Annex: Autonomy Implementation Examples
Autonomous onboard SW / HW Components

In October 2001 ESA launched the first satellite of the PROBA series – “Project for Onboard Autonomy”. With these satellites new technologies heading for higher levels of onboard autonomy and higher automation levels in satellite operations were tested.

PROBA 1 served for in-flight testing of following technologies (cf. [108]):

- First in orbit use of Europe’s 32bit space application microprocessor – the ERC32 chip set.
- First use of a digital signal processor, (DSP), as an instrument control computer ICU.
- First in orbit application of a newly designed “autonomous” star sensor.
- Use of onboard GPS for the first time.
- And following innovations in the onboard software:
  - ESA for the first time flying an OBSW coded in C instead of Ada.
  - ESA for the first time flying an OBSW based on an operating system instead of a pure Ada coded OBSW implementation (VxWorks was applied here).
  - The GNU C compiler for the ERC32 target was finally validated by flying a GNU C compiled OBSW running on the ERC32.

The achieved new onboard functionalities were:

- For the first time having an ESA satellite with position determination in orbit by means of GPS.
- Attitude determination through an active star sensor automatically identifying star constellations.
- Autonomous prediction of navigation events (target flyover, station flyover)
- A limited onboard “mission planning” functionality based thereupon.
Improvement Technology – Optimizing the Mission Product

This example (cf. [109]) depicts a combined ground / space architecture of the ESA study “Autonomy Testing” where the design of a potential onboard mission planning function for payload operation was analyzed.

The idea behind this is that users “only” needs to transmit their observation requests (“user requests”) to the combined system consisting of space segment (simulated satellite) and ground segment (simplified ground station). The customer requesting a mission product defines

- by which payload,
- in which operating mode,
- with which settings,
- they want to have which target area observed
- in which time window.

It was analyzed in how far it would make sense to implement parts of the mission planning and overall system timeline generation (ground + space) on board the spacecraft to shorten mission prediction response times. In such cases the satellite constantly has to collect customer requests from the various sequentially visible ground stations and is equipped with an intelligent mission planning system. This system generates a detailed timeline comprising all commands for all involved platform subsystems – mainly AOCS – and the involved payload(s).

Autonomous On-board Architecture:
- System Supervisor (from DLR MARCO study)
  Level of autonomy scaleable from simple macro-command execution via onboard control procedures processing up to onboard timeline execution
- TINA Timeline Generator, providing onboard generation of directly executable mission timelines from user requests and platform service requests.

Test Infrastructure:
- Simulated Satellite and Space Environment:
  - SSVF simulator
  - Spacecraft model, and environment models derived from SSVF
- Ground segment/checkout system:
  - SSVF/CGS configuration
  - TINA console for user-request definitions

Figure A2: Onboard autonomy test infrastructure: "Autonomy Testbed". © Astrium GmbH
The prototype from the ESA “Autonomy Testing” study consisted of:

- A Core EGSE acting as a simplified ground station
- A satellite simulator
- An onboard computer board as simplified single board computer
- An onboard software with a macrocommand interface (somewhat like OBCPs) running on this board
- A mission planning algorithm which created an activity timeline from the cited user requests including all macrocommands to the onboard software.

The onboard software executed the spacecraft macrocommands in the generated mission timeline and thus controlled the simulated satellite. In this autonomy testbed complex scenarios were tested which comprised:

- Nominal operational cases in which user requests were uplinked, processed and the results were downlinked at the next ground station contact.
- Furthermore scenarios which lead to planning conflicts on board and where the user requests could only be partially satisfied within the operating period.
- And finally scenarios during which manually injected equipment failures occurred and where initially a suitable error recovery needed to be identified and to be performed – followed by a replanning of the activities since after error recovery the satellite had already missed some of the observation targets. See also figure A4.

Such mission planning algorithms impose high requirements towards

- the onboard software (which needs to intercept any potentially erroneous commands, which might be created by the mission planning tool),
- and to the spacecraft simulation infrastructure which has to reflect sufficiently realistically the overall scenario including payload operations.
Figure A4: Autonomous recovery scenario on board. © Astrium GmbH
Enabling Technology – Autonomous OBSW for Deep Space Probes

In spring 2006 NASA launched the deep space probe “New Horizons” to explore the trans Neptunian objects Pluto and Charon. It represents probably the highest level of onboard autonomy ever flown to date.

The onboard software of New Horizons is based on a case based decision algorithm and a rule chainer algorithm. In place of onboard control procedures as used in conventional satellites here structures are implemented applying Artificial Intelligence techniques to control the nominal approach maneuvers as well as the error recovery. Cases are implemented on the lower processing level to identify abstract symptoms from parameter measurements and above these cases a rule network is implemented for situation analysis and system control.

The following figure provides a sketch of a small extract from the overall rule network – here for the handling of an error during Pluto approach. The failure can either be handled or results in the space probe going to Safe Mode – depending on the detailed conditions. The rule network implements a forward chaining method for processing.

For explanation of the figure below also please refer to [110] and [111]:

- The Rxxx-identifiers represent rules.
- The Myyy-identifiers represent macros which are executed by the activated rules.
- All spacecraft commands initiated by rules are encapsulated in such macros.
- The transition times for the rules / macro execution are depicted as well (some cover several days due to spacecraft coast or approach phases).
- For the rules / macros the onboard processor executing them is shown (in this extract from the rule network P3 and P5 are cited)
- and in the rule identification information is contained (for details see [110]):
  ◦ The rule priority
  ◦ The rule persistence
  ◦ The methodology how the rule result is to be handled by the inference system, when the rule result is obviously outdated
  ◦ The state during the loading of the rule into memory (active / inactive).

Figure A6: Extract of a rule-based mode-transition network of an OBSW (from [110]) © NASA
Tranquility Base here, the Eagle has landed.

Neil Armstrong

July 20, 1969, 20h 17m 43s UTC

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