Nomad Specifications (1 of 2)

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

Communications

High bandwidth telemetry	computer pointed directional antenna 1.54 Mbps continuous data rate
Low bandwidth	omni-directional, 19.2 kbps

Operation Modes

Safeguarded teleoperation	remote driver, onboard safety enabled
Autonomous	no human guidance
Direct teleoperation	remote driver, onboard safety disabled

Dimensions

Size	1.8m × 1.8m × 2.4m high (stowed) and 2.4m × 2.4m × 2.4m (deployed)
Mass	650 kg
Power consumption	2.4 kW

Nomad Specifications (2 of 2)

Sensors

Remote imaging	360° color panospheric camera
Terrain & landmark mapping	(2) stereo camera sets
Position estimation	gyro compass differential GPS
Science	high resolution stereo towed metal detector 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

Procedure:

- Range image produced from stereo
- 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

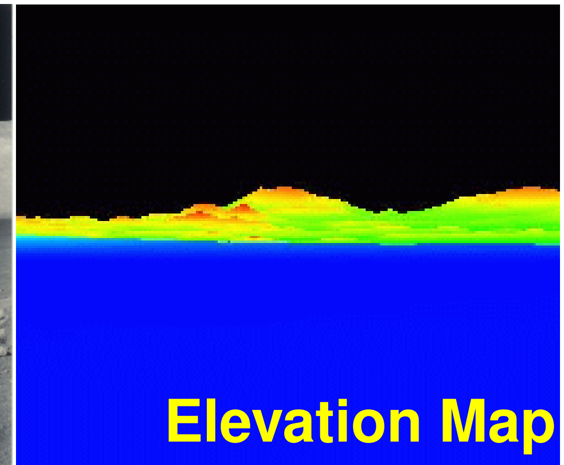
Safeguarded Teleoperation

Carnegie
Mellon

Skyline Positioning

- Combine images into a single panorama

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



- Accuracy between 84-300m depending on map resolution

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

Panospheric Imaging

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

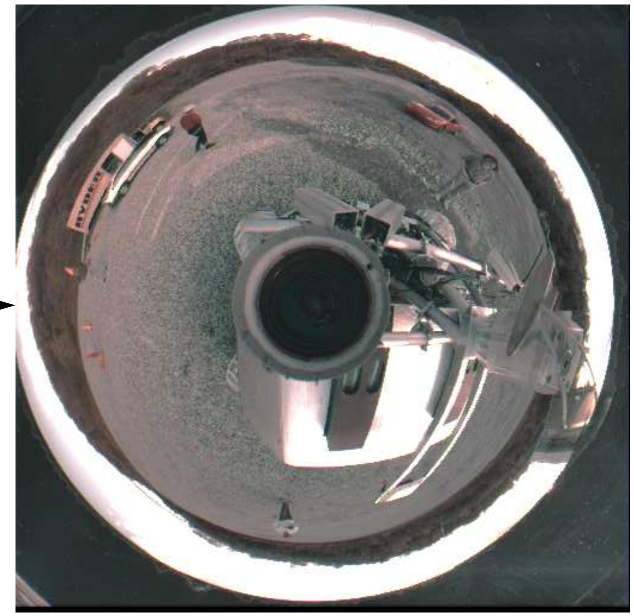
CCD: 1 k x 1k with Color filter overlay

Frame rate: 6-1 Hz possible

Compression: 1:60 using wavelet

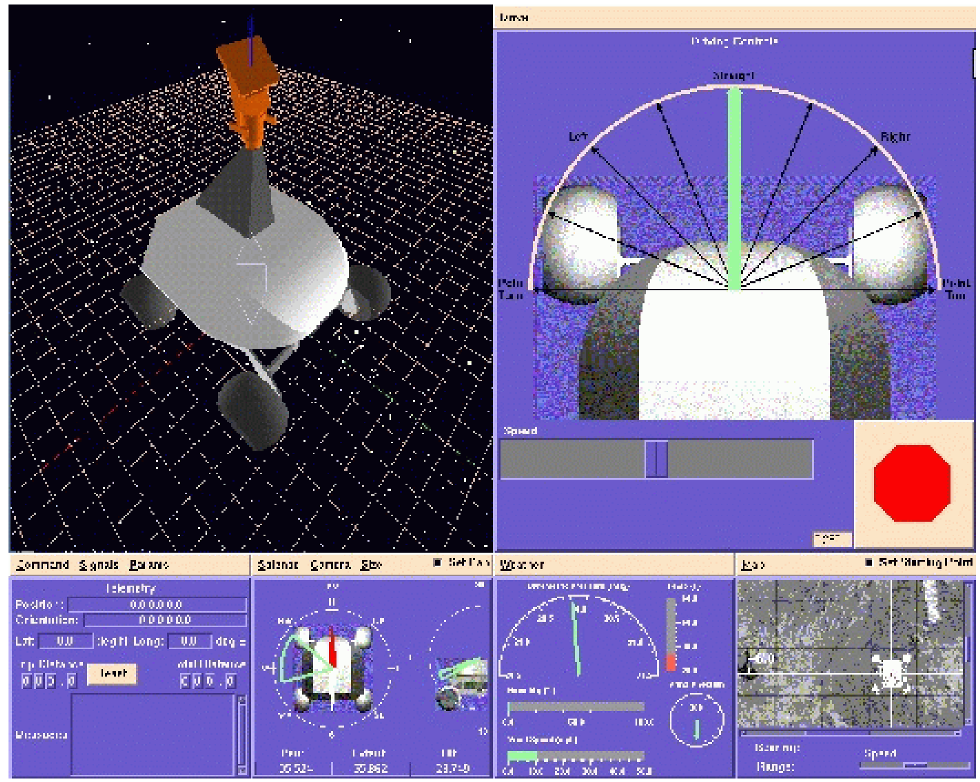
Ultrawide FOV:

- 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 km
- Autonomy: 21 km
- Driving modes: direct teleoperation, safeguardered teleoperation, autonomy, pattern search

Public Involvement

- 50,000 to Nomad exhibits
- 6000 participants at Nomad theatre
- 100 novice drivers
- Rover TV
- Web pages: CMU, NASA, Entel, PUC
- Newspapers, Magazines and TV

Science

- Successful science experiments
- Simulated 5 planetary analog missions
- Observation of possible fossil

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 km achieved between the rover and the relay station
- 98% packet success rate

Locomotion

- 200km+ traverse, max. of 24.22km in one day

- 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: PUC, U Catolica del Norte
- Friends of Nomad: 30+ institutions