Atacama Desert Trek: A Planetary Analog Field Experiment

Field Robotics Center
The Robotics Institute
Carnegie Mellon University

Overview

Nomad- Planetary precursor robot

Primary Objective:

Travel 200 km

Secondary Objectives:

- Involve public
- Perform remote geology
- Evaluate panospheric camera
- Demonstrate antenna pointing
- Demonstrate skyline positioning
- Autonomous safeguarding
- Evaluate locomotion
- Transcontinental Supervision

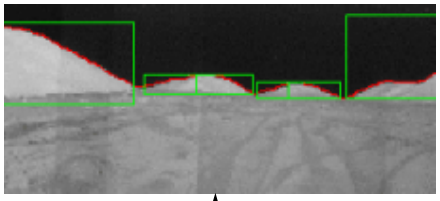
NASA Ames, Mountain View

Science Center, Pittsburgh

Atacama Desert, Chile

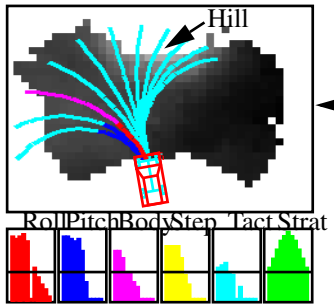
June 18- July 31, 1997

Atacama Desert Trek Technology

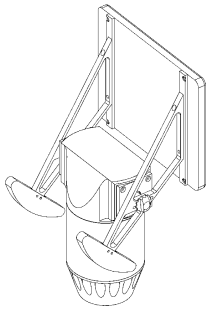


Skyline
Positioning

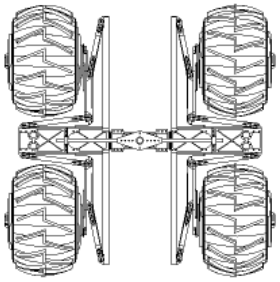
Safeguarded
Teleoperation

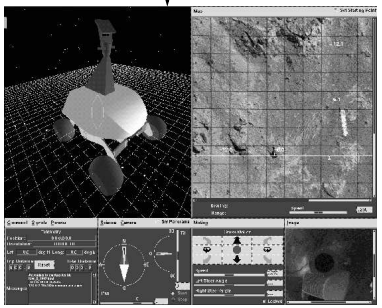


Antenna Pointing
Mechanism



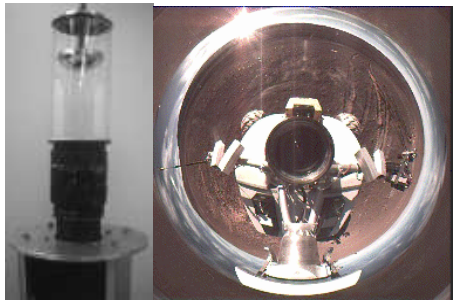
Transforming
Chassis





Public Outreach/Remote Science

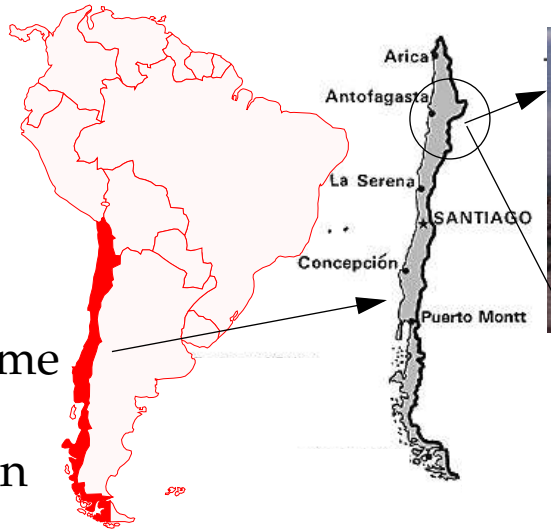
Panospheric
Camera



The Atacama Desert, Chile

Planetary Analog Terrain

- Craters, rocks and loose sand
- Complete lack of vegetation
- Varied topography



Operational Suitability

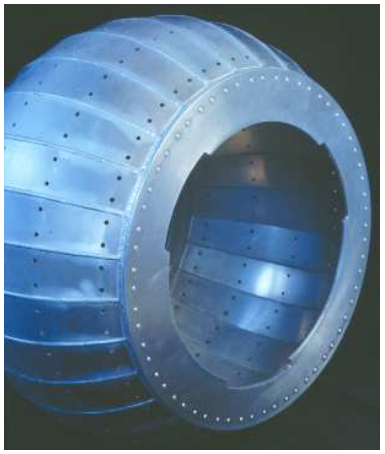
- Eastern Daylight Time
- Easy access
- Presence of NASA in Chile

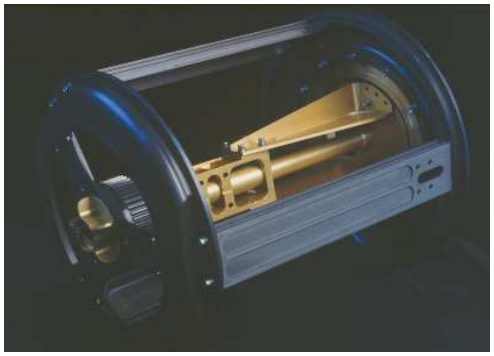
Vital Statistics

- Average elevation: 2400 m
- Temperature: 0°C to 25°C
- Precipitation: 1 cm/year from fog
- Rainfall: once every 100 years

Locomotion Electromechanism

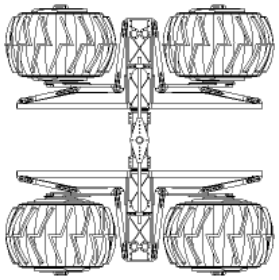
In-wheel independent drives for improved traction and motion control

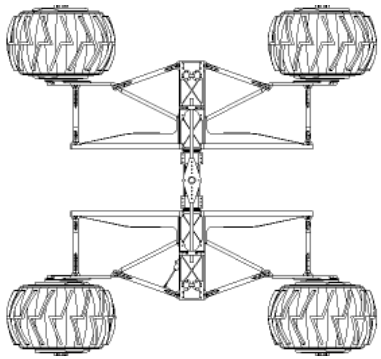




Transforming chassis provides terrain adaptation, deployment, and steering capabilities

- An actuator drives a pair of four-bar mechanisms on each side of the rover
- Motion of the follower linkages increases rover footprint
- Wheel heading changes while deployed, enabling steering





Suspension and Steering

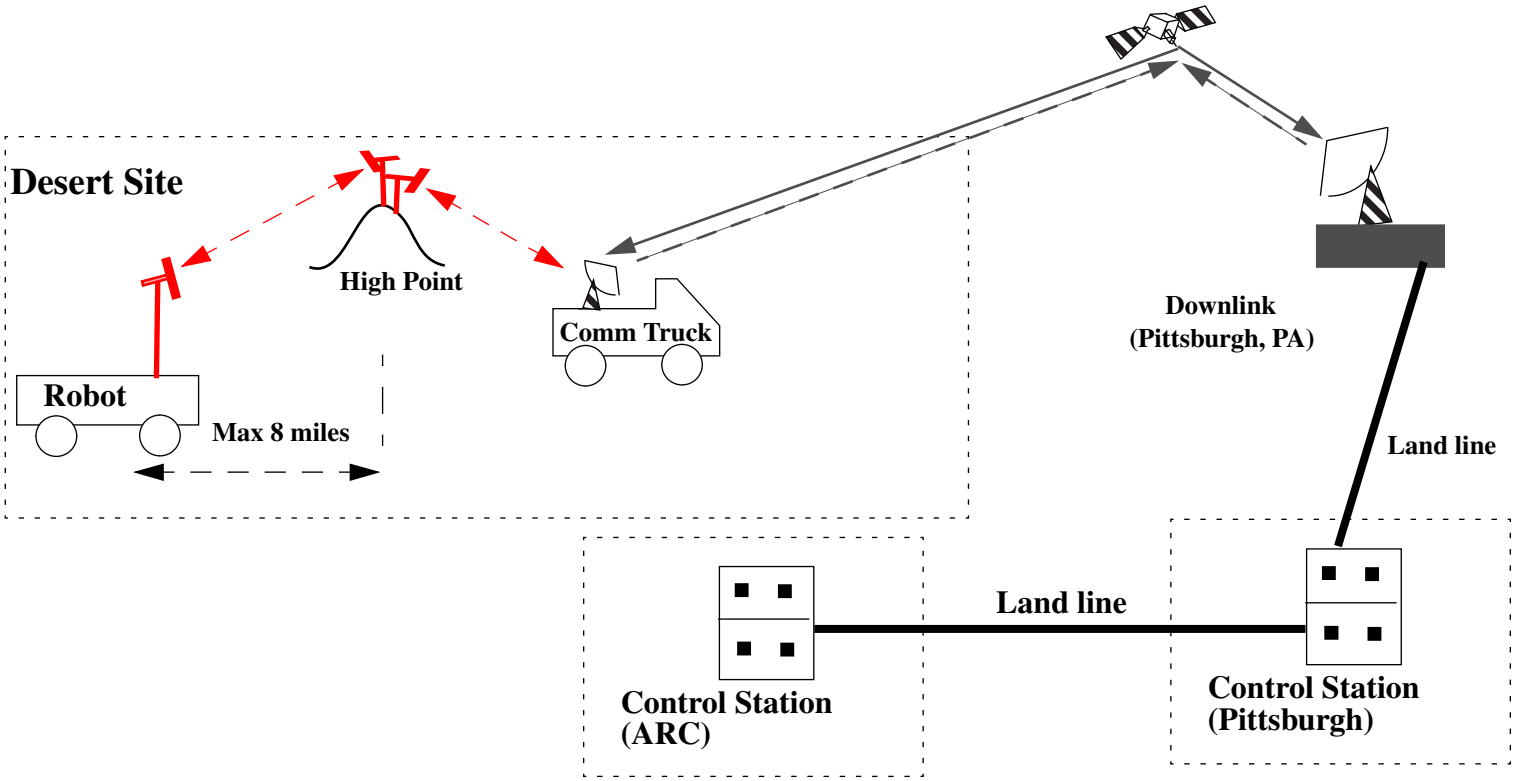
Bogey-type suspension for true body averaging

- Center of gravity moves 1/4 of the wheel elevations
- Body pitch is only 1/2 of the bogey angles
- Substantial obstacle negotiation capability

Coordinated Steering:

- Steers with mechanical linkages and few actuators
- All wheels are steered; steering angles are servoed
- Capable of both skid steering and double Ackerman

Communication



- High data rate (1.5 Mbps) required for video.
- Unprecedented from a moving robot.
- Range and rate achieved by stabilized high gain antenna.
- Pointing Mechanism and controls successfully developed.

Antenna Pointing Mechanism

- Azimuth/Elevation configuration

- less coupling

- Slip ring for elevation actuator

- continuous rotation unlike cable-wrap.
- reduces complexity (management of cables is easier)

- RF rotary joint

- to send RF signal from the transmitter to the antenna
- located co-axial with the slip ring
- RF characteristics remains constant unlike that for flexible RF cable
- Less losses (0.5 dB) compared to flexible RF cable (1.2 dB)

- Harmonic drive and brushed motor

- minimize backlash

- Balanced system

- minimizes disturbance torques

US Operations

Control centers: Carnegie Science Center (Pittsburgh, PA), and NASA Ames Research Center (Mountain View, CA)

Display: 6m diameter panoramic screen with 3 projectors at CSC, flat screen with single projector at ARC

User Interface: directional control, image pan/tilt, and heads-up overlay of instruments. [Extended interface includes low level controls of the vehicle and science instrumentation.]

Carnegie Science Center, Pittsburgh, PA

Nomad Specifications (1 of 2)

Dimensions	
Size	1.8m × 1.8m × 2.4m high (stowed) and 2.4m × 2.4m × 2.4m (deployed)
Mass	725 kg
Power consumption	3.5 kW max.
Communications	
High bandwidth telemetry	computer pointed directional antenna 1.54 Mbps continuous data rate
Backup	omni-directional, 19.2 kbps
Operation Modes	
Safeguarded teleoperation	remote driver, onboard safety enabled
Autonomous	no human guidance
Local teleoperation	remote driver, onboard safety disabled
Locomotion	
Type	4 wheel drive, 4 wheel steering, averaging suspension
Turning	2m minimum turn at vehicle center, sides synchronized
Speed	40 cm/s maximum, 20 cm/s average

Nomad Specifications (2 of 2)

Sensors

Remote imaging	360° color panospheric camera
Terrain & landmark mapping	(2) stereo camera sets
Navigation	differenial GPS gyro compass
Science	high resolution stereo towed metal detector and magetometer weather station

Computing

Robot control	(2) 68040 real time computers
Panoramic imaging	(1) Dual Pentium Pro
Navigation	(1) Pentium
Science	(1) Pentium Pro

Safeguarded Teleoperation

Sensors:

- 2 pairs of stereo cameras, 120 deg total FOV
- Laser based short range detection

Procedure:

- Range image produced from stereo and laser
- All possible paths are evaluated based on hazards along the path
- Nomad is allowed to move in a direction only if it is safe

Modes:

Safeguarded teleoperation: User Issues commands, Nomad picks safest accommodating direction

Obstacle Avoidance: Nomad picks safest direction, wanders without goal

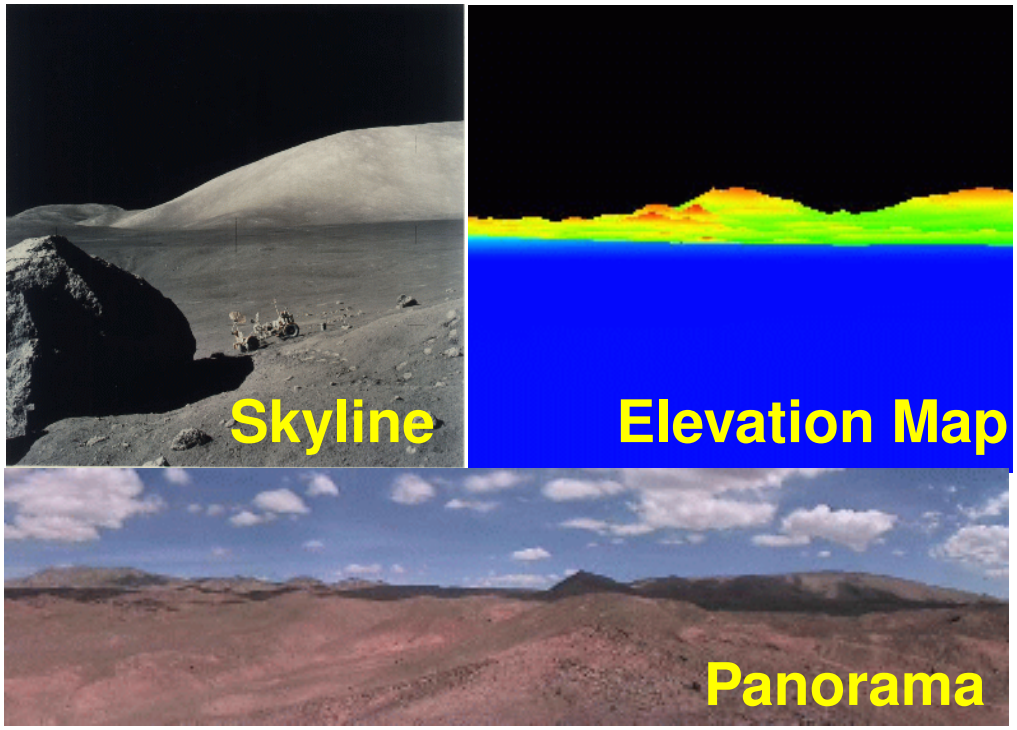
Waypoint Guidance: Nomad moves toward user-specified world point, subject to safe driving

Skyline Positioning

- Combines images into a single panorama

- Skyline from the panorama matched to the skyline obtained from maps

- Accuracy between 84-160 m



- Accuracy achieved using data from Pittsburgh, Utah, California, Atacama and the Moon

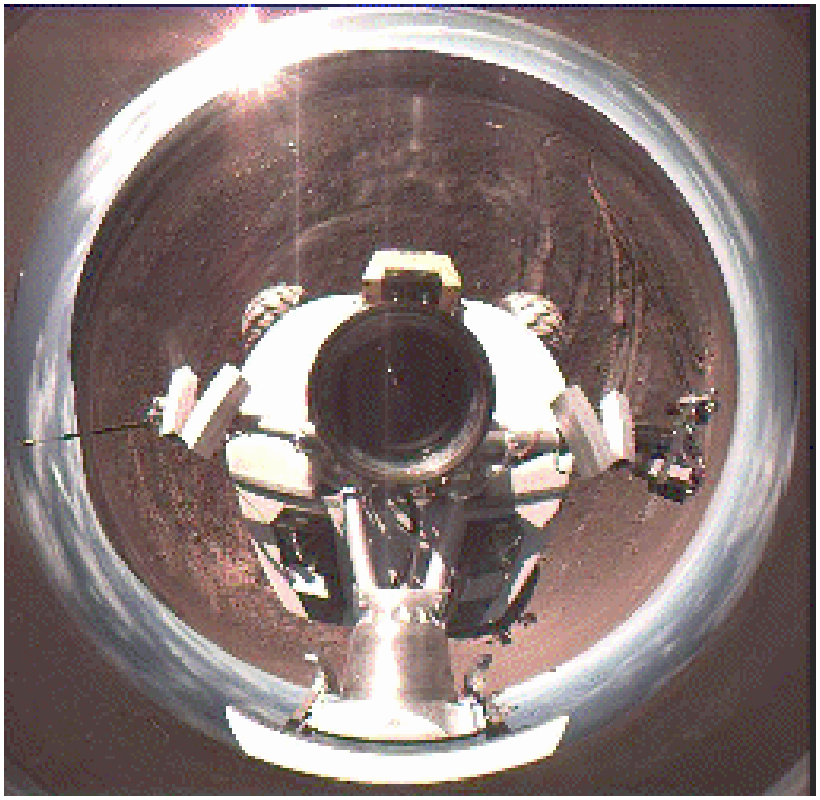
Panospheric Imaging

Camera FOV: 360 deg Azimuth, -90 to 40 deg

CCD: 1 k x 1k with Color filter overlay

Frame rate: 6-1 Hz possible

Compression: 1:60 using wavelet



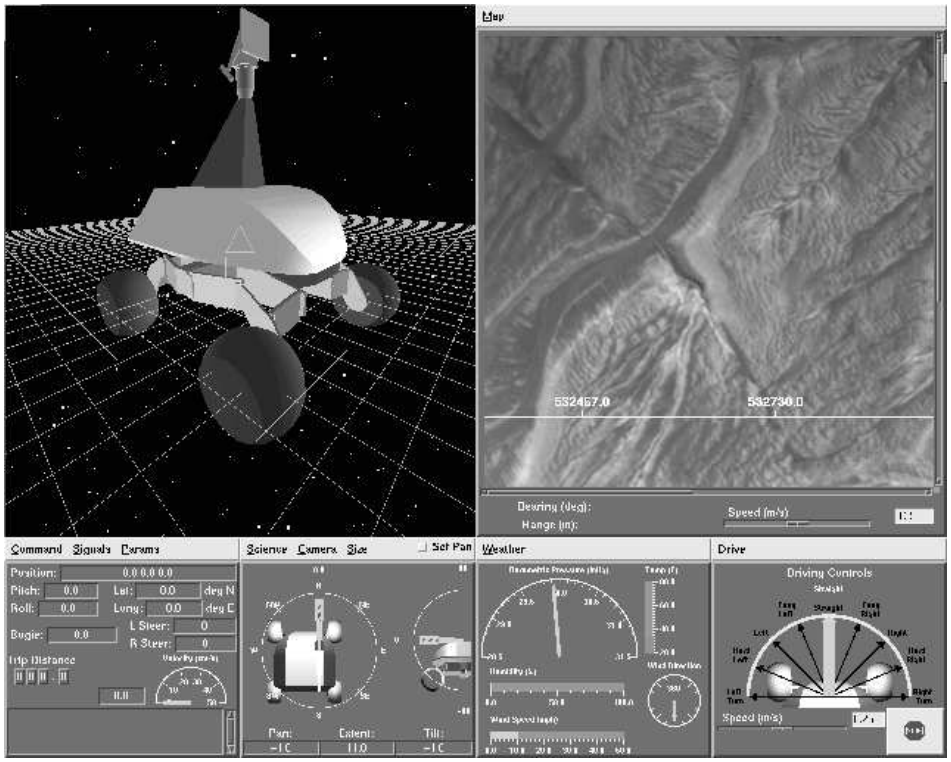
Ultrawide FOV:

- Improves situational awareness
- Allows multiple operators independent views
- Aid scientists by giving a feel of environment
- Provides enhanced feature detection and tracking

Virtual Dashboard for Nomad

Developed by NASA Ames Research Center

- Simplify assessment of current robot state
- Reduce the number of operators and the required skill level of the operator
- Develop understanding of the environment



- Operate as effectively, in locomotion and science tasks, as if present at the site.

Results

Distance Traversed

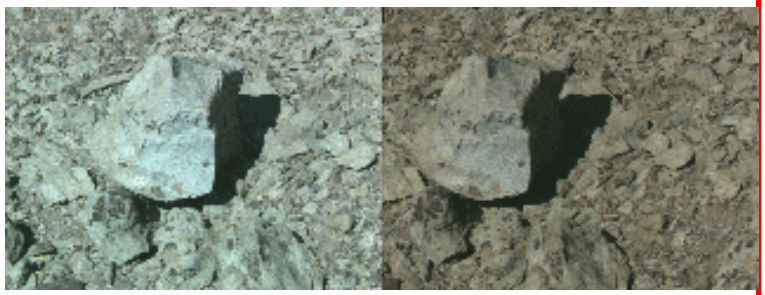
- Total: 223.59 kms
- Science Center, Ames and Santiago
- Direct teleoperation, safeguardered teleoperation, sutonomy, pattern search

Public Involvement

- 50,000 to Nomad exhibits
- 12,000 participants at Nomad theatre
- 200 novice drives
- Rover TV
- Web pages: CMU, NASA, Entel, PUC
- Newspapers, Magazines and TV

Science

- Successful science experiments
- Simulated 4planetary analog missions
- Observation of a fossil bed



Results ... Continued

- Detected meteorites visually and magentically
- Longest robotic traverse (1311m) in a day while performing science; visited 10 sites
- Cooperated with Chilean geologists for ground truth

Panospheric Imaging

- First time immersive imagery for driving
- 3-5 Hz frame rate from the robot
- 2-3 Hz frame rate display
- 20,000-30,000 images/day
- 40,000 bytes/image

Communication and Pointing

- 1.5 Mbps continuous data rate from the robot
- Stations in Santiago, Atacama, Pittsburgh and Mountian View.
- Range of 10 kms achieved between the rover and the relay station

Locomotion

- 200km+ traverse, max. of 24.22km
- 100 chassis opening and closings
- 38 deg down slopes, 22 deg up slopes, 33 deg. cross slopes and 22” obstacles traversed

Skyline Positioning

- 300 m accuracy in positioning in 1600 sq, km area

International Cooperation

- Nomad Team US: CMU, NASA Ames, U Iowa
- Nomad Team Chile: OUC, U Catolica del Norte
- Friends of Nomad: 30+ institutions