# The Commentary on: A generic modular architecture for the control of an autonomous spacecraft

**Gerard Verfaillie and Marie-Claire Charmeau**


**Comments by Andra Venkateswarlu[1] and Reiko Rager[2]**

[1]Control Systems Group
ISRO Satellite Centre
Bangalore 560017
India
venkat@isac.gov.in
[2]Space Telescope Science Institute,
Baltimore, MD, USA
rager@stsci.edu


In this paper entitled "A generic modular architecture for the control of an autonomous spacecraft", Gerard Verfaillie and Marie-Claire Charmeau describe modular architecture of onboard software meant for autonomous spacecraft. They also mention about the existing architectures in the areas of space and mobile robots,. They mention that the generic architecture adopted fits well for systems control. The modular architecture is then illustrated using two elaborated examples in the context of an Earth observation spacecraft. The expected qualities of control architecture are explained well.

The focus of the paper is on building an architecture for autonomous spacecraft where each module has the following four basic components:

- Received request tracking component (external reference or command input tracking),
- Emitted request tracking component (output state or command tracking),
- System state tracking component (state of all the internal variables which represent the state of the system under control), and
- Decision making component (conveying the outputs and commands at decided instances based on the facts available to the module).

Each module may also have optional components such as

- Supervision (a sort of controller for the module depending on the objectives set for the module),
- Model (an analytical or logical model to generate states of the system for which the module is responsible depending on the status of the inputs and outputs; useful for prognosis and diagnosis functions also), and
- Information processing service (computation or predicting the impact of the state of the module on the overall system, perhaps useful for passing on the predicted information for mission guidance modules for refining the input commands to the module etc.,)

There is also a communication component that interfaces with other modules for input and output.

These components are intended to make the module self sufficient and to make the module intelligent enough to interface with other modules, follow the mission objectives while keeping the independence of the module and services, and provide encapsulation while working as an object in an object oriented system. We agree the philosophy of the architecture can be applied in formation flying also.

The planning task is divided by distinguishing between various planning horizons such as:

- Commitment horizon (short term, and already initiated tasks);
- Decision horizon (medium term, where decisions are possible within next communication session with the ground and the spacecraft has to perform with reasonable optimization); and
- Reasoning horizon (long term, where spacecraft has enough time to do best possible optimization).

Our worry is whether this structure makes the objective of achieving overall system wide optimization very difficult. As optimization problem becomes more involved computationally or logically, the length of the reasoning horizon may have to be brought down to fit the onboard computational resources. The individual optimal solutions found should fit into the overall objective of optimization also. The planning for the modularity should keep in mind the linkages between modules for overall optimization.

Generally, optimizing all the criteria is a very hard problem. They have to be resolved based on certain priorities, heuristics, and safe states. Managing all the information in a modular context,

- Might demand optimization using a small set of criteria which may not be the best solution in the overall context of the spacecraft
- Increasing the criteria to maximally cover the overall objectives may result in lot of coupling in the optimization process, which might defeat the purpose of modularity

For example in an Earth observation spacecraft, an observation may require:

- Stereo imaging,
- Sun angle in a specified range to minimize the shadows effects in the image,
- Different strips of images with different ground sampling distances in a typical imaging session (Most of the recent high resolution imaging satellites such as IKONOS, QUICKBIRD take multiple spot or strip images in an imaging session.),
- Imaging of large areas with multiple spots to cover areas of width more than the swath (These will include constraints on look angles below some limit to facilitate proper knitting of images),
- Maneuvering of the satellite within the capability of the control system component capabilities, and algorithm capabilities,
- Minimization of the depth of discharge of the batteries,
- Optimization of the data from the attitude sensors while avoiding the sun and Earth in their Field of View (FOV),
- Transmission of the data to prescribed ground stations (constraints of antenna look angle limits, singularities in the antenna look angle calculations, shadows in the antenna FOV due to the spacecraft body projections, visibility constraints of the prescribed receiving stations etc.),
- Storage of the data onboard in the data recorders and subsequent transmission to the prescribed stations,
- Accommodation of the emergency observation requests from advance detection instruments, ground communication etc.,
- And many more subtle operational constraints due to the peculiarity of the subsystems, communication linkages, sampling intervals, time lines, synchronization of the events in various subsystems, etc.

A capability to breakdown the system requirements into multiple small optimization problems; back and forth communication among these optimization paths; and to ultimately achieve a globally optimal solution is a challenging task. This also has to be done to get anytime solution (latest optimized solution) to keep the limits of processing time, which means that the optimization should be done in such a way that we should be able to stop the processing at any step and pick up the latest solution. This requires that the current solution should always be a better solution than the previous solution.

**All these considerations pose problems in the decomposition and identification of the modules.**

The above considerations should be considered while modularizing the system. The difficulties of decentralization should be weighed against the advantages of modularity, similar to procedure based approach to object oriented approach. This is essential especially in the context of onboard implementation with good reactivity where the resources are very scarce compared to the ground systems.

In summary, the architecture described is very sound. However, this architecture should be tested for all possible scenarios for Earth observation spacecraft functioning along with autonomy requirements like fault detection isolation and recovery capabilities, goal oriented interaction with the ground, automated health processing.