two functionalities were left out of the first deployed version of the planning system:

- *Goal Generation.* To automatically generate all regular activities contributed by the SAC-D instrument operations team and the Flight Operation Team, starting from a high level science goal definitions.
- *Plan Execution Validation.* To monitor the plan execution and compare the predicted behavior with the values observed in the telemetry downloaded in order to generate alarms/warnings that cannot be computed by the usual check of limits alarms.

Goal Generation

- Usually, goals for the planning problem are generated by science teams from outside the planning system, and their generation is not included in the planning model.
- Modeling science objectives, priorities and constraints, and from that model, to automatically generate the planning problem goals it is an important matter to the success of flexible and efficient space mission planning systems.

- For this mission, automatic goal generation is computed from periodic orbit events related to science targets.



Goal Generation

Inputs I - Ground Station visibilities

The attributes of a GS visibility include the following:

- GS Identifier;
- start time;
- stop time;
- duration;
- revolution number.

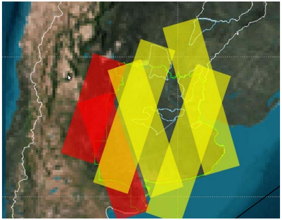
Outputs I

These are used to generate the following activities:

- Service platform X-band downlinks telecommands;
- S-band TT&C telecommands;
- DCS activities and instruments downlinks telecommands.

Inputs II - Science target accesses.
For each region of interest (*ROI*) described as a polygon, COD Service generates the accesses for a given period considering the geometry of the instrument. The attributes of an access include:

- place name;
- start time;
- end time;
- duration;
- four earth points (the region covered by the instrument).



Outputs II
These are used for *NIRST* and *HSC* cameras activities.

Activity Instantiation Rules I.

The instantiation rules key fields are the following:

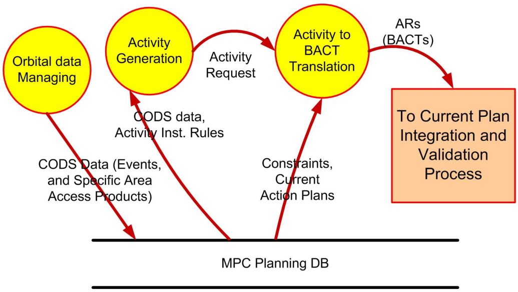
- *Event ID.* This is the ID of the event that implies the generation of a new activity.
- *Activity Type.* The type of the activity that must be generated.
- *Time Series.* These include a time window for which the activity must be generated and the periodicity used to enumerate the events.
- *Star Time Binding.* Specifies how the attributes of a given event are used to define the start time of an activity.

Activity Instantiation Rules II.

The instantiation rules key fields are the following:

- *Parameter Bindings.* Specify how the attributes of the event are bound to the parameters of the activity.
- *Selected Occurrences.* These are the indexes that indicate what occurrences of the events are used to generate activities within one period.
- *Minimum Access Time.* This is a filter that is applied to the duration of the events before the enumeration is done.

Process.



Results.

- More than 180 BACTs each week are generated and included in the plan automatically.
- Before, this task was done manually by SAC-D instrument and MOC teams.
- Less error prone and reduced operators efforts. One week plan, now generated in minutes, before took days.

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Approach.

- The planning system provides the predicted behavior of the system in terms of *SVs*.
- The stored telemetry (*TlmyVars*) contains the real behavior observed during plan execution.
- Both need to be compared, and any discrepancy must be impacted in the planning system in order to correct future plans.
- For this, a relation of each *SV* with a *TlmyVar* is defined.
- To allow the relation, abstract telemetry variables are computed from low-level telemetry variables, which domain coincide with the SVs domains.

A TlmyVar $\longleftrightarrow$ SV relation is defined by:

- *SV id*. The id of the SV.
- *Tlmy Var id*. The id of the abstract telemetry variable computed from row telemetry.
- *Accepted Latency*. Allows the specification of when the change in the SV is expected to be noticed in the telemetry. For example, SAC-D tlmy is stored each 8 seconds, and hence, this is the least expected latency.
- *Accepted Margin*. Allows the specification of the valid range of values to be noticed in the telemetry, according to the SV value. (Only for SV/TlmyVar with numeric domains: int, float, etc).

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Goal Generation

The automatic synthesis of the satellite activity plan from orbit events can be applied to any low-orbit earth observation science satellite mission, and provide the following advantages:

- reduces the work load;
- reduces human errors and contributes to the robustness of the mission operations.

Plan Execution Validation.

The validation of the correct execution of the satellite activity plan. is possible when the planning system:

- it is based on timelines/SVs;
- it allows flexible abstraction of telemetry variables;
- it considers the latency and margins of telemetry.

Plan Execution Validation provides the following advantages:

- It allows the detection of abnormal behavior not detected by the usual check of limits alarms.
- It provides a feedback that allows the generation of new plans considering the real state of the flight system.

Thank you for your attention!

Questions?