Mars Synthetic Terrain Generation And Rover Mission Simulation Using Supercomputers

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Our Role Has Been

- Generate & Serve Terrain (environments)
- Host Simulation Models
- Provide Visualization Services
- Provide High Performance Ensemble Simulation
- (jointly) Provide interfaces to the risk analysis tools

Joint Goal: Perform a complete risk analysis from scratch in a single afternoon.
Basic Information & Simulation Flow

MORE DATA

TARGET SCIENCE MODELS
- Comet
- Mars
- Earth

MISSION

SYNTHETIC ENVIRONMENTS

VIRTUAL PROTOTYPES

Terrain - Starting With What We Know & Filling in the Details

30 m image by Viking
Details by Geoscience
More Details

Terrain Server is meant to be 24/7 capability for wide spectrum customers.
Creating the Virtual Environment and Simulation Model Is the Hard Part......

• But It's Not Enough!
• To Be Effective These Modules Should Be Embedded in an 'Ensemble' Simulation Environment.

Ensemble simulation is the performance key for:
• Rapid Design Space Exploration
• Monte Carlo Risk Analyses
• Mission Replan During Operations
Some Performance Results

- Terrain Generation - Several Hours to Several Minutes
- Can run ~ 100 simulations at once
- By moving to a 'data agile' environment, the execution time of each simulation went from 6 hours to 45 minutes.

**Overall - An improvement of nearly 3 orders of magnitude!**
Under the Hood

Analysis Flow Control & Knowledge Management

- Specify
- Verify
- Gen Terrain
- Construct Sim
- Execute Sim
- Compare Reliability
- Assess Risk

Simulation Component Libraries

- Environment
  - Atmosphere
  - Surface Sol
- Nav algorithms
  - Sojourner
  - Athena CM-03
- Rover mechanics
  - Wheel slip & inverse kinematics
  - None

Supporting Systems

- Terrain
- Scripts for Other Vehicles
- Sim state history
- Interactive Sim visualization
- Computer performance
  - Flap counter
  - Emulator

Rovers at Three Rock Densities

- 5.9% Rock Density
- 8.8% Rock Density
- 11.8% Rock Density

Time to Reach Goal
Starting With What We Know & Modeling It

A Candidate Mars '03 Landing Site in Isidis

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Validation with Laser Altimetry

MOLA DATA
First Light: Real Terrain Enriched Synthetically

Hi Fidelity Sun Angle Modeling

10 Deg
30 Deg
50 Deg
70 Deg
A New Paradigm for System Validation

Validation - Ensuring that the system will work as required

- The old paradigm.
  - Tests validate the system.
- The new paradigm.
  - Tests validate the simulation.
  - The simulation validates the system.
- Example #1 – Validating Pathfinder Descent.
  - Parachute, backshell, bridle, and lander tested at China Lake.
  - System simulator replicated the China Lake results.
  - Simulation using the projected Mars environment validated the flight system.
- Example #2 - Similarly, the Mars Yard can validate Mars Rover simulations under both obstacle and lighting conditions.
Entry Descent & Landing - A Second Example

The EDL Architecture Problem
Hazard Avoidance & Precision Landing

**Terrain Server**
- Actual DEM
  - Actual S/C State
  - LIDAR Simulation & Terrain Estimation
    - DEM Estimate
    - Hazard Avoidance:
      - Hazard Detection & Landing Site Selection
        - Nominal Site
        - New Site
      - Other Sensor Data (IMU, Gyros)
  - Position Change Estimation
    - Horizontal Velocity Estimate

**Guidance & Navigation**

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Multi-Center Simulation Architecture

**Visualization & Control**

Langley Hypersonic Entry Ensemble Simulator

Individual States

JPL EDL Ensemble Simulator

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View of landing site with synthetic terrain enhancement.

An Ensemble EDL Simulation - Keeping Track
Integrated Processes

Conceptual Design Process
- Configure a feasible system solution
- Knowledge Management

Product Formulation Process
- Test every aspect of proposed system/mission changes or options
- Knowledge Management

Detailed Design & Implementation Process
- Critical issues have been fixed—execute implementation plan

JPL’s Product Design Center (PDC)

JPL’s Proposed Mission/Technology Analysis and Synthesis (MTAS) Center

JPL’s Design Hubs & Flight Systems Test beds

The Big Picture

Team experiences - Dialogue between system designers (e.g., Team X & Team Y)
What we want to accomplish

Analysis & Synthesis - Dialogue between system designers and a software prototype

Explicit processes & procedures - Dialogue between system designers & actual flight hardware and software

Major benefit: MTAS allows you to test and iterate your design without committing resources to detailed design and acquisition

JPL
Schoppers Algorithm, 20 cm Hazards

Time To Call Home