COMMENTARY ON

USING ITERATIVE REPAIR TO IMPROVE THE RESPONSIVENESS OF PLANNING AND SCHEDULING

Commentary Author: Mario Merri

ESA/ESOC, Robert-Bosch-Str 5, D-64293 Darmstadt, Germany. Fax: +49 (6151) 903010, E-mail: mmerri@esoc.esa.de

Paper Authors: Steve Chien, Russell Knight, Andre Stechert, Rob Sherwood, and Gregg Rabideau

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, {firstname.lastname}@jpl.nasa.gov

Method

As recommended by the workshop organising committee, we have adopted an "open ended" commentary process. This translated by an informal exchange of e-mails between the commentator and the authors of the paper.

In the following, the main findings in the commentary process are reported. Firstly, I briefly introduce my understanding of the paper assigned to me. Subsequently, I summarise the dialogue that took place between the paper authors and myself. Wherever possible, I have tried to use the exact wording of the authors' replies.

Main Findings

Understanding of the Paper

The paper presents an innovative approach to modify almost in real-time the planning of a mission. Actually, the terminology used is to "repair" the planning following the occurrence of events. In this context, I feel that we are more in the field of on-board autonomous system than in that of mission planning proper, although the boundary between them is clearly difficult to define.

The approach presented in this paper is in alternative to the more traditional batch planning where only a very limited reactivity to negative or positive unforeseen events is possible. On the contrary, the proposed dynamic planning is claimed to allow a faster response to unpredicted event with the consequence of, on one hand, having a safer spacecraft, and, on the other hand, maximising the scientific return and the resource utilisation. In fact, the on-board planner starts from a current set of goals, a plan, a current state, and a model of the expected future state. At any time, an incremental update to the goals, current state, or planning horizon may trigger a request for re-planning with the constraint to maintain a consistent and satisfactory plan with the most current information available. Synchronisation between planning and execution is achieved by defining a time window where activities are committed and can no longer be modified by the planner.

Furthermore, the system proposes a hierarchical approach to planning with several levels. Starting from an abstract long-term planning, shorter and shorter planning horizons are considered which include greater and greater details, until finally we arrive to the short time planning. This approach aims at limiting the use of on-board computational and at maximise the system responsiveness by requesting detailed planning only on the short term.

Commentary

General: I have found the topic of the paper very interesting. The paper is also quite clear and reads fine.

Testing: I have pointed out to the author that one of the known critical issue for these types of autonomous system is the complexity of testing. In fact, as the system will have to make decisions in isolation, it is clearly extremely important to have the system undergoing an extensive testing campaign. It is also well know that testing a mission planning system might be extremely complicated as it is often difficult to cover all possible cases. In this context, I have asked the authors of the paper to provide details on how the testing had being planned, set up and performed in their case.

The author's response was that "testing is planned on series of testbeds, but testing for our system is intended to be similar as for other planning systems:

1. test case generation - based on scenario analysis, etc.
2. regression testing
3. the above can be run on progressively higher fidelity environments

It is true that our approach, because it relies more on environmental feedback, is more likely to have greater execution variability.

However, precisely because of this reliance, it is less reliant on model accuracy."

Safety-Critical Operations: My next question concerned safety-critical operations. Usually, operational staff would like as much as possible to be in control of the execution of safety-critical operations. On the other hand, technology provides today tools and methods to achieve reasonably-safe levels of autonomy. These are clearly two distinguished schools of thought. More specifically, my question to the authors was if, in their opinion, they felt that their system was adequate also for the execution of safety-critical operations or if their concept foresaw that such operations were only handled under strict supervision from ground

The author's response was that "this depends on the ability to characterize system behavior via testing and analysis, and on the risk-aversness of the mission. We see our approach as being comparable in riskiness to traditional batch planning autonomy."

Ground Observability of Timeline Execution Status: We then continued discussing on the dualism between fully autonomous systems versus ground controlled ones. I felt that an autonomous system would stand more chances to be accepted even by "conservative" operational staff if it had the capability to provide operational staff with relevant information on the execution of the autonomous timeline. In this context, I asked if any mission intending to make use of their autonomous planning tool had put observability requirements on the execution status of the timeline. That is to say, if missions have specified mandatory information to be downlinked to ground so that operational staff could know exactly what is going on on-board. Furthermore, in case of positive answer to the previous question, I asked how do they handle these observability requirements.

The author's response was that they "are not that far on the technological maturity to have encountered that issue. In general, our execution and timeline analysis is not restricted by our representation, that is to say that if they could build monitors and state determination software to provide this observability in conventional flight software, we can incorporate such software in our approach. Thus, we do not introduce any additional observability problems."

Autonomy Valid Only for Simple Planning Problems?: The complexity of the planning problem clearly plays a fundamental role in the outcome of the planning system. Furthermore, complex planning problems require complex planning systems that are clearly more prone to errors also considering that it is more difficult to exhaustively testing them. My observation was that, for simple planning problems, the behaviour of the planning system, and thus the status of the spacecraft, is mainly deterministic (see also observability point above). Instead, if the mission planning problem is a complex one, the overall status of the spacecraft is somehow more stochastic, which, in case of problems, might bring to unrecoverable situations.

The author's response was that "Yes - this is certainly true. Indeed, it is precisely these situation that one has two options:

1. make the decision making onboard, with the ability to respond in known patterns of behavior to execution feedback. (our approach).
2. introduce abstraction, worst-case reasoning, and reduce efficiency in order to increase stability/predictability (common approach)"

How Complex is your System?: As follow on of the discussion reported to the point above, I have asked the authors to comment on how their system scale for increasingly complex planning problems and what is their operational concept to recover from timeline errors.

The author's response was that they "have demonstrated the iterative repair on what we would call medium-size problems, and are able to get on the order of 100+ search operators in the planner (i.e., move add, delete activity) on the order of CPU seconds, however, it is always possible that problems from execution require wholesale changes (e.g. beyond the computational ability of the planner to resolve). [Their] approach to dealing with this has been two-fold.

1. develop anytime approaches, which are able to adopt a feasible but poor (quality-wise) solution and improve it as computational resources are available.
2. use abstraction to enable larger-scale changes to take place with fewer search steps."

Conclusions

My personal experience on this exercise was certainly positive as it allowed a direct discussion with experts on the hot topic of autonomous mission planning. Although I am not in a position to express an unconditioned acceptance of all the authors' replies, I certainly feel that this field is very important and requires further investigation. It is clear that, as the space frontier is moving farther and farther from the Earth, this technology becomes more and more required.

As a final remark, I think that the format proposed by this workshop worked quite well and, despite the limited time available, it was possible to establish some interesting technical discussion on stimulating topics.