Task Evaluation for Robotic Explorers

Ph.D. Thesis Proposal

Submitted by:
Kimberly Shillcutt
The Robotics Institute
Carnegie Mellon University
December 2, 1998

Robotic Antarctic Meteorite Search

Mission Goals

- search area completely
- classify any potential meteorites

Resources of Interest

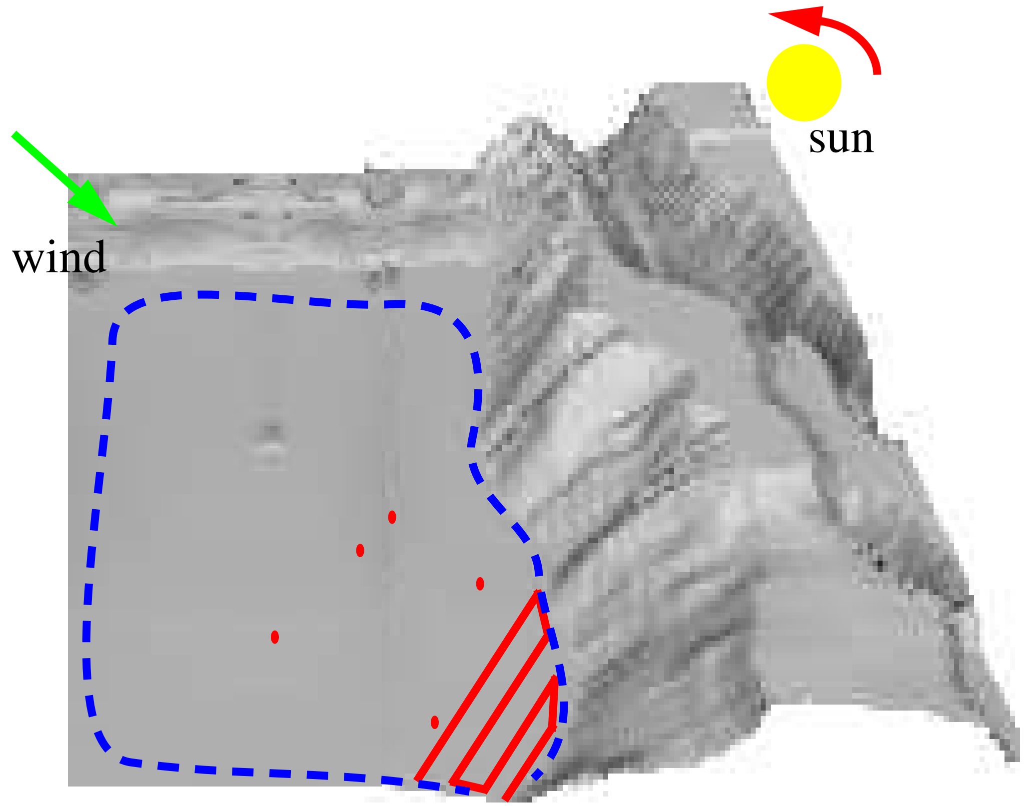
- power generation
- power consumption

Tasks to Evaluate

- coverage patterns
- drive to target location
- sensor measurements

Carnegie Mellon

Meteorobot Search



Carnegie Mellon

Motivation

Harsh conditions
Dynamic environment
Time delays

Autonomous Reasoning

Critical Issues

- power generation - solar, wind, other?
- power consumption - terrain, maneuvering
- limited resources - power, time, computing

Carnegie Mellon

Task Mediation

Multiple Tasks

- path or patterned driving
- sensor measurements
- communication

Multiple Goals

- complete coverage
- target classification

Multiple Resources

- solar and wind power gain
- power consumption
- time

Priorities?

Environment?

Mission Stage?

Carnegie Mellon

Problem Statement

The evaluation of coverage patterns and exploration tasks with respect to power generation, power consumption, and other resources and goals will enable crucial improvements in the productivity and return value of robotic explorers.

Problem Space

- autonomous, outdoor, remote, mobile, surface robots
- predefined repertoire of tasks and plans
- primary power sources - fixed solar panels, wind turbine
- primary power drains - locomotion, sensors
- dynamically changing goals and resources
- dynamically changing priorities

Carnegie Mellon

Problem Assumptions

The following functions are assumed to exist:

- Robot localization
- Obstacle detection and avoidance
- Locomotion, control and manipulation
- Sensor acquisition and processing of data
- Robust executing architecture and communications

Mechanical failure detection, compensation and recovery are not addressed

Carnegie Mellon

Prior Work (1)

Solar Power

- ✓ material composition, stationary platforms, Mars Pathfinder power models, power resource profile for scheduling

- ✗ no coverage patterns, no orbital motion/terrain algorithm, no continual task evaluation

Resource Optimization

- ✓ minimizing fuel, time, distance, temporal scheduling, conflicting demands

- ✗ no power generation, limited coverage patterns

Carnegie Mellon

Prior Work (2)

Navigation & Path Planners

- ✓ map formulation, concise graph representation, optimal search algorithms, path following, localization

- ✗ no power generation, limited integration with other types of task evaluations

Coverage Patterns

- ✓ straight rows, contour following, minimal distance, obstacle deviations, random searches, pattern efficiency

- ✗ no power generation, no power consumption, limited types of patterns

Carnegie Mellon

Prior Work (3)

Mission Planning & Agent Architectures

- ✓ multiple layers, complete architectures, replanning, human interaction, weighted sum evaluations
- ✗ limited solar power consideration, no wind power, no coverage patterns

Carnegie Mellon

Technical Approach (1)

Tasks

- types - driving, coverage patterns, maneuvering, communicating, using sensors, manipulating, ...

⇒ input - robot configuration & capabilities, terrain, start time

⇐ output - sequence of timestamped poses, list of resources being used or goals being addressed

Plans

- types - combinations of tasks

⇒ input - predefined permutations, combination heuristics

⇐ output - component tasks, relative starting times

Carnegie Mellon

Technical Approach (2)

Resources

- types - solar power, wind power, stored power, time, computing resources

⇒ input - robot configuration, environment, task information, uncertainty

⇐ output - normalized gain or loss of resource

Goals

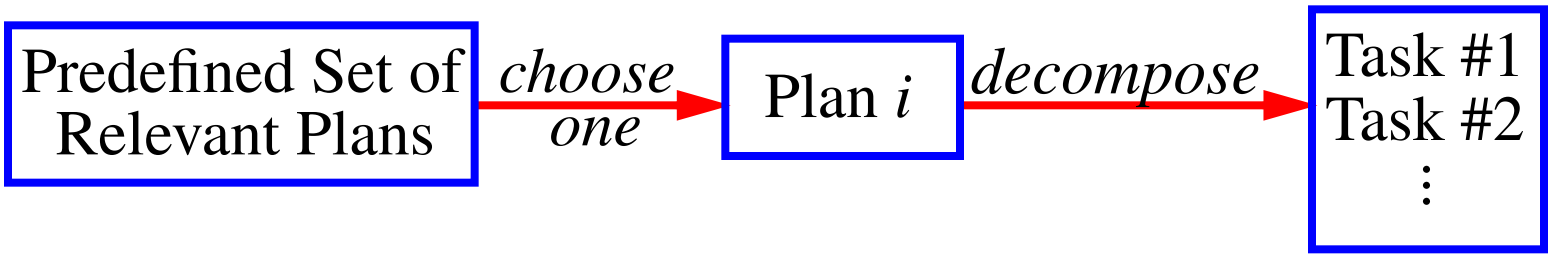
- types - amount of area covered, amount of overlap, target classification, site analysis

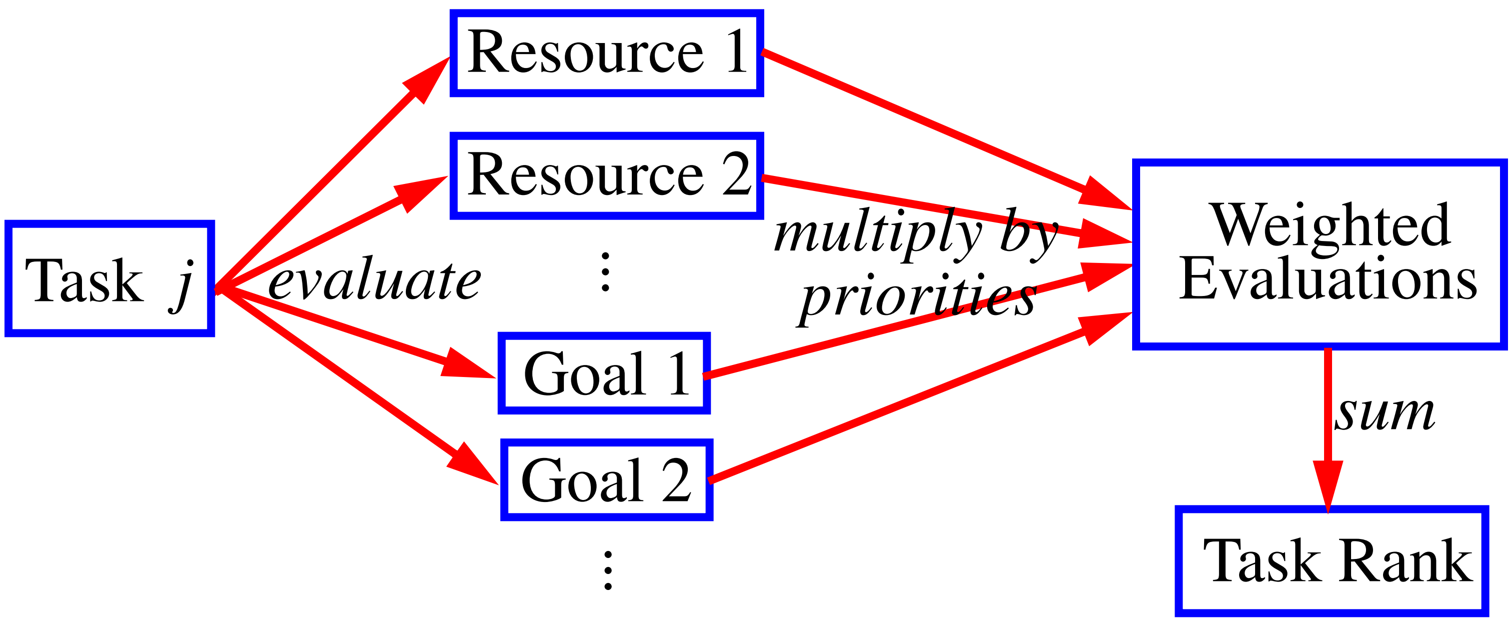
⇒ input - task information, goal quantification, uncertainty

⇐ output - percentage of area, or information gain

Carnegie Mellon

Task Ranking





Carnegie Mellon

Example

Tasks	Resources: Power – Solar	Resources: Power – Wind	Resources: Power – Consumed	Goals: Area – Covered	Goals: Area – Overlap	Rank
Coverage Pattern #1	*0.6*	*1.0*	*0.5*	*1.0*	*0.0*	*5.5*
Coverage Pattern #2	*0.6*	*0.6*	*0.6*	*1.0*	*0.0*	*4.2*
Coverage Pattern #3	*0.9*	*0.6*	*0.8*	*0.5*	*0.1*	*2.2*
Coverage Pattern #4	*1.0*	*0.6*	*0.9*	*0.8*	*0.2*	*2.1*
Priority	*5*	*2*	*-5*	*3*	*-10*	

Carnegie Mellon

Task Ranking Details

- timing
- default starting task and task switching
- uncertainty and risk
- evaluation thresholds and task vetoing
- summing component task ranks
- plan reevaluation
- selection of priorities and normalizing evaluations

Priorities	Task #1 0.8A + 1.0B	Task #2 1.0A + 0.8B	Task #3 0.8A + 0.9B	Task Rankings
A = 5, B = 5	*9.0*	*9.0*	*8.5*	1 & 2 tied, 3
A = 4, B = 5	*8.2*	*8.0*	*7.7*	1, 2, 3
A = 1, B = 5	*5.8*	*5.0*	*5.3*	1, 3, 2

Carnegie Mellon

Work to Date (1) - Task Evaluation

Refueling Simulation

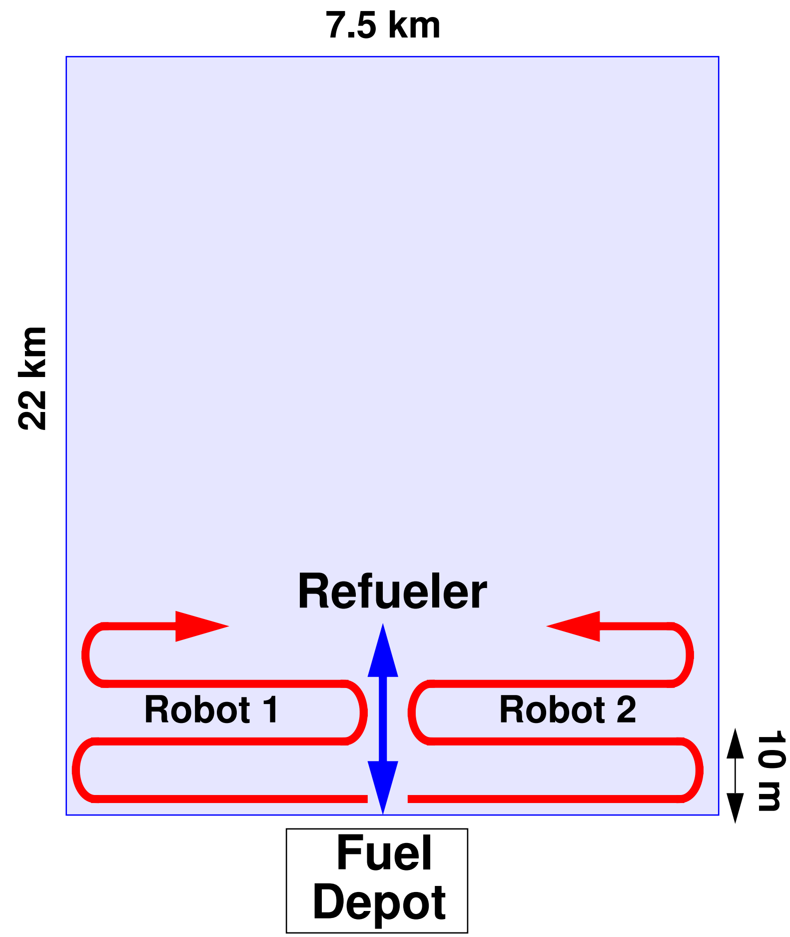
- straight rows pattern
- multiple robots
- time and fuel evaluations

Without Refueler

- 2,050 gallons
- 142 days
- 426 refueling trips

With Refueler

- 1,324 gallons
- 87 days
- 42 refueling trips



Carnegie Mellon

Work to Date (2) - Task Evaluation

Coverage Pattern Simulation

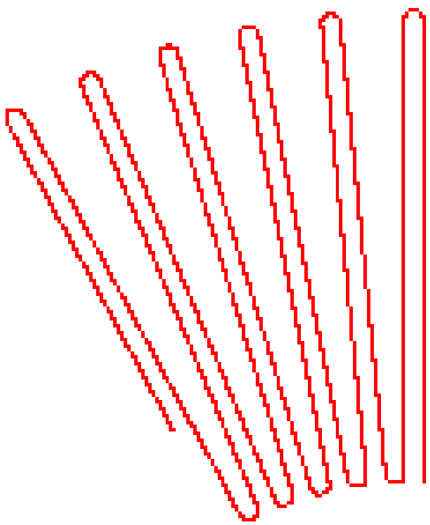
- 2 solar panel, 2 wind turbine configurations
- tasks - 5 coverage patterns
- goals - area coverage, area overlap
- resources - solar and wind power generation

Goal Evaluation

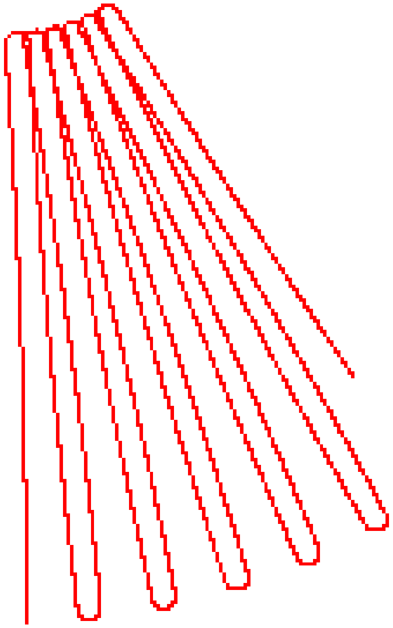
Pattern type	Straight rows	Spiral	Curved	Sun-following	Random
Designated area missed	*0%*	*0%*	*50%*	*20%*	*90%*
Area overlap	*0%*	*0%*	*3%*	*23%*	*23%*

Carnegie Mellon

Simulated Pattern Types



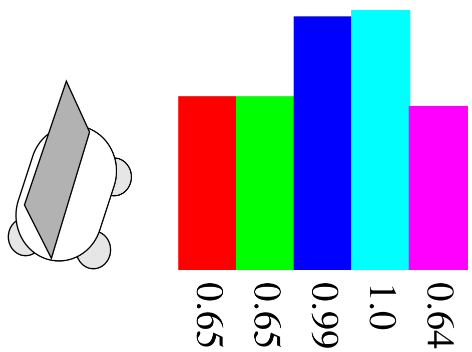
Curved Rows

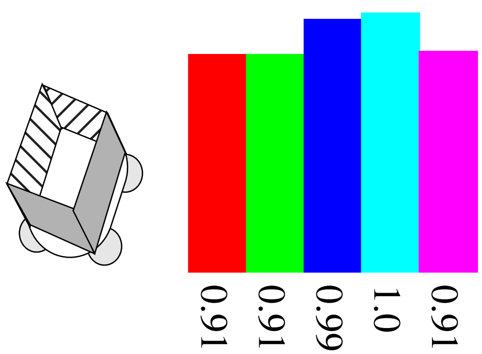


Sun-Following Rows

Carnegie Mellon

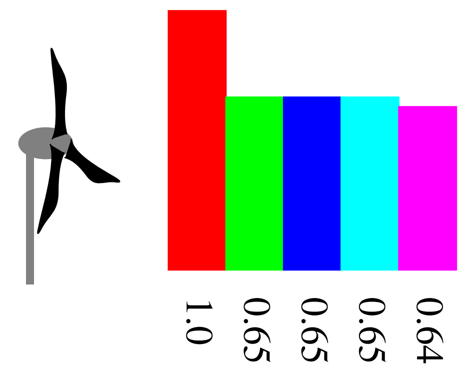
Resource Evaluation

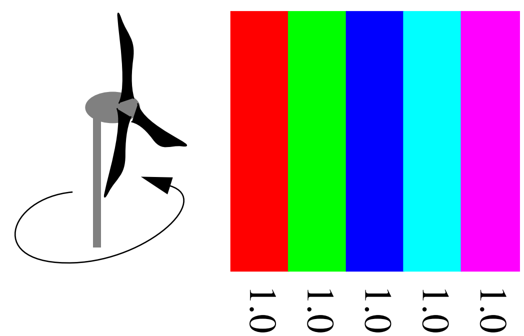




Solar Power Generation

- = Straight Rows
- = Spiral
- = Curved
- = Sun-Following
- = Random





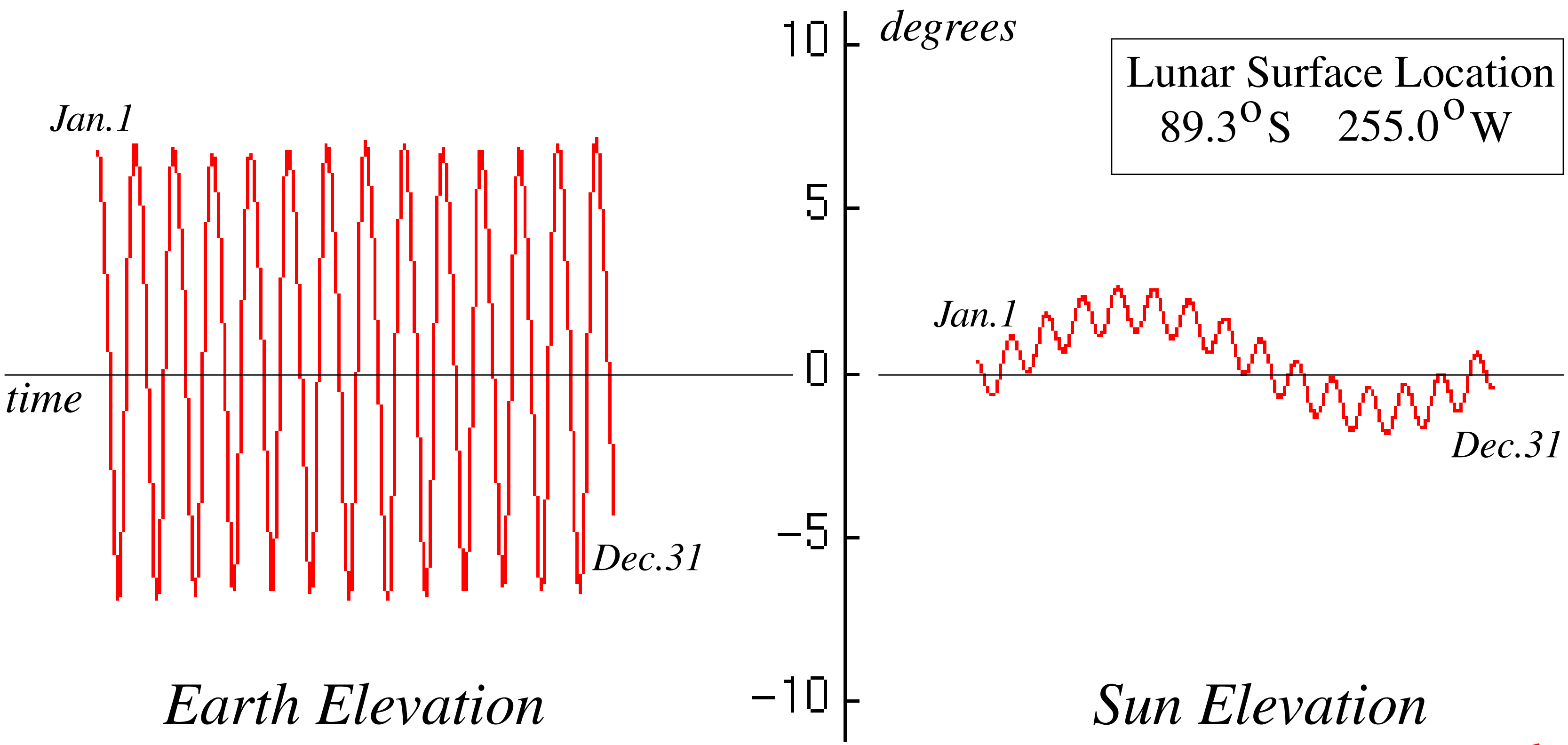
Wind Power Generation

Carnegie Mellon

Work to Date (3) - Resource Availability

Solar and Earth Visibility from Moon

Year 2000



Carnegie Mellon

Work to Date (4) - Implementation

Nomad Tests

- software framework for task evaluation, mediation, and execution
- structure for future additions, simulations, and field testing

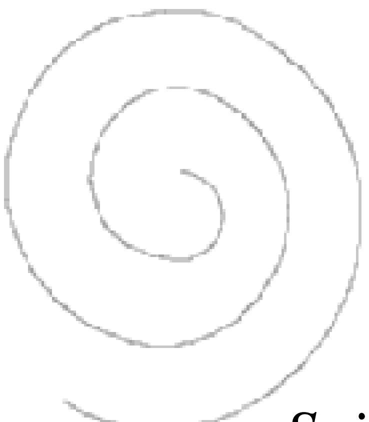
Current Functionality

- straight rows and spiral coverage patterns
- waypoint task interruptions
- path following
- human operator interface

Carnegie Mellon

Field Testing - Slag Heaps, Pittsburgh

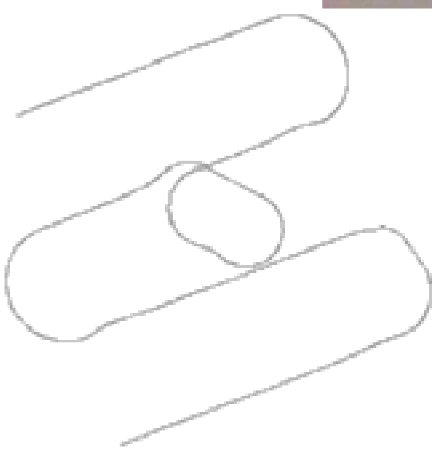
Straight rows groundtrack



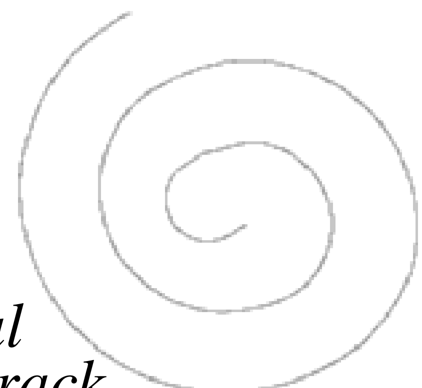
Spiral groundtrack

Carnegie Mellon

Field Testing - Patriot Hills, Antarctica



Straight rows groundtrack, with deviation



Spiral groundtrack

Carnegie Mellon

Proposed Research Plan (1)

General Research

1. develop orbital parameters algorithm for Sun and Earth
2. combine terrain map with Sun/Earth position
3. incorporate large-scale terrain map with local map

Power Generation

1. define robot configuration
2. merge solar panel configuration with robot pose and sun position
3. merge wind turbine configuration with robot pose and wind direction

Carnegie Mellon

Proposed Research Plan (2)

Power Consumption

1. relate steering activity to power consumption
2. determine power and time costs of sensors
3. relate coverage patterns to steering activity
4. incorporate terrain with power consumption

Uncertainty

1. determine method for handling uncertainty
2. develop measure for uncertainty in power generation and area coverage based on terrain and robot pose
3. develop measure for uncertainty in power consumption based on terrain and steering activity

Carnegie Mellon

Proposed Research Plan (3)

Tasks

1. develop sun-following and other patterns
2. define task steps for sensor and other non-coverage tasks
3. develop maneuver planner
4. incorporate maps with path and maneuver planners

Rankings

1. develop evaluation methods for goals
2. coordinate evaluations and priorities
3. develop algorithms or heuristics for relating priorities to the environment and mission stages

Carnegie Mellon

Schedule

Time Period	Task
January - May 1999	*General Research* 1, 2; *Power Generation* 1, 2; *Tasks* 1, 2
June - October 1999	*General Research* 3; *Power Consumption* 1, 2; *Uncertainty* 1; *Tasks* 3, 4; *Rankings* 1
November - December 1999	Proposed testing in Antarctica
January - May 2000	*Power Generation* 3; *Power Consumption* 3, 4; *Uncertainty* 2, 3; *Rankings* 2, 3
June - August 2000	Proposed testing at slag heaps, overall planner evaluations
September - December 2000	Final write-up
December 2000	Defend thesis

Carnegie Mellon

Research Evaluation Methods

Individual Plans and Tasks

Highest ranking vs. *Alternate*

- power evaluation - generation, consumption

Predefined Mission - area coverage, rock classification

Task mediation vs. *Single pattern with rule-based deviations*

- power evaluation - generation, consumption
- time evaluation - completion time, productive time
- mission evaluation - # of targets classified, area covered

Implementation

- simulation
- actual robot

Carnegie Mellon

Significance

Implementation of a Fully Autonomous, Multi-Task Mission Planner for a Remote Surface Exploring Robot

Task Selection based on Power Generation Evaluations

Evaluation of Solar Power during Coverage Patterns

Carnegie Mellon