Rover System and Performance

Life in the Atacama Workshop
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Polar Rover

- Antenna
- Mirror
- Cameras
- Laser
- Pivot
- Motor
- 3.5m²
- 2.2m
- 1.8m
- 2m
- 156kg

Life in the Atacama
Desert Rover

Changed panel to horizontal, laser to vertical, cover to cloth
Added SPI and mast, roll/pitch sensor, radios, gyroscope, power sensors, sun sensor, side camera, laptop, fluorescence imager

181kg
Rover Architecture

- **Mission Planner**
  - Waypoints
- **Mission Executive**
  - Waypoint
  - Curvature, Speed & Time
- **Navigator**
  - Terrain Evaluation
  - Odometry
- **State Estimator**
- **Telemetry Router**
  - Status
- **Health Monitor**
  - Status
  - Stop
- **Operator Interface**
  - Status
  - Curvature, Speed & Time
- **Vehicle Controller**
  - Status
  - Images
- **Sensors**
  - Images
- **Stereo Mapper**

Offboard

Onboard

Images

Life in the Atacama
Mission Planner and Executive

Model the environment (sun and terrain) and vehicle (power input and output)

Estimate the resources (power) required to reach the goal

Optimize path to expend minimum and acquire maximum resources

Execute path and replan as necessary

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QuickTime™ and a Sorenson Video decompressor are needed to see this picture.
Stereo Mapper

Stereo cameras map terrain in range from 2m to 8m at 10cm resolution

Terrain evaluation (slope, roughness) determines traversability
Navigator operates on composite terrain evaluation

Selects arc based on speed, obstacle height and goal
Operational Modes

Health Monitor or Operator Interface set the operational mode from state information

Monitored
- Rover provides safety information to operator

Safeguarded
- Rover overrides dangerous operations

Autonomous
- Rover navigates independently

Manual Operation
- Monitored Teleoperation
  - Human Control

Safeguarded Teleoperation
  - Human Initiative

Navigational Autonomy
  - Robot Initiative
Operational Modes

- Operator Interface
- Telemetry Router
- Vehicle Controller
- State Estimator
- Health Monitor
- Laser Mapper
- Stereo Mapper
- Navigator
- Mission Executive
- Mission Planner

- Monitored Teleoperation
- Safeguarded Teleoperation
- Navigational Autonomy
Monitored Teleoperation

- **Mission Planner**
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Offboard

Onboard
Operational Modes

Percentage of Cumulative Distance Traveled for Operational Modes

- Monitored
- Safeguarded
- Autonomous

Data (April 2003)

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State Estimator

Uses one axis fiber-optic and dual wheel encoders to estimate direction and distance of motion

Uses roll and pitch inclinometers to estimate motion vector

Performs piecewise integration to estimate position

Operates independent of GPS
Position Estimation

Error about 5% of distance
Test Integrated Rover Operation

Measure rover performance in the field and identify priorities for research and development.

In autonomous traverse measure:
- Path
- Odometric distance
- Duration
- Speed
- Duty Cycle
- Autonomy
- Power
Test Site
Longest Traverses

Varied terrain

DEM plot, 3D visualization of 9 Traverses

- April 13, 411 m
- April 17, 315 m
- April 19, 423 m
- April 25, 309 m
- April 25, 1119 m
- April 26, 555 m
- April 26, 502 m
- April 26, 328 m
- April 26, 291 m
Terrain Roll and Pitch
Slope Climbing

Histogram of Angle to Gradient by Pitch Slopes while moving on all days

- 12:15 degree slope
- 8:12 degree slope
- 6:9 degree slope
- 3:6 degree slope
- 0:3 degree slope
- -3:0 degree slope
- -6:3 degree slope
- -9:6 degree slope
- -12:9 degree slope
- -15:12 degree slope

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Longest Traverses

Over 90 autonomous traverses were conducted of which 9 were longer than 300m

Autonomous traverse initiated by single command to Mission Planner

Average speed 0.254m/s

Common traverse-ending faults: roll/pitch limit, no path ahead, off schedule

Longest 1118m
Plan-to-Actual Path Ratio

Average (of 9 long traverses) 1:1.14
Best 1:1.00 (straight traverse)
Worst 1:1.21 (two turns)
Conclusions and Implications

Why it worked

Rover
- Rover capable of moderate terrain and small obstacles
- Rover stable in wind (up to 45kph)
- Rust and dust happen, thermal not a problem

Software
- Autonomous navigation architecture mature
- Navigator reliable
- Mission Planner creates executable plans
- Coherent state and status monitoring
- Capabilities added incrementally, refined online
- Field development works, maintain software functional baseline, document inter-module communication
Conclusions and Implications

Where to improve

Rover design
  Insufficient wheel traction and slope climbing
  Go faster: greater speed means more time for science

Software design
  Coherent state and status monitoring
  Need to detect and reason about slopes from a distance
  Power low at end of day, need to consider night
  Need robust fault recovery to extend traverse length
  Need better capability models to extend traverse length

Summary
  Probably pushing limit with 1km traverse: need far-field perception and fault recovery
  Multi-day autonomy desirable and feasible