COMMENT

Planning in Interplanetary Space: Theory and Practice

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Introduction

Autonomous closed-loop planning/scheduling engines will definitely replace the role of the human mission planner for manned interplanetary space missions. It is likely that the roles of mission director and mission managers will, as well, be eliminated. This commentary is divided into responses to the theoretical development and practical application of the Remote Agent Experiment Planner/Scheduler (RAX-PS) developed for NASA's New Millennium Deep Space One spacecraft.

Comment on Theory

RAX-PS theoretical descriptions range from integrated planning and scheduling to planning databases to a planning oracle. These topics are well laid out to establish the necessary framework for a planner/scheduler application to reside on board the restrictive computer architecture of an unmanned spacecraft.

Planning versus Scheduling

There is no defined difference in RAX-PS between planning and scheduling functions. The belief that intermixing these methodologies is unavoidable with complex synchronization constraints seems to be a future growth limitation. The ability to define a phased mission profile through planning against an abstract resource allocation should allow greater mission scheduling autonomy during execution. Put simply, mission goals will for the foreseeable future of space flight be decided well in advance, and the production of an abstract planned mission profile to ensure achievable schedules should be considered an advantage.

Planning Databases

Reading about RAX-PS's planning databases provides some very exciting insight into the possibilities of autonomous scheduling. In the commenter's opinion, the use of reasoning steps to map given databases for conflict detection is very important to plan validation. Also, the inference that it is not necessary to resolve all flaws injects reality into the model.

In scheduling, the counterpart to conflict detection is conflict resolution, which requires evaluation or grading functions to be resident and available in a more persistent scheduling database. Of course, grading implies reaching the most optimized plan as an end goal; however, this should be driven by pre-execution definition of flight rules and a planned mission profile.

Oracles and Flight Rules

The application of flight rules to an oracle may, for the purposes of developing and operating an autonomous closed-loop planner/scheduler, be improper. The oracle's definitions for operational preferences within the RAX-PS search controller are equivalent to planning/scheduling groundrules for manned space flight. The oracle's operational preferences (i.e. groundrules), which should be driven by planned mission phases, should drive grading functions. Theoretically, the oracle should have all data concerning the mission profile, the planning/scheduling groundrules, and the grading functions to validly schedule a timeline.

Comment on Practice

The use of RAX-PS on the Deep Space One spacecraft definitely proves the viability of the software for unmanned space missions. The extension of a variant of RAX-PS to manned deep space missions brings into question knowledge capture, data archival, and extensibility.

Knowledge Capture

Here again, reading about capturing the domain expertise of mission operators to drive search control through development of a high-level language seems filled with possibilities. It is stated that it is plausible to define the semantics to "automatically understand dependencies that point to effective search controls", so it should also be plausible for a high-level control language to automatically update dependencies, such as consumables, in a planning database which change over a mission profile.

Data Archival during Flight

Although storage memory for ground-bound computer systems is no longer a problem, it seems RAX-PS did not have this luxury. Even onboard the International Space Station (ISS), the mission planners will be limited to 1000 automatically initiated activities in the plan for a typical day. However, for longer duration, deep space missions that may encounter limited communications for data downlink, autonomous closed-loop planners like RAX-PS will need to archive plans for executed mission phases. This data could also be utilized in grading the best new plans based on previous results.

Extensibility to Manned Missions

The use of an autonomous planning/scheduling capability onboard ISS has been discussed amongst space station engineers many times. The idea of allowing astronauts in low earth orbit to schedule their own day's work is not ideal to mission directors and mission managers concerned with less than perfect assembly operations. However, mission planners believe operations will, in the future, be more relaxed. This opens the possibility of having a software system define the crew's workday without ground control intervention.

For deep space manned vehicles that would also require assembly, RAX-PS has already shown a fundamental solution to incrementally develop a timeline against a model. However, the requirements to plan bringing new spacecraft systems on-line and then automatically schedule the system verification and autonomously include nominal operation of each additional system within daily timelines only hints at the complexity of the next generation RAX-PS.

Conclusion

The background of this commenter is manned low earth orbit mission planning and scheduling, and the RAX-PS, as it is designed, is eliminating that job. The framework of the software system definitely lends itself to future growth in manned deep space missions. The comment, though, is primarily concerned with the overall use of the planning database from oracles to operational preferences to data capture and storage. The commenter hopes that the issues raised in this paper will highlight pertinent questions to drive future development decisions of the first manned quality RAX-PS.

References

Jonsson, Ari K., Morris, Paul H., Muscettola, Nicola, Rajan, Kanna, Smith, Ben. 1999. Planning in Interplanetary Space: Theory and Practice

Questions?

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