On-Board Real-Time Techniques for Safe and Precise Landing

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Go For Lunar Landing Conference
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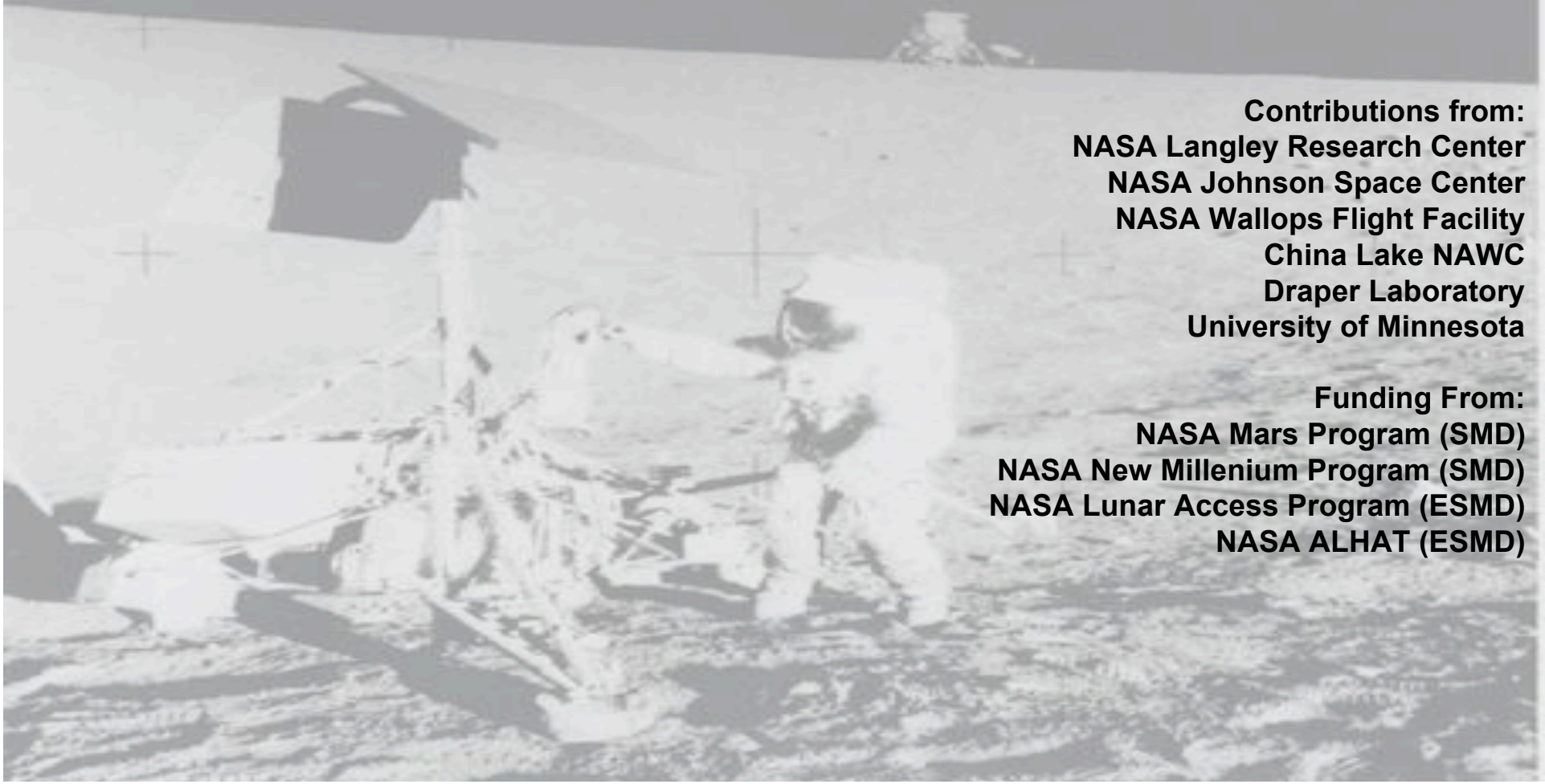

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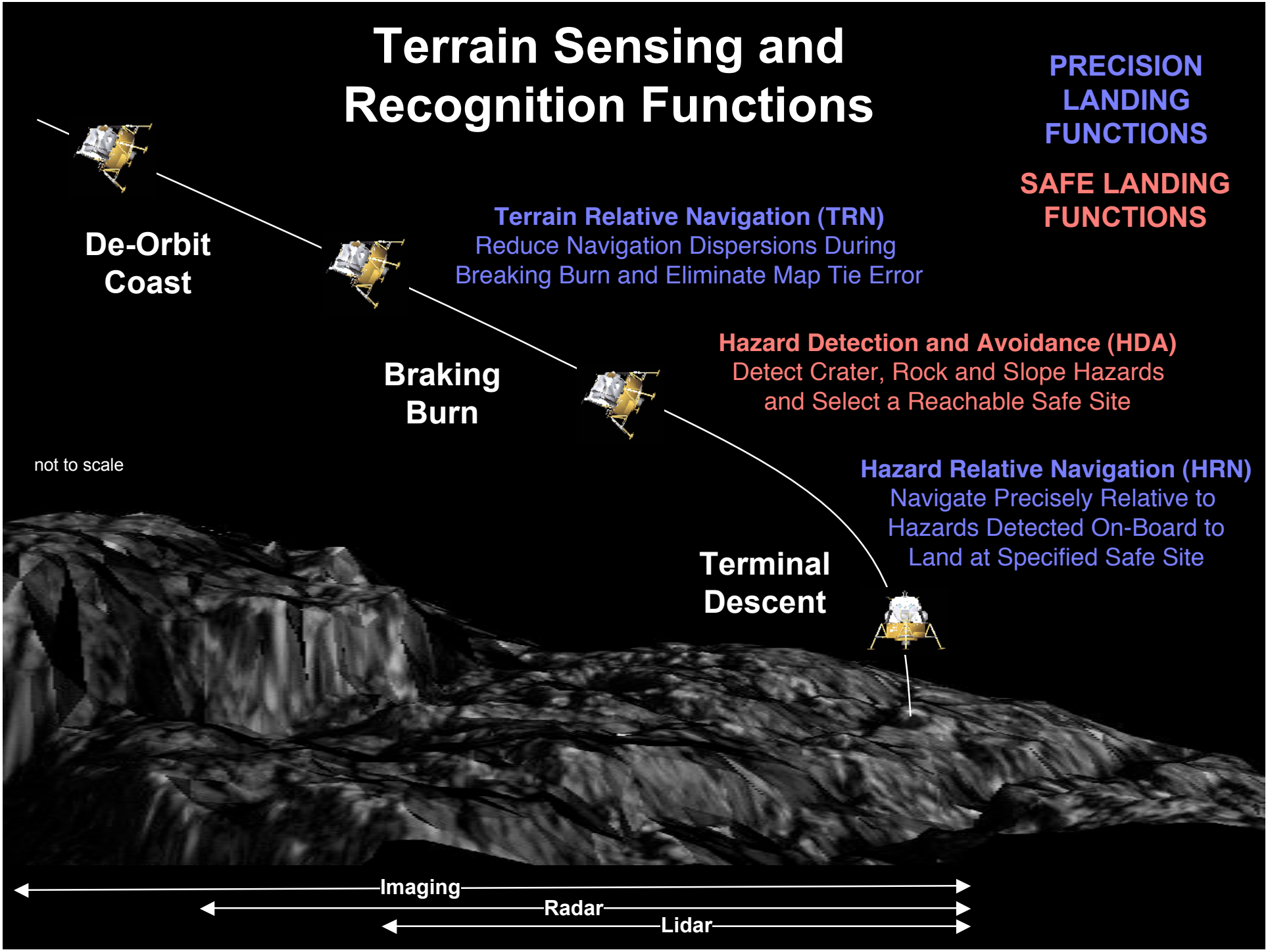
NASA Lunar Access Program (ESMD)
NASA ALHAT (ESMD)

Terrain Sensing and Recognition Functions

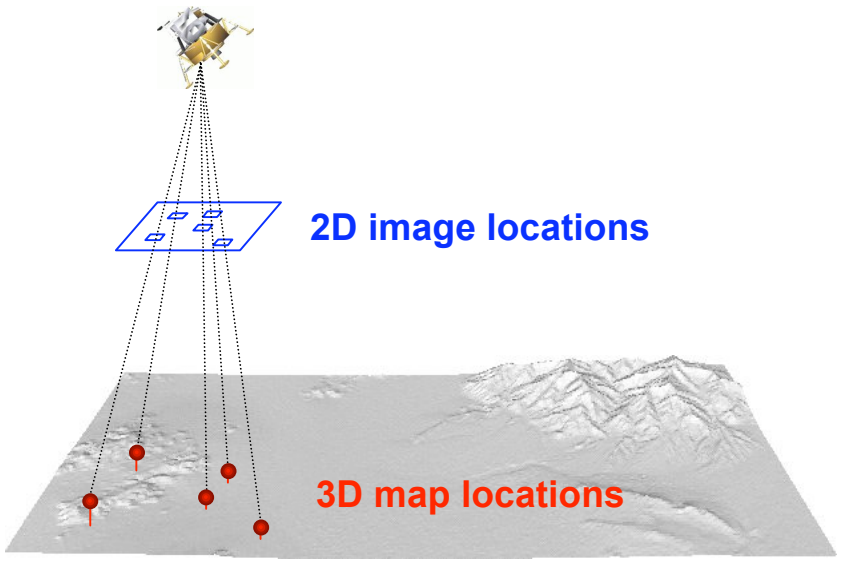
PRECISION LANDING FUNCTIONS

SAFE LANDING FUNCTIONS



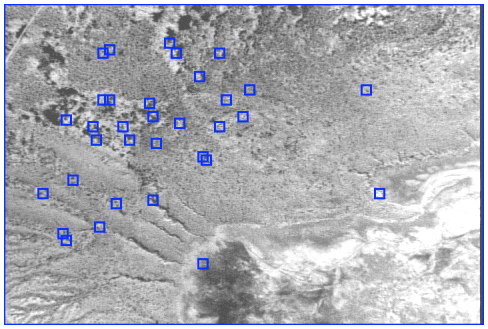
Passive Optical Terrain Relative Navigation

- Image correlation automaticallly determines correspondences between 2D image locations and 3D map locations.
- From these correspondences the position of the spacecraft with respect to the map can be computed from triangulation
- Map can be an orbital image or a rendered digital relevation map

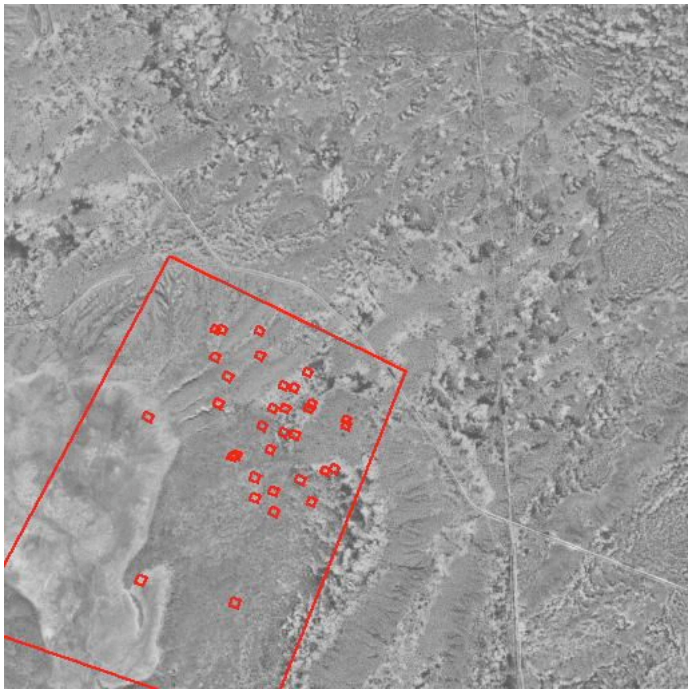


Example from Sounding Rocket Test

descent image

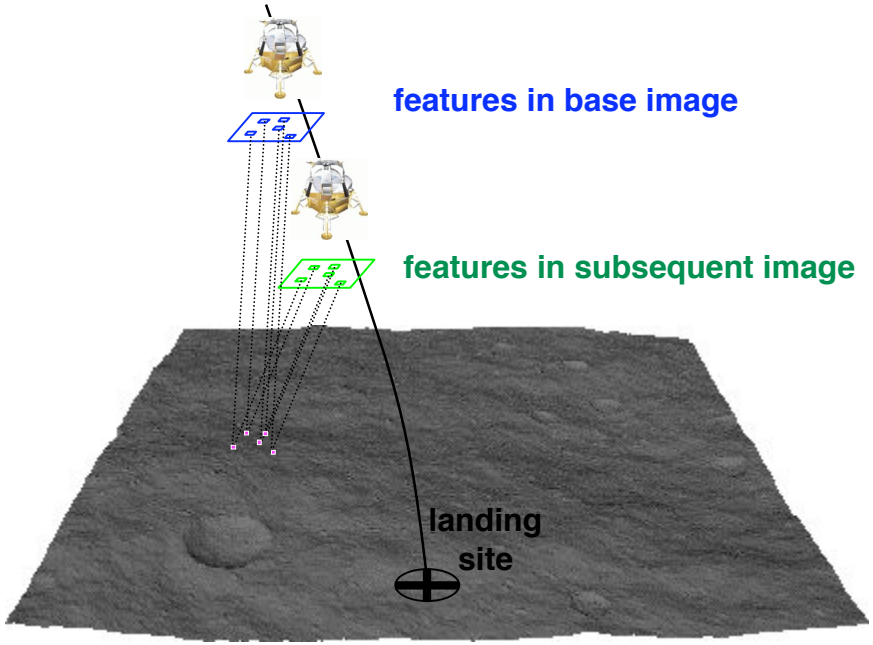


map

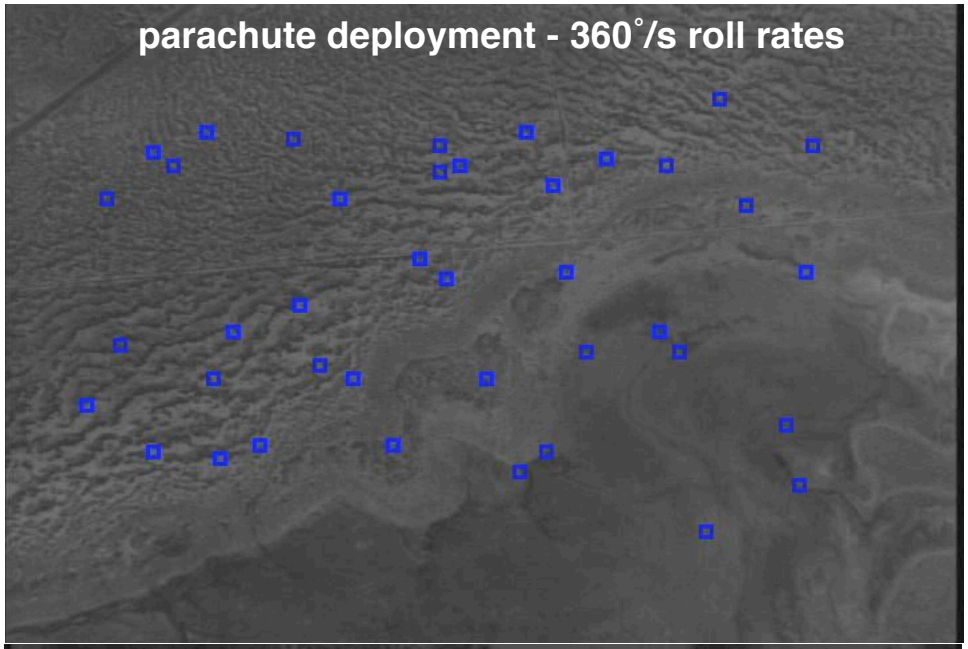


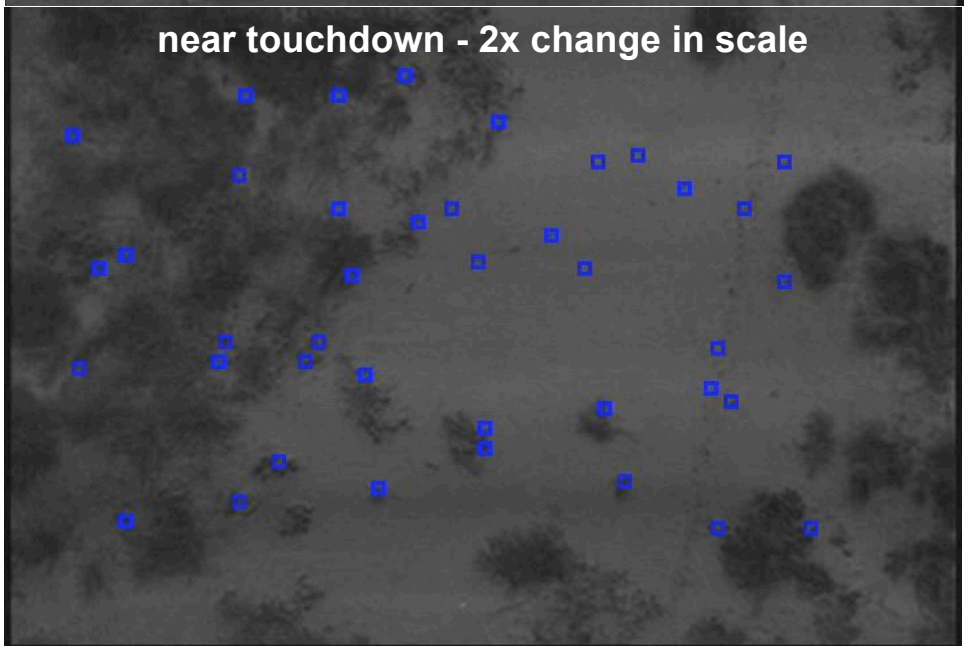
Passive Optical Hazard Relative Navigation

- Feature tracking automaticallly determines pixel correspondences between a base image and subsequent images
- Does not require apriori landmarks
- If the base image also defines the hazard locations then the hazard relative position of the spacecraft can be computed from these correspondences

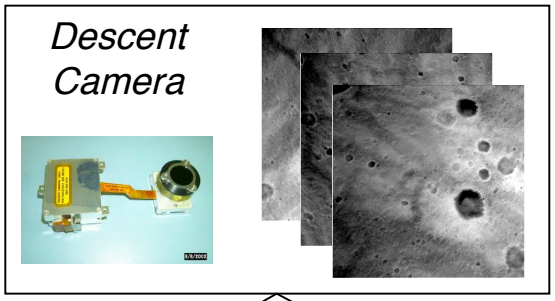


Examples from Sounding Rocket Test

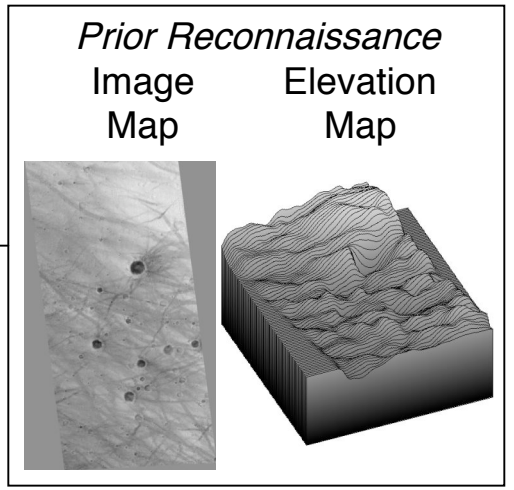




Vision Aided Inertial Navigation



Descent Images



Feature Tracking

Image Alignment

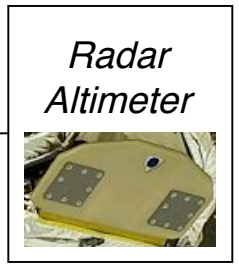
2D image to 2D image matches

2D image to 3D map matches

angular rates and accelerations

VISINAV Kalman Filter

altitudes



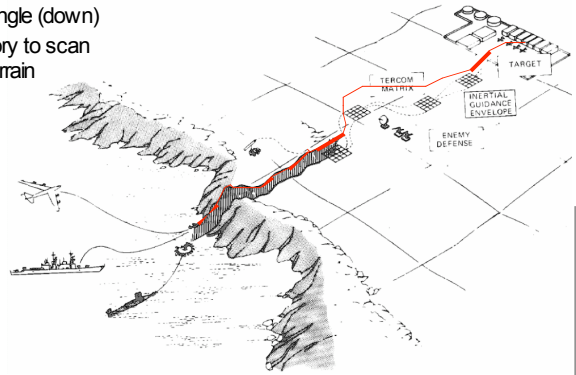
Lander position, velocity, attitude

SOUNDING ROCKET TEST RESULTS	North	East	Down
Position Error at Touchdown (m)	-1.7	0.1	-6.2
Velocity Error at Touchdown (m/s)	0.13	0.06	-0.07

Lidar-based TRN and HRN

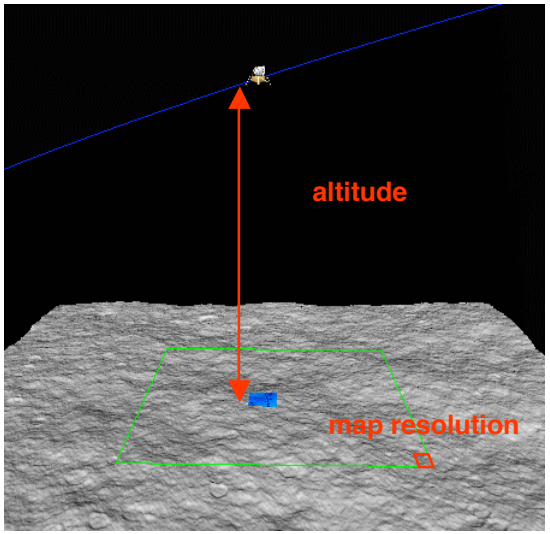
Cruise Missile TRN as a Basis for Lunar Lidar TRN

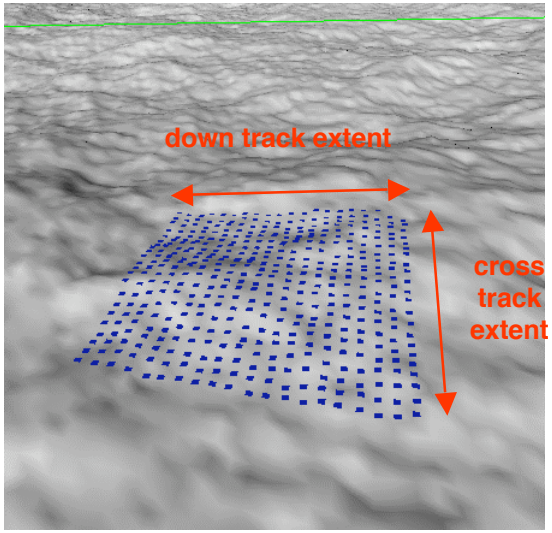
- Fixed look angle (down)
- Vary trajectory to scan distinctive terrain

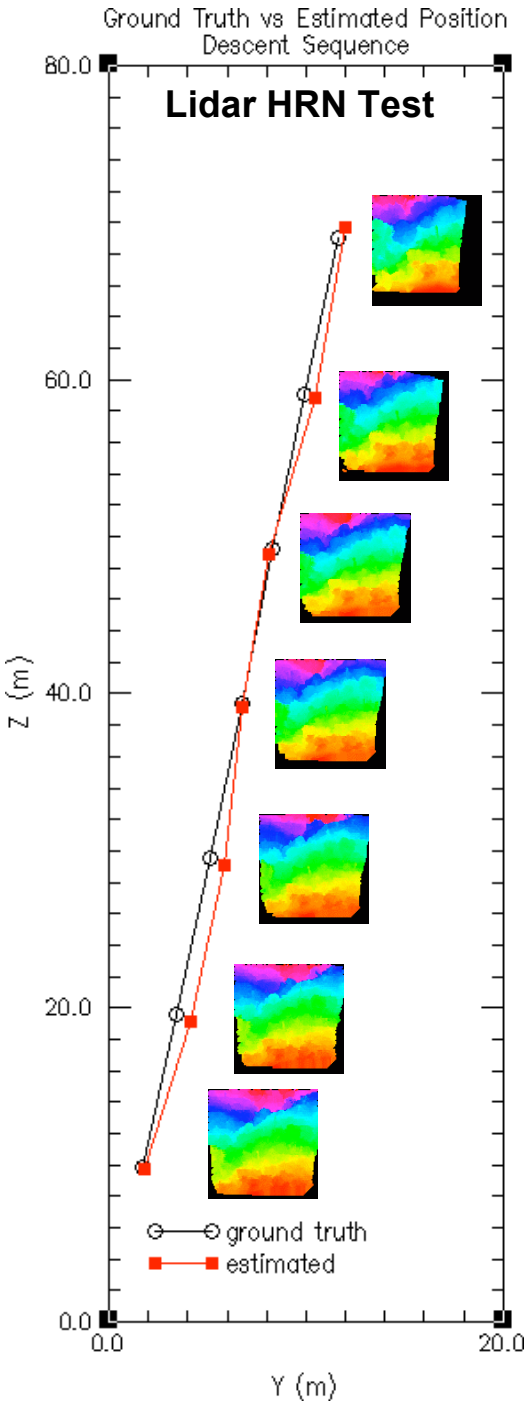


- **TRN landing precision is driven by map resolution (<10m)**
- **TRN robustness driven by areal coverage of sensor**
- **HRN precision driven by sensor resolution (<1m)**

Single Axis Scanning Lidar Operated in a Pushbroom Mode

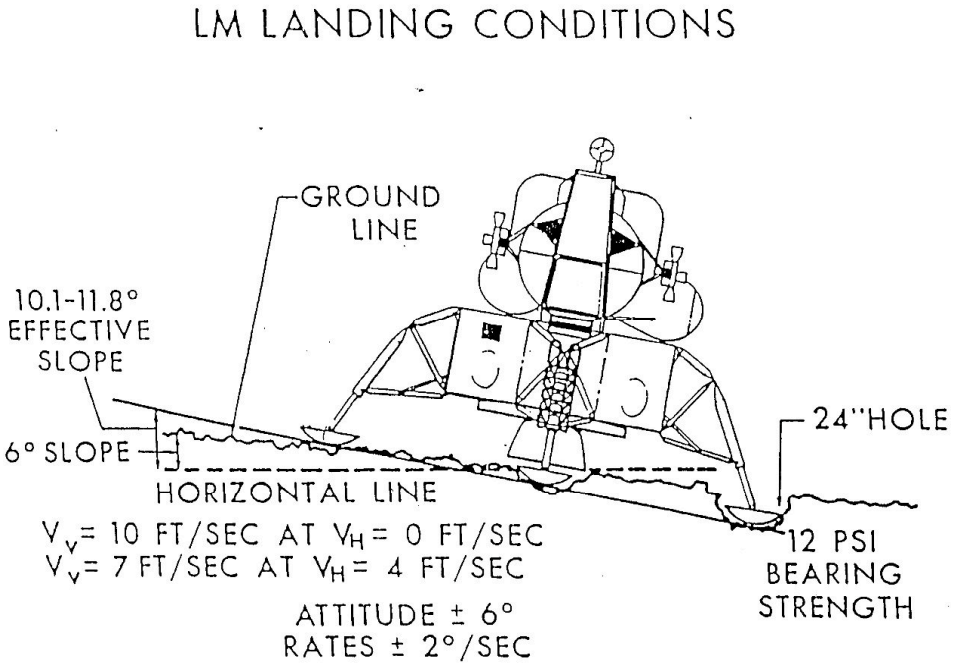




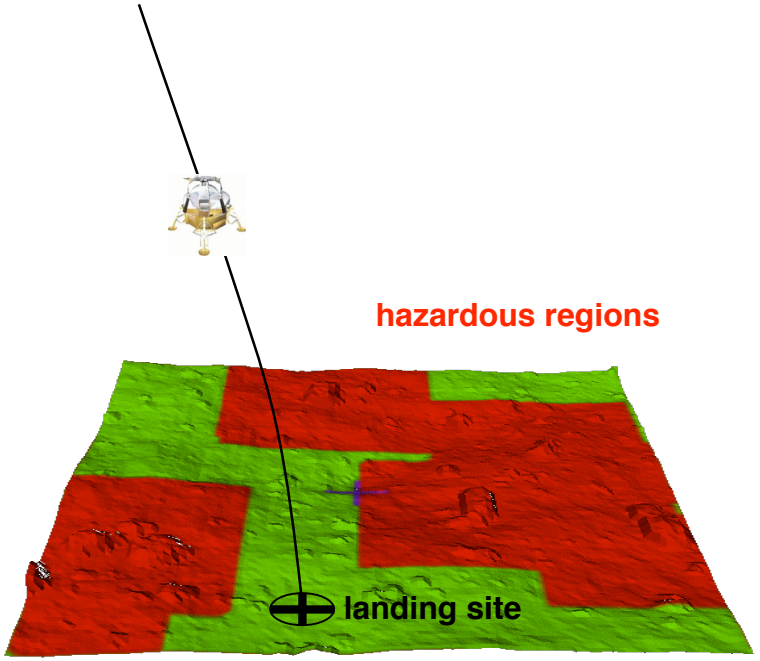


Hazard Detection and Avoidance

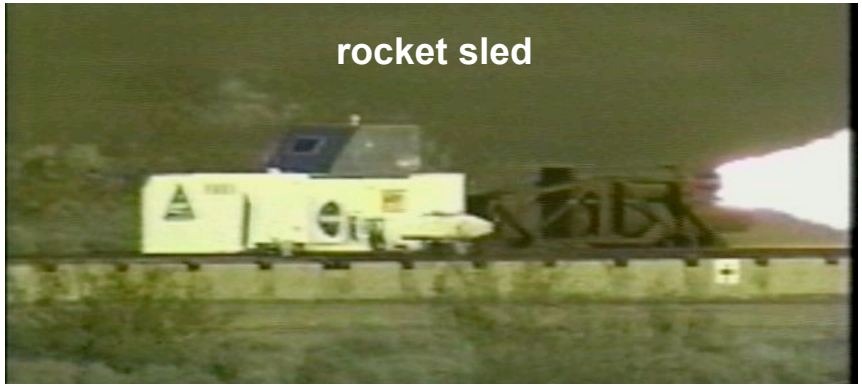
Autonomous Landing Hazard Avoidance Technology (ALHAT)



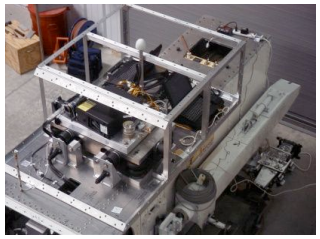
Sensor-Based On-Board
Hazard Detection and Avoidance



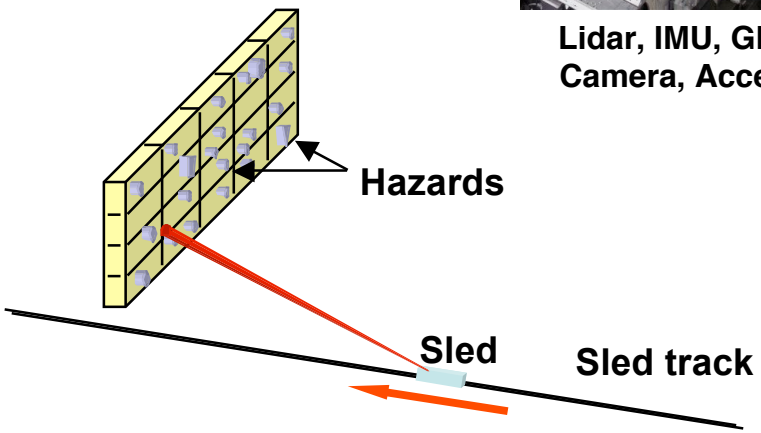
Lidar Hazard Detection Sled Test

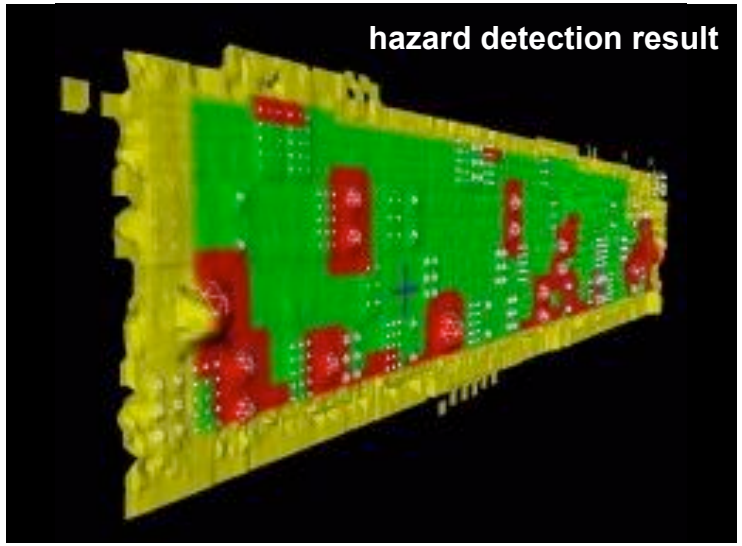


onboard sensing
& data logging



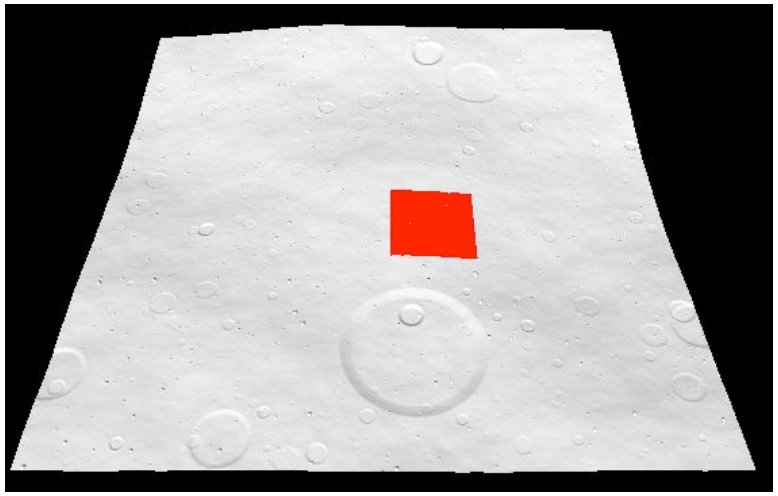
Lidar, IMU, GPS
Camera, Accels



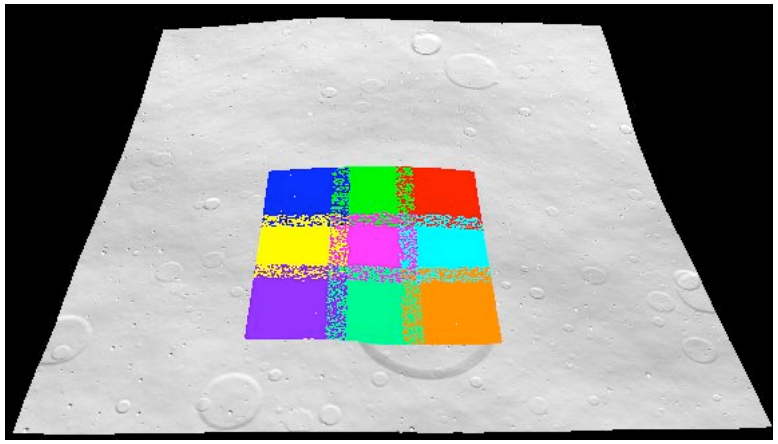


High Fidelity Flash Lidar Simulation

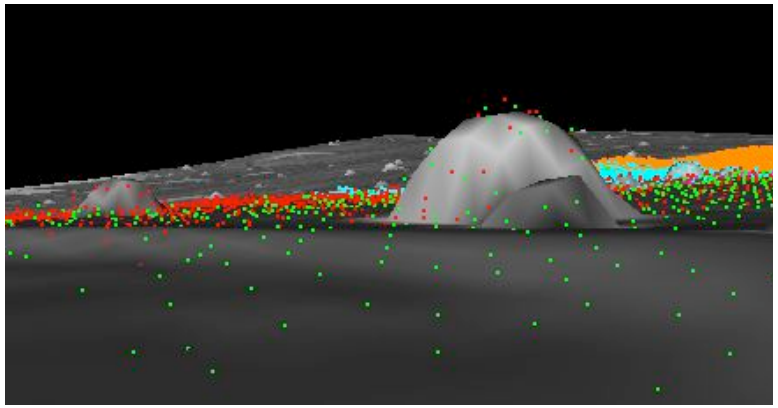
Single Lidar Image on Truth Terrain



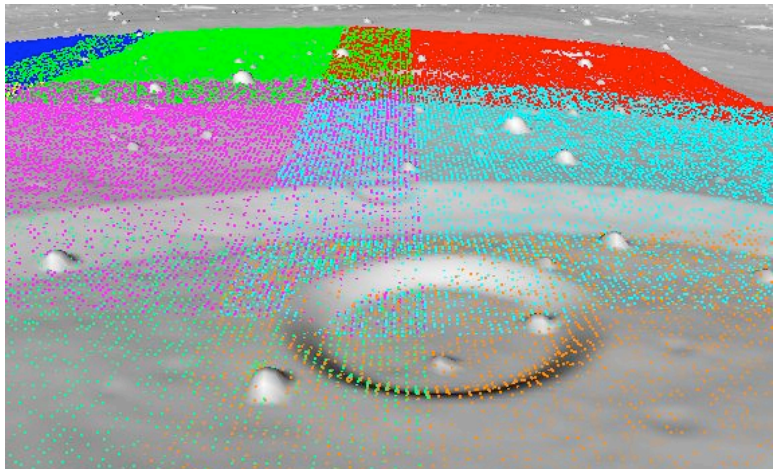
Mosaic of Lidar Images



Close Up of Lidar Samples on a Rock

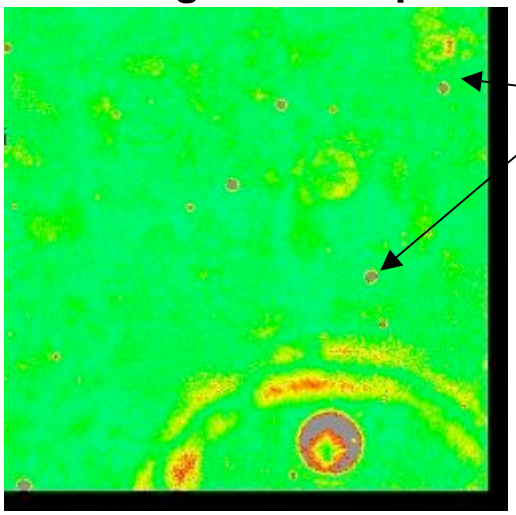


Close Up of Lidar Mosaic



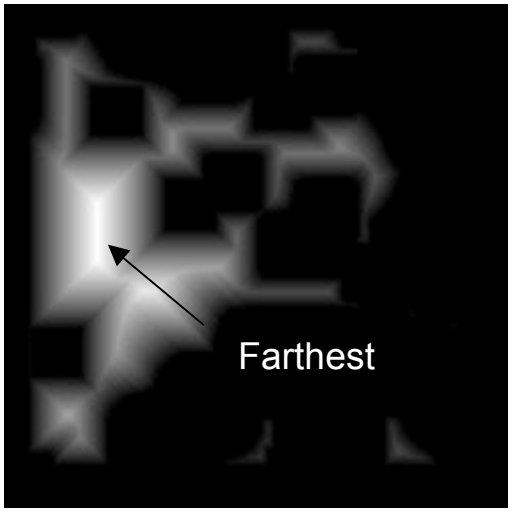
Hazard Detection Processing

Roughness Map

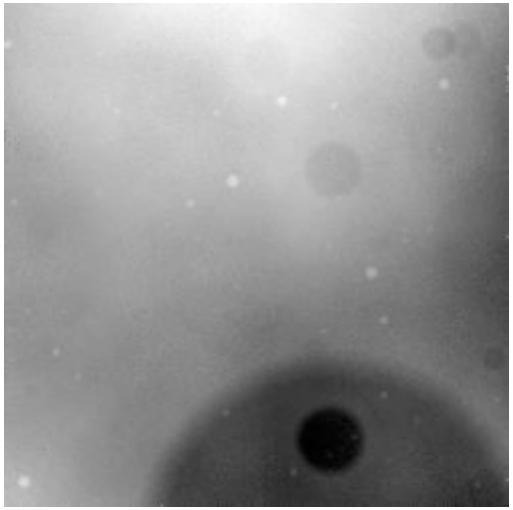


Roughness > 30 cm

Distance From Nearest Hazard Map

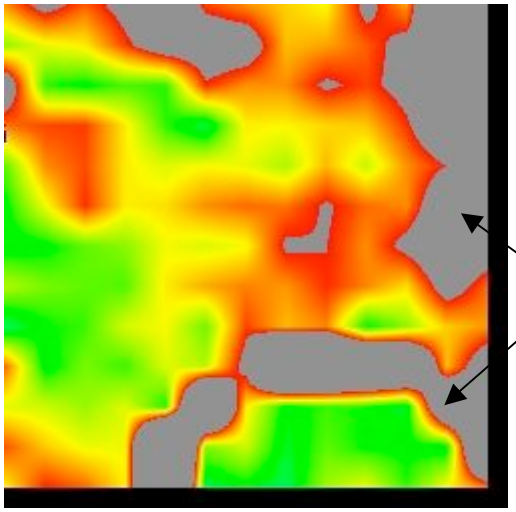


Elevation Map



black = -1.5m
white = 2.5m

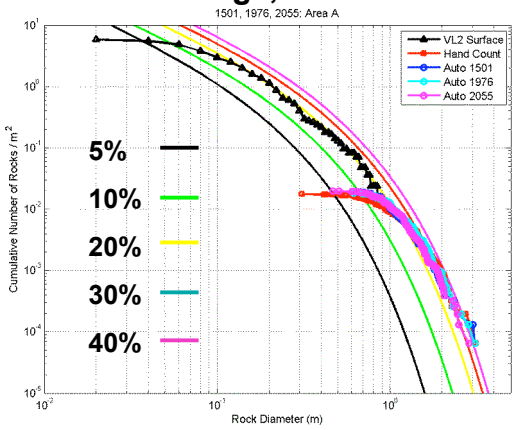
Slope Map



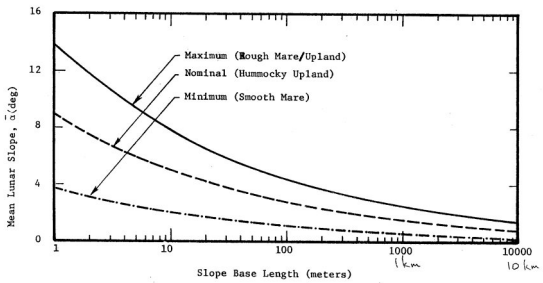
Slope > 5˚

Synthetic Lunar Terrain Models from Published Scientific Models

Rock Coverage, Golombek 1997



Slope Distribution, Hutton 1972

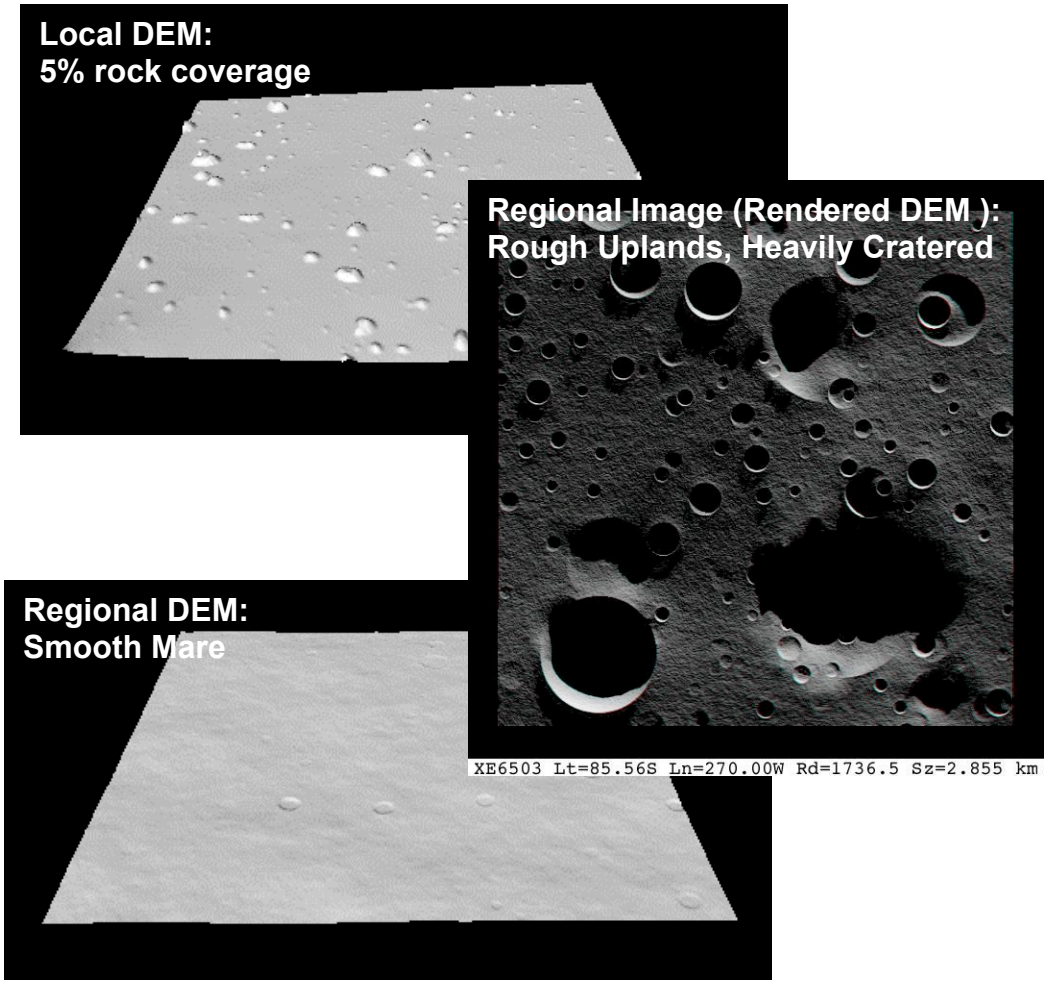


Crater Distribution, Moore 1972

Rough Mare

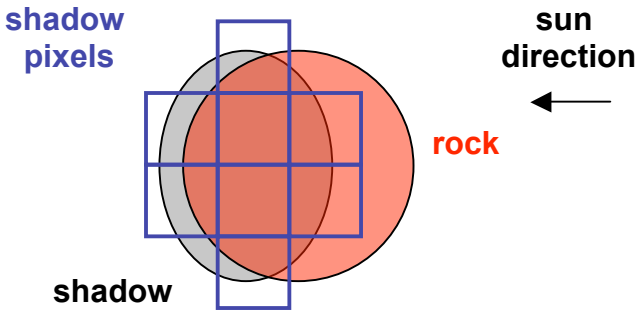
$N = 10^{-1} D^{-2}$ (D<100m)

$N = 10 D^{-3}$ (D>100m)

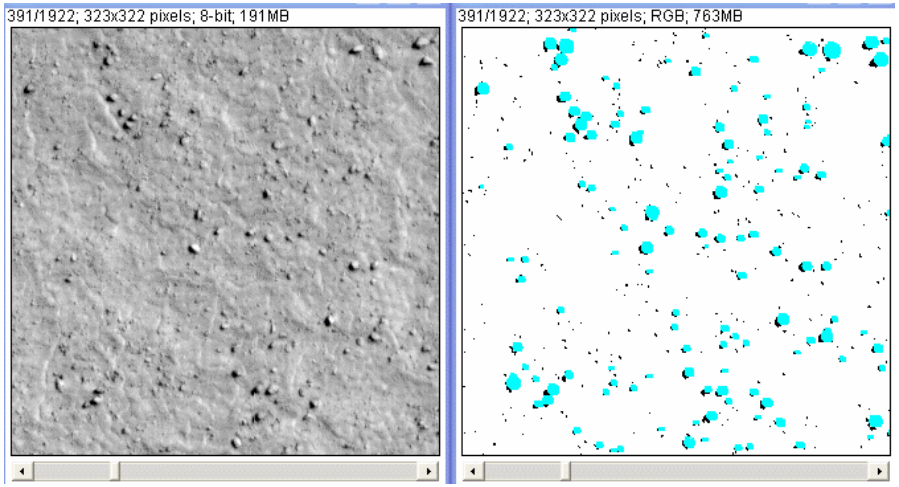


What is the Smallest Hazard Detectable from Orbit?

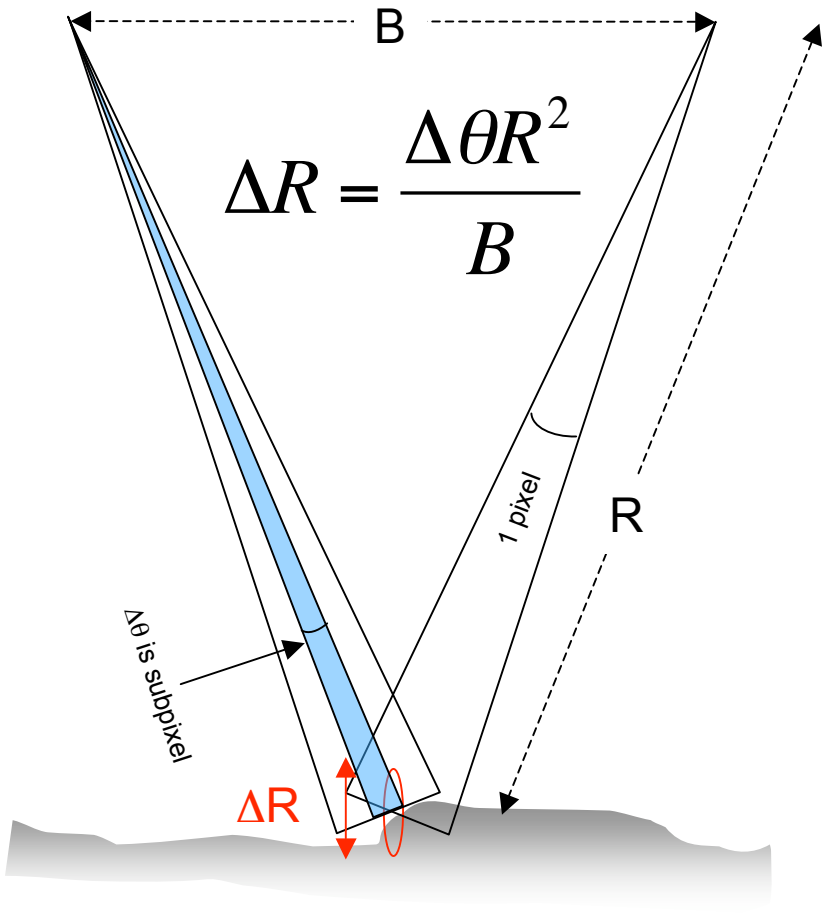
Shadow-based Detection



Automatic Shadow-Based Rock Detection Tool



Stereo Vision Based Detection



Summary

- Safe and precise technologies are being developed and tested under flight like conditions for lunar landing
- Terrain sensing and recognition functions make heavy use of a-priori orbital reconnaissance
- Validated statistical models of surface features are desired for development and testing or sensors and algorithms
- Questions for Discussion
  - What errors are present in maps (DEMs and images) and what are the root causes of these errors?
  - Can a parameterized error model be created for the map generation process?
  - Where will the next generation of statistical lunar surface feature models come from?
  - What is the smallest detectable hazard from orbit?