Selection of Landing Sites for Future Lunar Missions with Multi-Objective Optimization

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1. Introduction

Conflicting Objectives for Landing Sites

Technical requirement : Minimize continuous night length

Continuous nights: Night — Can't generate electricity all the time — Run out of power

Daytime and night alternate: Daytime Night Daytime Night — Can generate electricity during daytime

→ Long daytime & short continuous night site is good

Conflict

Mission requirement : Minimize the distance between landing site and ice

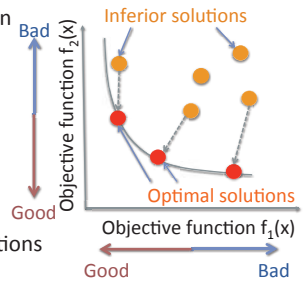
Less ice exists at illuminated sites

☐Requirements for landing sites
- Minimize continuous night length
- Maximize communicable time between moon and the Earth
- Minimize slope angles
- Minimize the distance between the landing site and ice etc...

Use Multi-Objective Optimization to select sites that satisfy all the requirements

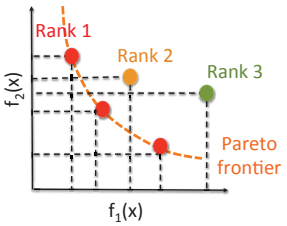
What is Multi-Objective Optimization?

☐Advantages of Multi-Objective Optimization
- No need weighting factors
  - Each objective value is evaluated separately
- Find several optimal solutions at once
- We can choose any favorable optimal solution



☐How to select multi-objective optimal solutions

Pareto ranking
- Each solution's rank is defined as
  $r(X_i) = 1+n_i$
  (i : the order of the solution,
  n_i : The number of solutions that are superior to X_i)
- No need to compare between objective values that have different units
- Rank 1 solutions form a Pareto frontier
  → Multi-objective optimal solutions exist on the Pareto frontier

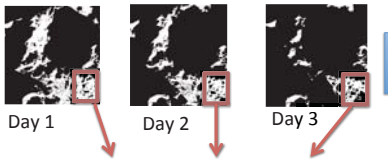


2. Method

Create Moon Database

☐Calculate moon data by moon simulator
- The amount of sunshine
- Communicability
- Slope angles

Simulation result pictures (Sunshine)



Moon database at one point on the moon (10-m resolution)

Day	1	2	3	4	5	6
Sunshine	1	1	0	0	0	1
Comm	1	0	0	0	1	1
Angle	10.5					

Check Constraints

☐Constraint 1 : Slope angles < 15.0 degrees

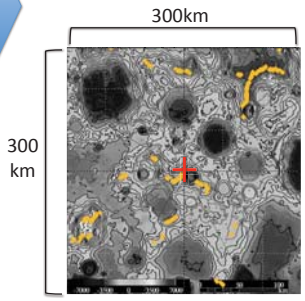
☐Constraint 2 : Continuous night length < 14 days

If the site doesn't meet the constraints, remove from search targets

All sites : Over 900 millions

Under constraint : Around 170 thousands

→ Speed-up full search



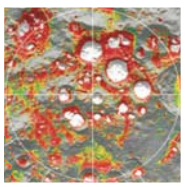
Yellow dots : Feasible solutions

Red cross : South pole of moon

Calculate Objective Functions

☐Minimum objective value is the best
- Continuous night length
  (Max night length) / (Constraint night length)
- Communicable day length
  1.0 – (Illuminative & Communicable day) / 365
- Slope angles
  (Slope angles) / (Constraint slope angles)
- Ice distribution
  (3D distance from ice) x (depth of ice)

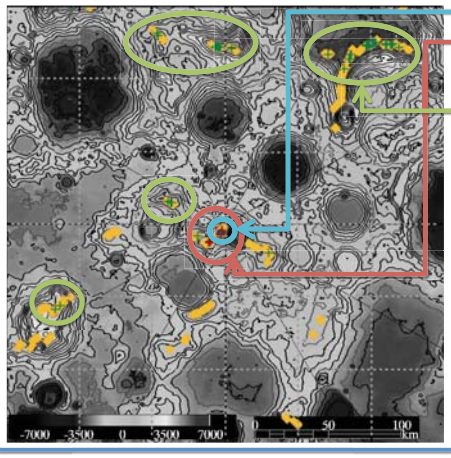
Make reference to the map that shows estimated ice distribution the moon



Paige et al., 2010

3. Result & Conclusion

Multi-Objective optimal solutions
17413 sites



A : At the South Pole

B : Around the South Pole (Within 20 km)

C : Top of the mountains & Facing the Earth

Divided landing sites by objective functions

Sunshine	Communication	Slope	Ice distribution	Landing sites
○	○	○	○	0
○	○	×	○	A (6 sites)
○	×	○	○	B (745 sites)
×	○	○	○	C（4037 sites）

Conclusion

- Search landing sites that satisfy conflicting objectives by multi-objective optimization
- Classify multi-objective optimal landing sites by objectives
  → Analyze missions suitable for each site

  At the South Pole : Extremely narrow, but desirable sites for lunar exploration

  Around the South Pole (Within 20 km) : Suitable for missions using high autonomy rovers

  Top of mountains & Facing the Earth : Suitable for explorers that communicate with the Earth and are controlled by human frequently