Executive Summary

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Presentation Title

Collaborative Human-Robot Science Exploration on the Lunar Surface

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Key Ideas

The problem addressed is the allocation of tasks among humans and robots to most productively achieve mission goals. With support from NASA's Directorate Integration Office of the Exploration Systems Mission Directorate, and in coordination with the Surface Operations/ EVA Focus Element of the Lunar Architecture Team, we have developed the methodology, implemented and validated the software and conducted analyses of trades between conducting activities EVA, IVA and robotically teleoperated from earth.

The activities studied were science based (i.e. sample acquisition, geological context survey, coring, raking etc.) and productivity measured in terms of task time completion. (we're currently looking at other measures such as cost, quality etc.). A scenario in which astronauts identify interesting geological sites, and lay beacons for subsequent sample coring by earth based teleoperated robots avoids the necessity of astronauts performing time-consuming drilling operations allowing them to use their time more productively.

Supporting Information

Approach:

1. Identify
   - **agents** : astronauts on the moon, robots operating autonomously or controlled from earth,
   - **activities** (move, carry, deploy, etc.),
   - **resources** (tools, vehicles, power, etc.)
2. Identify **constraints** (ex: EVA is done in pairs for M hours/day; robots need recharging after N hours, etc.)

3. Define **figure of merit** to be optimized (ex: maximize science productivity)
4. Define **starting configuration state S** (e.g. astronauts unsuited in habitat, with pressurized and unpressurized vehicle, etc..
5. Define **goal configuration state G** (e.g. 6 science activities at each of two sites completed; agents and resources at their starting configuration)
6. Search for **optimal allocation sequence of tasks** to available agents in parallel and/or sequential order.
   - **a.** Starting from S, generate all the new possible configurations
   - **b.** Evaluate each new configuration using FOM, select best alternative that does not violate any constraint
   - **c.** Repeat until Goal is reached

Mission Scenarios

The mission objective is to complete rock sampling, geological context survey, raking of samples, soil sampling, drive tube sample, and core drill sample at each of two science sites 10 and 20 km from the habitat respectively.

The study showed that having astronauts conduct 5 of the tasks directly, but leaving beacon markers at locations for earth based teleoperated robots to drill and acquire samples at these locations and bring them back to the habitat would save almost two hours per day of EVA time which could be productively used for other tasks. It would take 7.5 hours/day of teleoperated robot time (and associated ground operations).

Current Capability

- Our planning software approach is **independent of the specific problem being solved**
- The software **gives the user freedom to specify agents, actions, resources, parameters, constraints, start and goal states, and the objective function to be optimized**
  - Many of the large-scale planners discussed in the literature focus primarily on scheduling activities already associated with agents, tools, etc.; our approach considers alternative assignments of agents, tools, etc.
- Using constraints and a “smart” objective function, an multi-hour search of 30,000+ nodes was reduced to hundreds of nodes searched in a few seconds.
- This methodology can be applied to **conduct systematic comparisons of different mission architectures from the point of view of mission efficiency**