Commentary on:
On-board Plan Modification for Opportunistic Science

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Paper Summary

This paper describes a system for supporting onboard, autonomous handling of opportunistic science during a rover traverse. The system includes capabilities for identifying science targets through image analysis, responding to target identification and re-planning in order to accommodate the necessary actions to further investigate the target. Further investigation of identified targets typically includes a high-resolution image, a short traverse to the target and then instrument deployment on the target. Much of the paper focuses on the onboard planning management system, which is probably of most interest to the audience of this workshop. This system handles the tasks of 1) evaluating whether a new science target can be further investigated given current rover state and required resources and 2) modifying the current plan so this investigation can occur (which can include adding new plan activities and moving or deleting portions of the current plan). The planning system also provides capabilities for: 3) monitoring general plan execution, 4) validating whether the remaining portion of a plan remains executable and 5) repairing the plan if validation or execution fails, however these are not the focus of this paper.

Planning Approach and System Testing

The general planning approach used by the authors is to represent a plan using plan fragments which contain both primitive actions and constraints between actions. Constraints that can be imposed between actions or between full plan fragments include temporal constraints, dependencies, mutual exclusion, as well as other general constraints that help to represent real-world interactions. Plan modification is done using an iterative repair strategy. Plan fragments for current plan operations as well as for opportunistic activities have priorities associated with them which can be used to guide plan modification if a current plan is not executable. When adding opportunistic science activities, an evaluation is done to ensure a newly required plan fragment can be achieved given current rover state and other plan constraints.

Overall I find the author's planning approach to be quite valid. It actually shares many similarities which the approach used for much of my team's deployment of automated planning on research rovers at JPL. (Estlin, et al., 2008) However it was difficult to determine how well the author's system performed in practice. The authors do describe some limited testing performed with an ExoMars Rover prototype in a semi-realistic environment. However, only small cases were tested and no performance numbers are provided in the paper. It would be interesting to know (even for the small cases) how long planning took to add in new opportunistic activities? Also, what type of computational platform was used? Can the system be easily scaled to operate on a flight platform (which is typically very constrained in terms of performance and available memory)? Have the author's been able to run additional tests in simulation with more complex problems?

Interaction with Ground Operations

The authors mention several ways their developed system with interact with mission ground operations. One way is that the initial plan will be constructed on the ground, by mission planners, and will contain plan fragments that both the ground operators and the onboard system can reason about. The onboard planning system can then further refine the plan during plan execution. Ground operators can also supply extra plan fragments that contain activities which could be pursued if extra time and resource become available during plan execution. Further, the authors have considered how a history of execution events should be communicated back to ground and developed their new target generation technique (which adds the new target description to the overall planning problem description) so that it can be recreated on the ground. Finally, mission operators can also define priorities for general opportunistic plan fragments that will be used to guide onboard planning when new opportunistic arise.

I would like to commend the authors for considering these factors. There are many challenges in enabling a planning system to support future space missions. One large challenge is ensuring that the mission ground operations team can easily sequence and understand how to use the

planning capabilities. If these capabilities are difficult to understand, difficult to apply in practice and/or do not provide decent telemetry to support ground data analysis, they will likely not be adopted. I was quite happy to see the authors had considered some of these issues.

Single-Cycle Instrument Placement

One important of the element of the authors' approach is supporting what's often known as SCIP (or Single-Cycle Instrument Placement). There are a number of technologies that are needed to support SCIP, including obstacle avoidance (or navigation), rover pose estimation, visual tracking, rover base placement and instrument placement (Bajracharya, et al., 2005; Backes, et al., 2005; Kim, et al. 2005). Many of the elements needed to support SCIP have not yet been tied into the author's system.

The main element of SCIP that was integrated with the author's overall system was a module for arm approach and placement. During an instrument placement step, this module uses a digital elevation map of the target and arm kinematics to determine candidate placement sites and arm trajectories. Not many details were given on this subsystem however I do like that the authors' incorporated actual instrument placement into their tests. I hope in future work they continue to enhance this component to incorporate more realistic instruments and placements.

Regarding the other elements, the authors mention that a navigation system had not yet been integrated and I assume the same for rover pose estimation and visual tracking – all of which will be necessary to support the opportunistic science measurements targeted by the authors. Though it is reasonable to report on the system before it is integrated with all supporting components, I was disappointed that integration with at least a few of these systems had not yet occurred. Some of the most interesting challenges of applying planning and scheduling to support onboard rover command sequencing come from the rover's interaction with the environment and uncertainty inherent in rover surface operations. Needing to correctly represent and reason about rover traverse and target tracking activities brings out many new challenges for a planning system. For instance, rovers are typically subject to high amounts of slip while driving which can cause large errors in rover position estimation. Though this error is partly addressed in onboard pose estimation approaches (e.g., visual odometry), these systems can still incur large error and often are only used in limited fashion due to their high complexity. Thus an onboard planner will likely need to reason about this issue when planning rover activities. For example, position error can affect how a target's location is represented in the plan model. The planner will likely need to reason about when a navigation or drive activity has successfully reached an area close enough to the target location to place an instrument. How close does the rover need to be to the target location? How is this success criteria represented? Is potential position error factored in? Are their multiple locations the rover could drive to in order to successfully place an instrument and can the planner reason about those? When should the traverse to a new target be aborted if the rover is taking too long to reach the target location (e.g., due to obstacles or terrain conditions)? The author's have made a great start in testing their system in a semi-realistic environment. I hope they continue to improve on the complexity of their tests and integrate with other important rover control modules that will be needed to address their overall objectives.

References

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