Spatial Coverage Planning and Optimization for a Planetary Exploration Rover

Dan Gaines
Tara Estlin, Caroline Chouinard

International Workshop on Planning and Scheduling for Space
October 22nd-25th, 2006
Exploring Geographical Features

(a) Channels (MGS MOC Image)
(b) Layers (MGS MOC Image)
(c) Craters (MRO HiRISE Image)
(d) Boundary (MGS MOC Image)
(e) Large area characterization (Spirit Image)
Exploring a Geographical Area
Variety of Observations and Preferences

Reasons for taking an observation:

• Scientific merit (geology, mineralogy, rock/soil props, atmospheric, long term planning. . . )

• Engineering merit (long range route planning, localization, energy predict . . . )

• **Spatial coverage:** select observations that increase area covered
Constraints

- Limited resources (RAM, energy, time)
- Limited downlink opportunities/bandwidth
- Different observations require different amount of resources
- Some observations may have time constraints
Additional Challenges / Considerations

• Observation visibility impacted by terrain
• Observation may not provide uniform coverage quality
• Should take into account any a priori knowledge (e.g. orbital imagery)
• We may want to mark certain regions as more (or less) important for coverage
• As the rover collects data, terrain map may be updated
Algorithm Overview

Input
- A set of science observations (oversubscribed)
- Time & resource constraints

Repeat:
- Process updates from Executive
- Optimize for \( n \) iterations
  - Satisfy requested observation
    - satisfy obs with **largest spatial coverage contribution**
  - Resolve conflicts
    - if delete, delete obs with
      **smallest spatial coverage contribution**
- Commit and/or Rescind activities
- If idle, attempt to move up future activities
Overlay Terrain with Grid

Can adjust resolution to trade solution quality for reduced computational cost
Terrain Weight Matrix

Enables scientists or onboard analysis to designate relative importance of covering regions of the terrain.
Modeling Observations

- Compute observation visibility (Shapira, 1990)

- For each visible cell, compute observation coverage

- Multiply coverage by terrain weight matrix, giving observation overlay
Spatial coverage quality = sum matrix
Maintain Two Coverage Quality Matrices

1. **Executed Coverage Quality Matrix**: coverage quality resulting from having executed observations.
2. **Pending Coverage Quality Matrix**: coverage quality expected after pending observations executed.
Which Observation to Add / Delete Next?
- Rank observations on how much they improve coverage

- Maintain two rankings:

  Ranked Pending Observations: relative to executed coverage quality matrix
  Ranked Requested Observations: relative to pending coverage quality matrix
Effect of Resolution on Observation Computation Time

Time for Single Observation vs. Resolution

Resolution (meters per pixel)

Time (milliseconds)

Setup
Compute Contribution

Observation = 30m radius panorama
Effect of Number of Observations on Ranking Time

Time for Ranking Observations vs. Number of Observations

Resolution = 0.1
Resolution = 0.25
Resolution = 0.5

Observation = 30m radius panorama
Effect of Resolution on Observation Ranking

Rank Correlation vs. Resolution

Resolution (meters per pixel)

Rank Correlation (-1.0 to 1.0)

Data averaged over 10 runs
Related Work

Art Gallery Problem:
- 2D problem is NP-hard
- Popular approximation runs in $O(n \log n)$
- Does not model quality of coverage, does not consider costs
- Able to select guard locations

Visual Surveillance:  Rana, 2004 (ROPE)
- Planning visual surveillance for 3D open spaces
- Similar greedy algorithm for selecting guards
- Does not model quality of coverage, does not consider costs

Swath Coverage:  Knight, 2006; Oddi, 2003; Muraoka, 1998 (ASTER);
- Also concerned with increasing coverage
- Different types of constraints, choice points and observation modeling
- We use same greedy approach as ASTER
Limitations

- Greedy algorithm – suboptimal when observations overlap
- Does not currently distinguish between different sample modalities (e.g. spectral, visual, . . .)
- Does not currently select new goals
- Does not currently combine multiple preferences
Conclusions

Approach for reasoning about spatial coverage of science observations

- 3D, large scale terrains
- models instrument coverage / visibility
- scientist input on areas of importance
- can use a priori knowledge of area

Current Status:

- implemented in Casper planning system
- single instrument model
- tested with high-fidelity rover simulation (ROAMS)

Future Work:

- increase set of instrument models
- multi-objective prioritization
- deploy on prototype rovers
- select new goals
Initial Knowledge May be Incomplete / Incorrect