Commentary on: “Mission Operations with Autonomy: A preliminary report for Earth Observing-1”

David Jameux

Data Systems Division, ESTEC, European Space Agency
David.Jameux@esa.int

Abstract. This paper comments on paper #68 called “Mission Operations with Autonomy: A preliminary report for Earth Observing-1”. We discuss first the progressive approach to the demonstration of Planning & Scheduling and the choice of associated technology. Then the issue of on-board resources for autonomy is addressed. Then we conclude on the closing of the EO-1 autonomy loop and on the difficult approach to the demonstration of on-board autonomy.

1 Introduction

The scenario presented is this paper is a simple but perfect study case for the introduction of autonomy in spacecraft payload operations. Indeed, the expected benefits of the complete ASE software suite on EO-1 operations and scientific return are dramatic. On the one hand, the ground support software for Planning & Scheduling (here based on CASPER) would allow reducing weekly planning of spacecraft activity from days to hours. This leads directly to a reduction of operations cost. On the other, on-board Planning & Scheduling capability, when coupled with on-board science data analysis and selection (the third part of ASE, the SCL, being only a necessary safeguard for the other two), will reduce observation reactivity with respect to transient phenomena from days (typically more than one week) to hours (down to 90 minutes), actually allowing hazard monitoring on Earth. The latter does not provide only cost reduction – which the people operating spacecraft might not be in favour of anyway – but a new ability of space systems, a new Earth Observation service. However, the path to spacecraft payload autonomy is difficult and there is still a long way to go.

2 Progressive Approach to the Demonstration of Planning & Scheduling Technology

The reluctance to introduce autonomy in spacecraft payload operations is twofold. On the one hand, autonomous payload operation is based on on-board analysis of science data. The scientists are usually not in favour of such automation of part of their work because they claim that computers are far from being able to analyse science data with the same quality than human beings. This is certainly true but the loss of data resulting from on-board selection is fully compensated by the quantitative increase of science data provided by the introduction of on-board re-planning capability. From their point of view, improving ground planning with software support tools (based on CASPER in this case), i.e. without introducing any kind of autonomy, would already be an improvement since it would increase reactivity with respect to observation of transient phenomena. On the other, spacecraft operations people are reluctant to loose control of spacecraft activity planning, even for non-critical sub-systems such as the payload. The best way to have them accept this loss is probably to demonstrate the reliability of currently available Planning & Scheduling algorithms. In order to convince those two communities, one would expect that the first step would be to implement more and more computer aided Planning & Scheduling within ground segment infrastructure. It is therefore surprising that the ASE project focussed first on the introduction of on-board autonomy capabilities before validating the associated technologies in the frame of ground control.

3 On-board vs. Ground Planning & Scheduling Technologies

The intended use of CASPER as such as a ground segment support tool for mission Planning & Scheduling is surprising as well. Indeed, in order to cope with the limited computing capability available on board spacecraft, CASPER is based on AI techniques while Planning & Scheduling can be implemented using many other techniques that provide plans of higher quality but at a higher computation cost. This is for example the case of more classical hierarchical planning. Using plan libraries could also significantly enhance quality and speed of planning since ground systems can offer the necessary large amounts of memory. At last, the benefits of mixed initiative planning and variable autonomy is obvious when the goal is to support operators and gradually convince them of the quality of the tools.

4 On-board Resources for Autonomy

The papers shows that, because it was properly designed for embedded use, the SCL and CASPER software modules have been operated successfully on a 12 MHz processor that was already in charge of the management of the solid state recorder. Moreover, the authors of the paper are confident that the same processor will host as well the last software module, the science data analysis algorithms without risk of any overload. This is a clear demonstration that, as opposed to was is sometimes stated, on-board software for spacecraft autonomy can provide dramatic benefits while consuming very low computing resources. The availability of ESA developed rad-hard processors such as the 20 MIPS ERC32, the 25 MIPS / 25 MFLOPS DSP21020 and the soon-to-come 100 MIPS Leon2FT would therefore allow running even more advanced autonomy support software on board spacecraft.

5 Closing the EO-1 Autonomy Loop

Two solutions are presented in this paper to overcome the one-day limitation in autonomous operation of the payload. The second "would result in slightly degraded science data" and is therefore not acceptable: what would be the benefit of spending significant effort in the development and maintenance of on-board software for autonomy if the resulting science data is degraded, even slightly? The first option is clearly the way to go: to port even more functionality from ground to space, following the increase of on-board processing capability. Nevertheless, in the particular case of the Earth Observing-1 mission, autonomy would anyway be limited to one day by the frequency of ephemeris uplink due to the limited accuracy of this ephemeris and its computation from Ground Network data. To achieve one-week autonomous operation, one would have to autonomously plan and perform daily ephemeris computation and uplink as well.

6 Conclusion

The paper states that the on-board Planning & Scheduling software module CASPER "[changes] the plan to accommodate the [new] requests while maintaining consistency with spacecraft constraints". To what extend does CASPER know about the spacecraft resources (e.g. battery load) and what are its rights on these resources? This leads us to the problems that engineers still need to sort out about autonomous payload operations – as opposed to the doubts of spacecraft operators about the reliability of the technology, which we think do not have any technical ground and can be cleared out thanks to more communication. Spacecraft engineers are indeed pretty confident that Planning & Scheduling technology is mature enough to provide significant and reliable services on board spacecraft. But, in order to provide real benefits in terms of autonomous operations, on-board re-planning must follow science data selection as clearly identified in this paper. This is probably where one problem is: the science data analysis and selection techniques proposed by engineers have not yet been approved by the scientists themselves. The second issue is related to spacecraft operators. Indeed, like any new technology, autonomy must be introduced at the level of non-critical sub-systems, such as the payload. But, as clearly shown is this paper, autonomous science acquisition cannot rely only on the payload since it implies spacecraft manoeuvres. Autonomous payload operation has therefore an impact on critical aspects of a mission such as Attitude and Orbit Control. This is why the demonstration of on-board autonomy, even restricted to payload operations, has always been relying on specific non-critical (often technology demonstration) missions such as Earth Observing-1 and an approach is still to be defined to demonstrate this technology on more critical missions.

References

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