Jet Propulsion Laboratory
California Institute of Technology

Real-Time Image Processing in Support of Aerial Sensing Applications

Presentation to 2012 Mobility Air Forces Tactics Review Board

November 2012

Content By

Curtis Padgett (curtis.padgett@jpl.nasa.gov)

Relevant Image Based Localization and Terrain Relative Navigation Projects at JPL

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- NASA Precision Landing
  - Terrain Relative Navigation
  - Hazard Avoidance
  - Projects
    - ALHAT (Lunar landing)
    - Lander Vision System (LVS—Mars Precision Landing)
    - MSL (Mars Science Lander)
- AFRL—Blue Devil
  - Terrain Relative Navigation
  - 3D structure from image based techniques
  - Automated, on board mapping for image based navigation
- ONR—AACUS
  - Autonomous sensing and landing for VTOL aircraft
  - Terrain Relative Navigation
  - Hazard Avoidance
  - Navigation Capabilities to reach landing site
  - Site selection based on ground crews reaching site

ALHAT Lunar Safe Landing ConOps

HDA: Mosaic flash lidar and generate elevation map

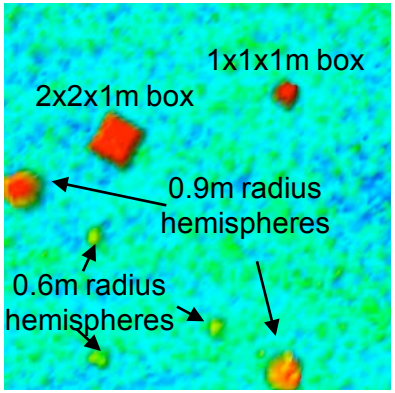
HDA: Detect Hazards

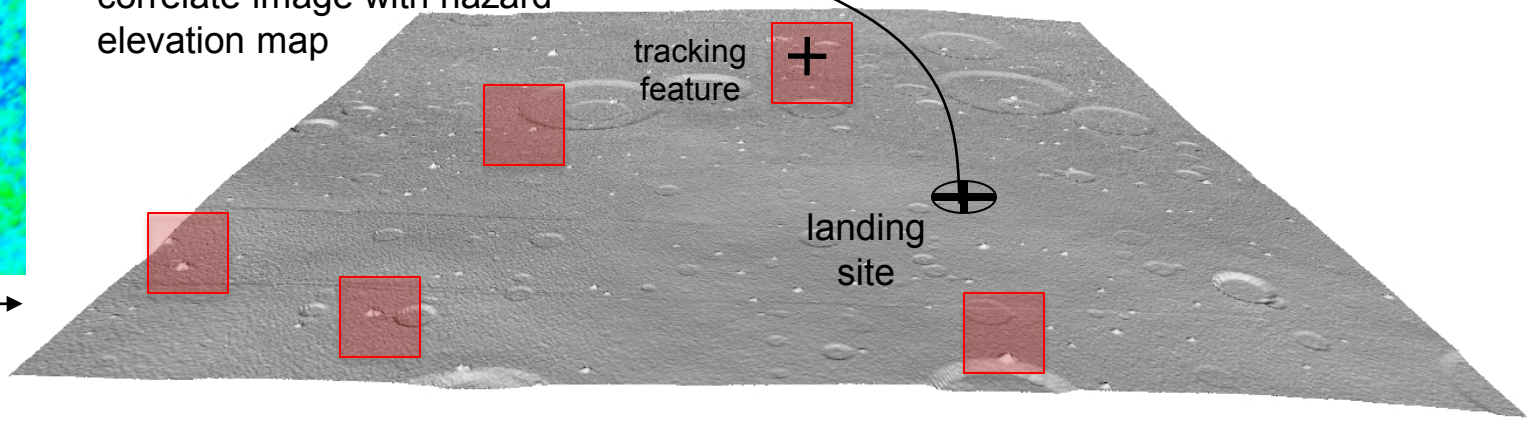
HDA: Select Safe Landing Site

HRN: Select terrain feature to track

HRN: Point at feature and correlate image with hazard elevation map

Flash Lidar Image

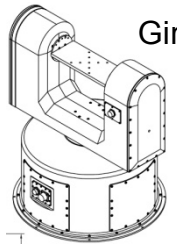


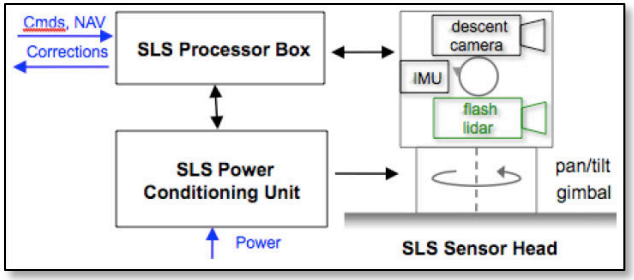


Hazard Detection System

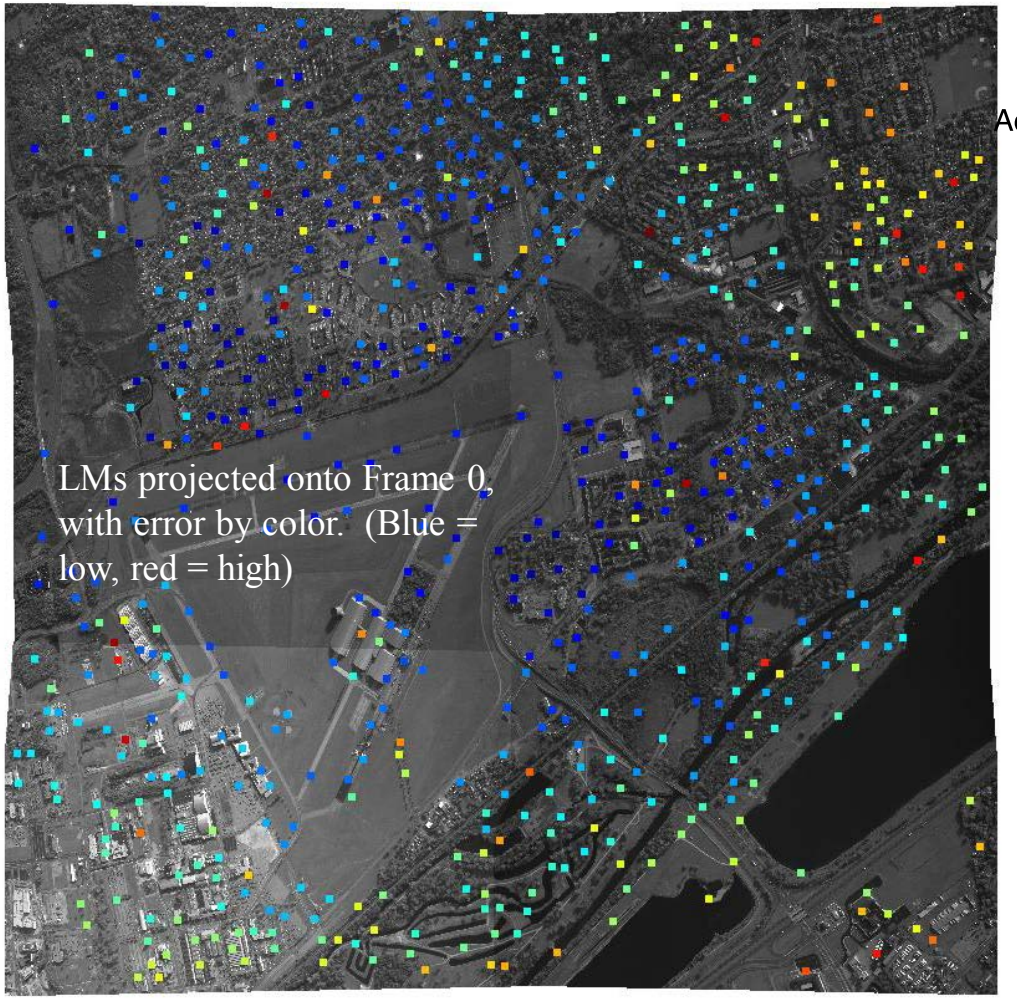
Multi-core processor

Gimbal





Feature Tracking & Landmark Generation



LM Error histogram

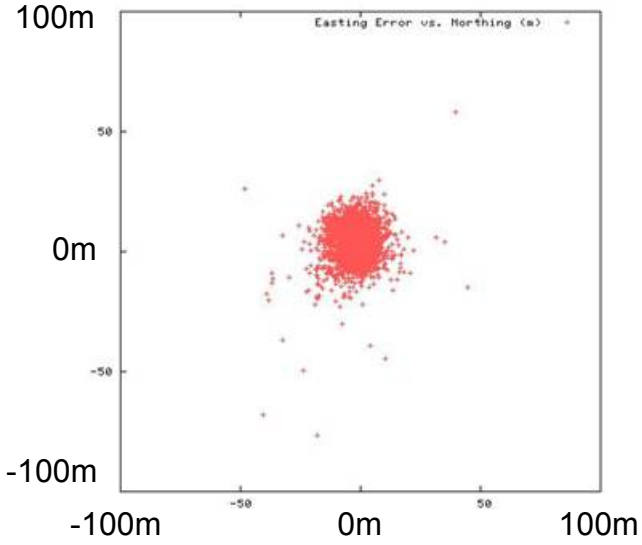
Adjust using A3D and Rays (three passes, with outlier rejection)

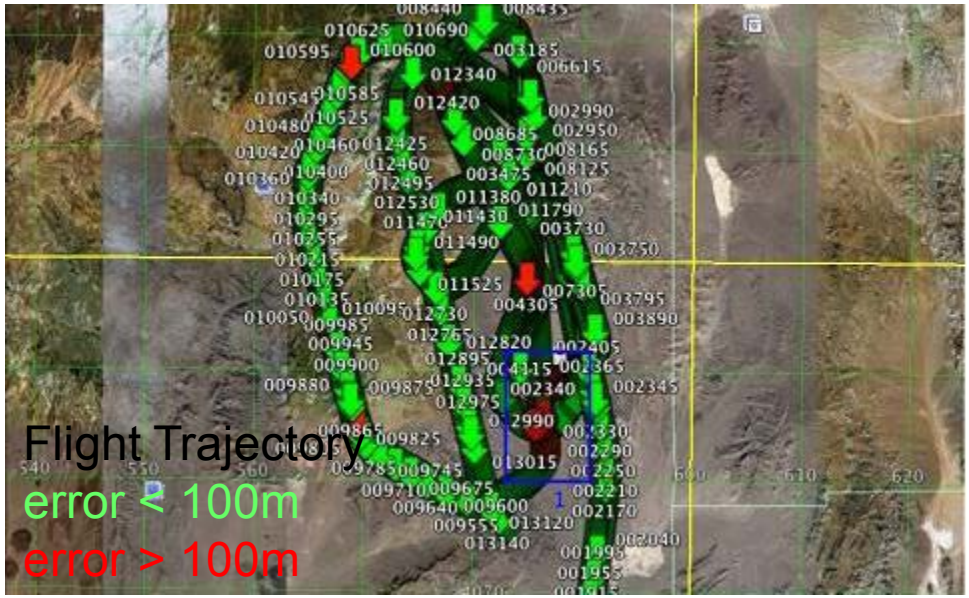
Reproj. error (pixels)

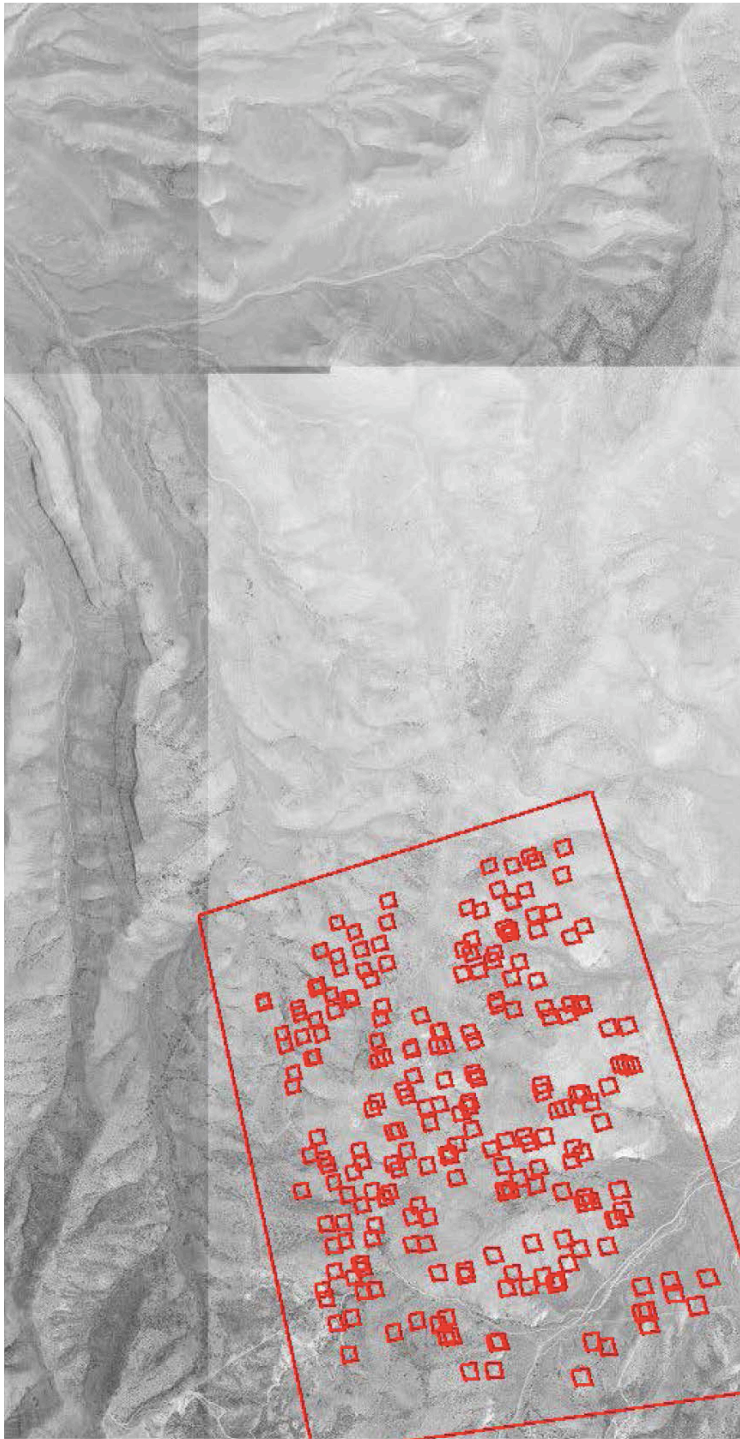
Features tracked over 5 minutes—used to derive landmarks

TRN Test Results: Airplane, Rugged Terrain

Error Scatter Plot



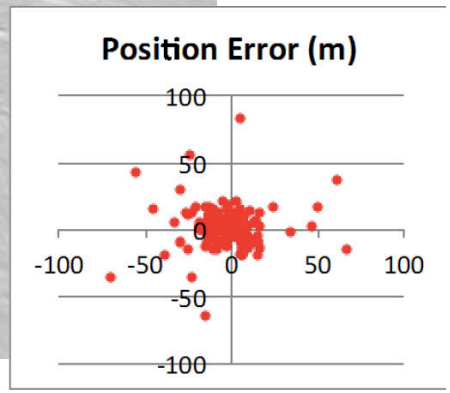


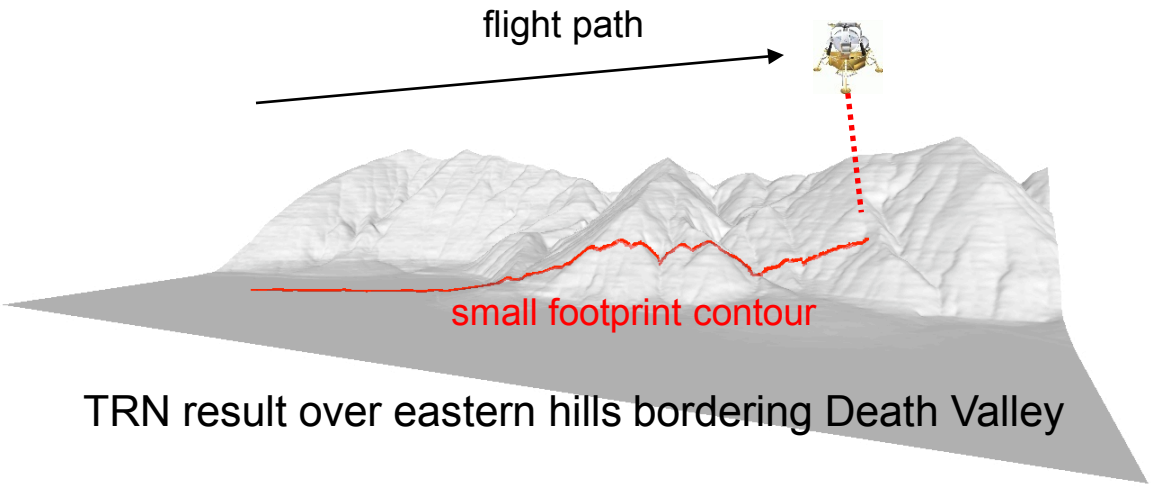


Yang Cheng / Dan Clouse

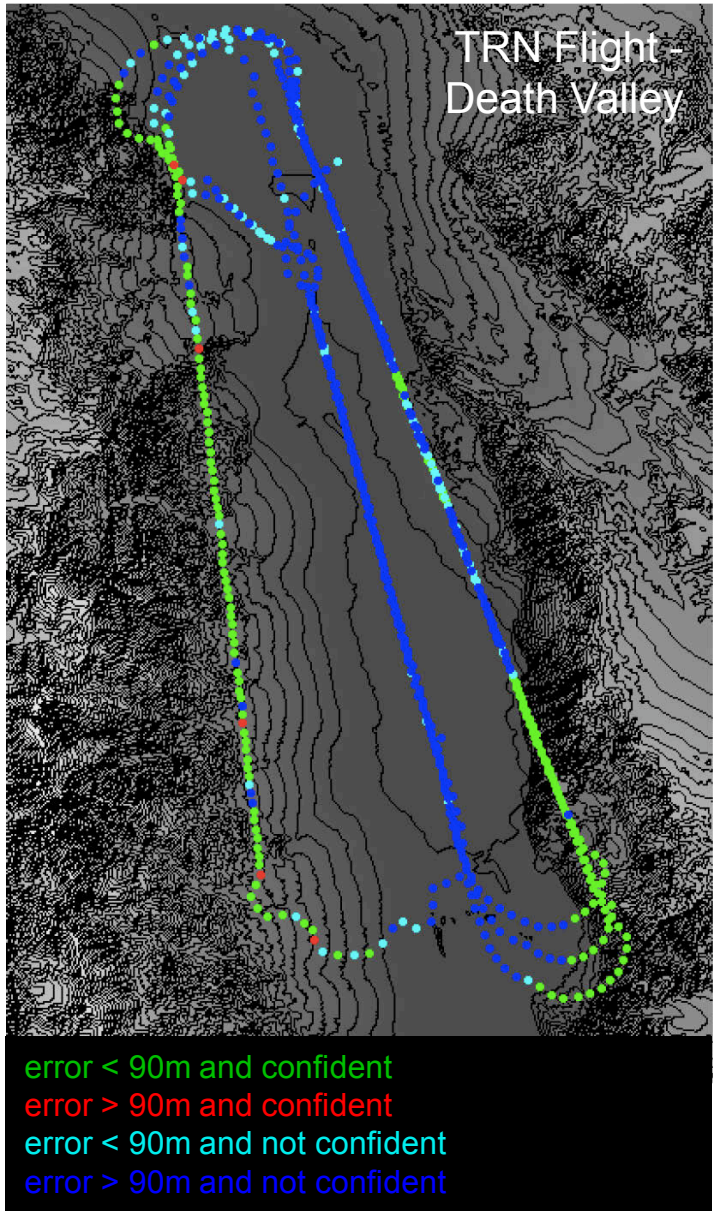
Lidar Based Terrain Relative Navigation for GPS Denied Environments

Lidar TRN algorithm constructs an elevation contour from multiple lidar images, correlates contour with reference DEM and then solves for a **position** fix





TRN result over eastern hills bordering Death Valley

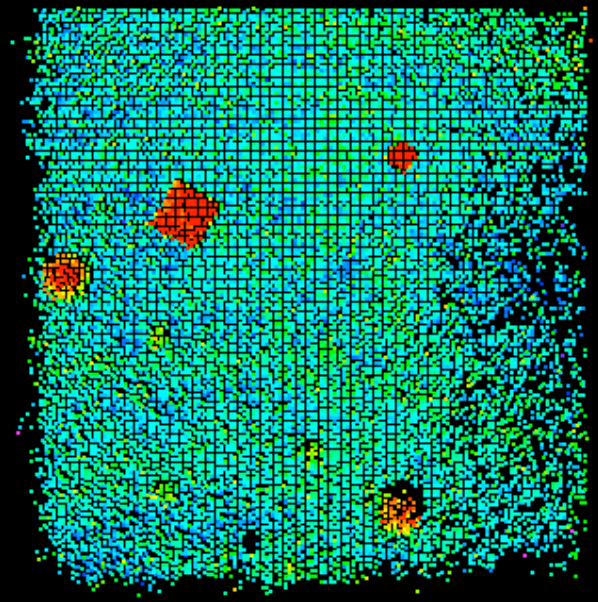


Example Flash Lidar Image

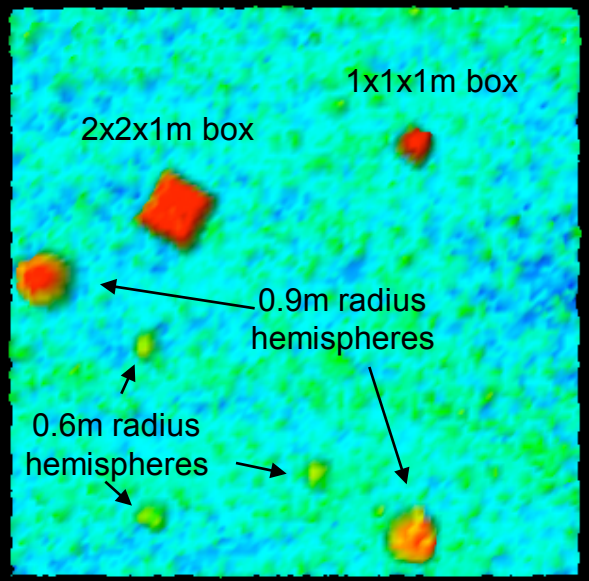
128x128 pixels
430m Range
7˚ Off Nadir

3D Points

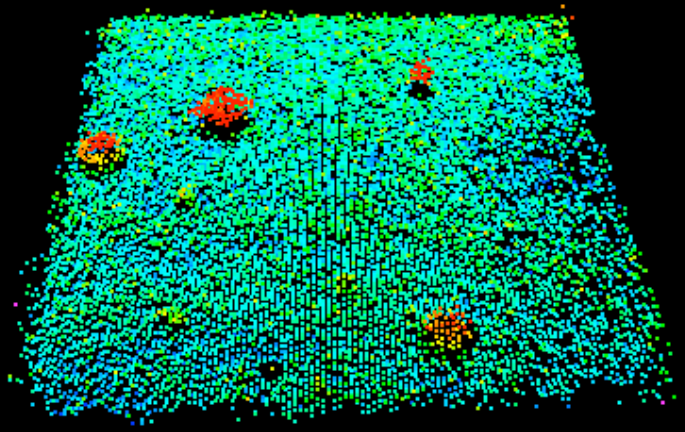
Elevation Map

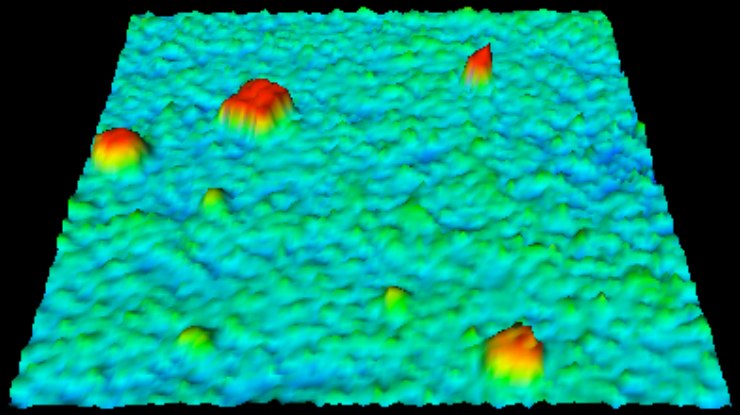


Top View

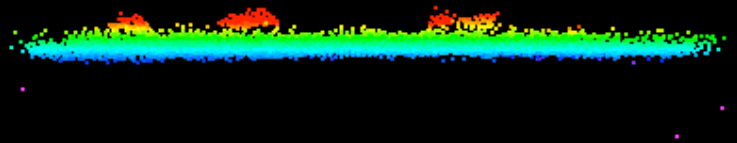


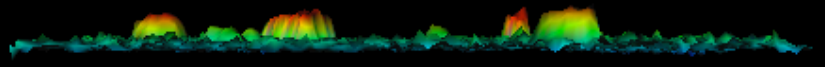
Oblique View





Side View





JPL Focus on Wide Area Sensing (Blue Devil)

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Provide Real-Time Image Processing Technology

- On Board Calibration of Multiple Sensor Systems
  - Automatic, Aerial Calibration (extrinsic alignment, gyro)
  - Generate seamless composite imagery
- Generation of Geo-Rectified Data Product
  - Augment Sensor Pose Estimation with Image-based Analysis
  - Projection of Imagery to Terrain Models
  - On-line Creation or Enhancement of 3D Terrain Models

Result: High quality imagery suitable for detection, geolocation and analysis applications

Development of 3D Terrain Models

- On-line processes that take image data and produce terrain model
  - Collect imagery during initialization
  - Process data in flight
  - Produce 3D terrain map in local frame
- Track local landmarks and use filter to refine local→global transformation using INS/GPS measurements
- Improves Geo-registration

On-Board Generation of 3D Terrain From Collected Images (38)

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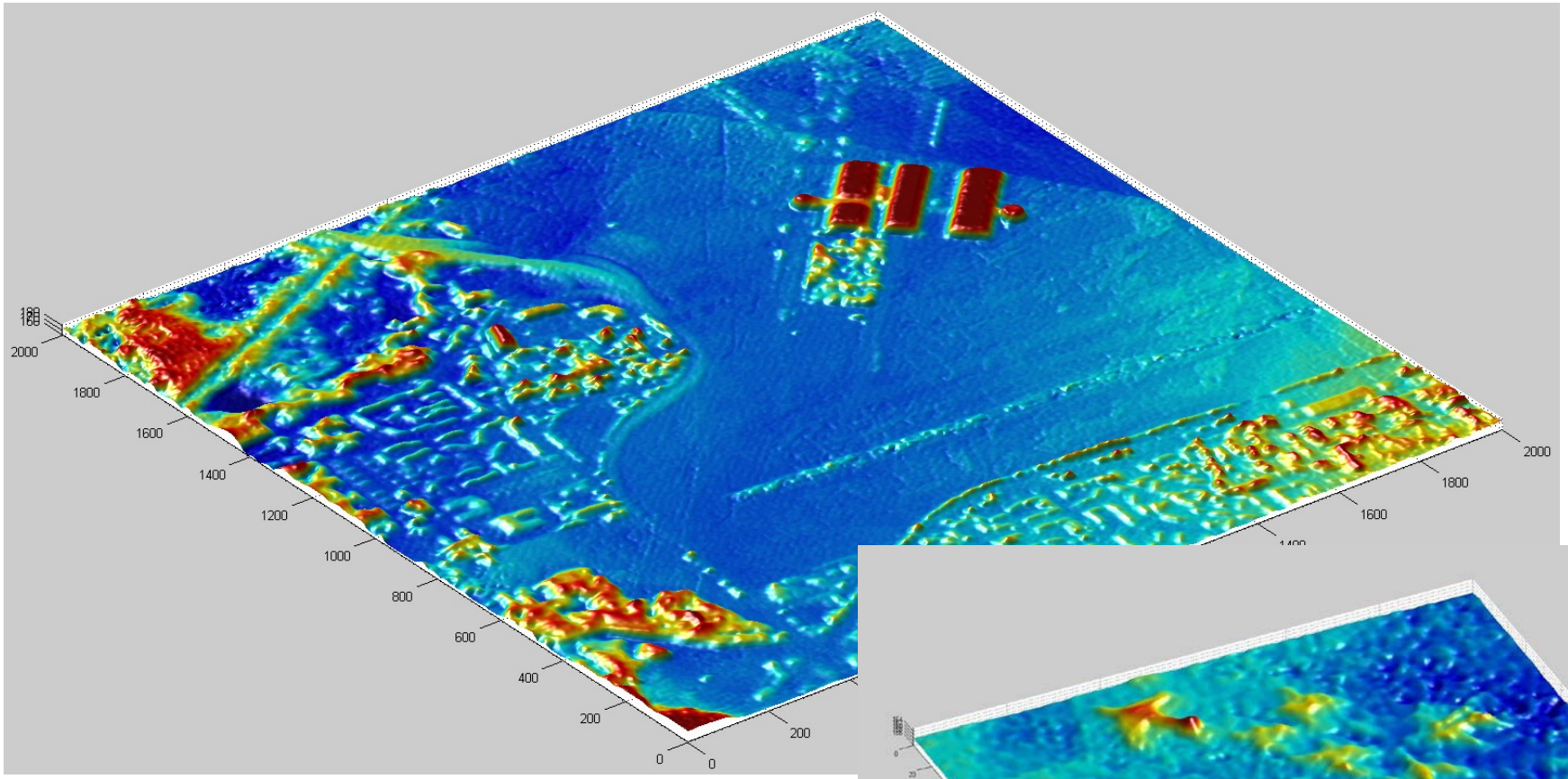
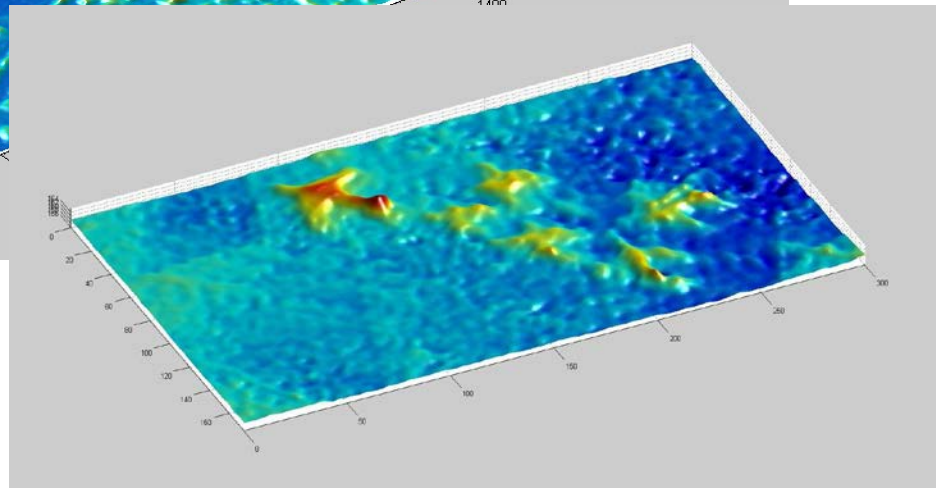
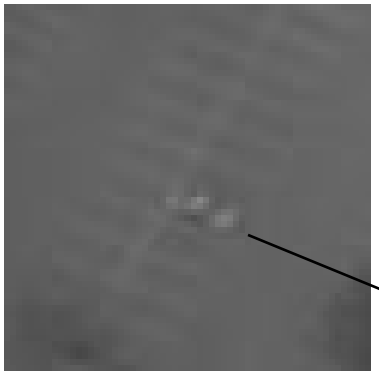




Blow up of Wright Pat Parking Lot



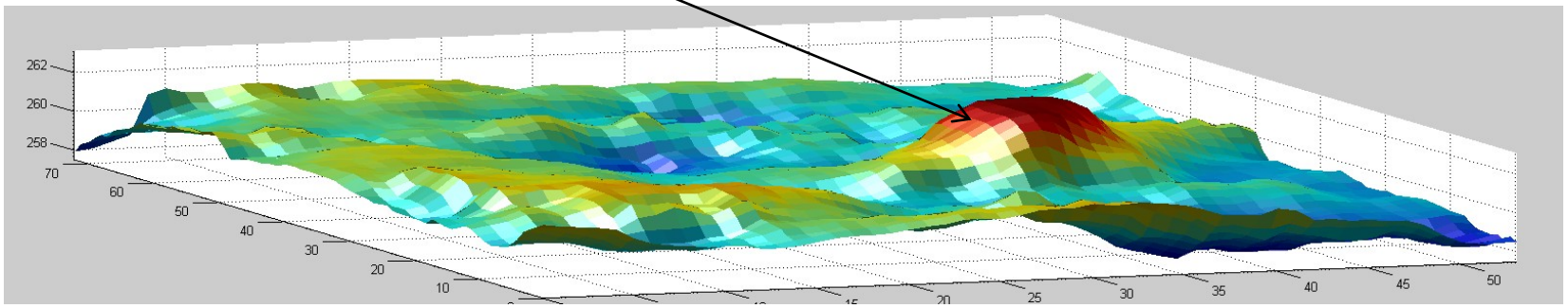
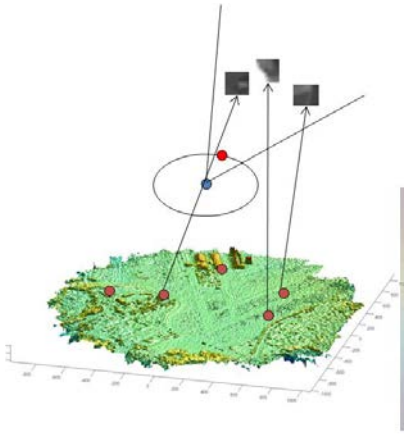
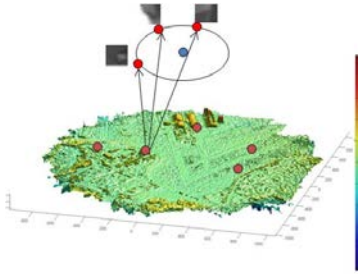


Image-Based Landmark Pose Estimation

- Landmark Generation
  - Inputs:
    - Image Sequence
    - Poses (GPS Frame)
    - Camera Model Intrinsics
  - Output:
    - Landmark locations in GPS Frame
    - Landmark locations in image coordinates
    - Updated Camera Poses
  - Technique
    - Find features in image
    - Track features through image sequence
    - Use feature tracks and camera pose to estimate landmark position
    - Estimate the camera pose from the new landmark positions (iterate up to 25 times)
- Landmark Database
  - Inputs:
    - Image Sequence
    - Camera Poses
    - Landmark locations in GPS Frame
    - Landmark locations in image coordinates
  - Output:
    - Landmark Database
  - Technique
    - For each landmark, collect image views of landmark
    - Use image location and landmark location to establish orientation of view
    - Place information in Landmark Data Structure

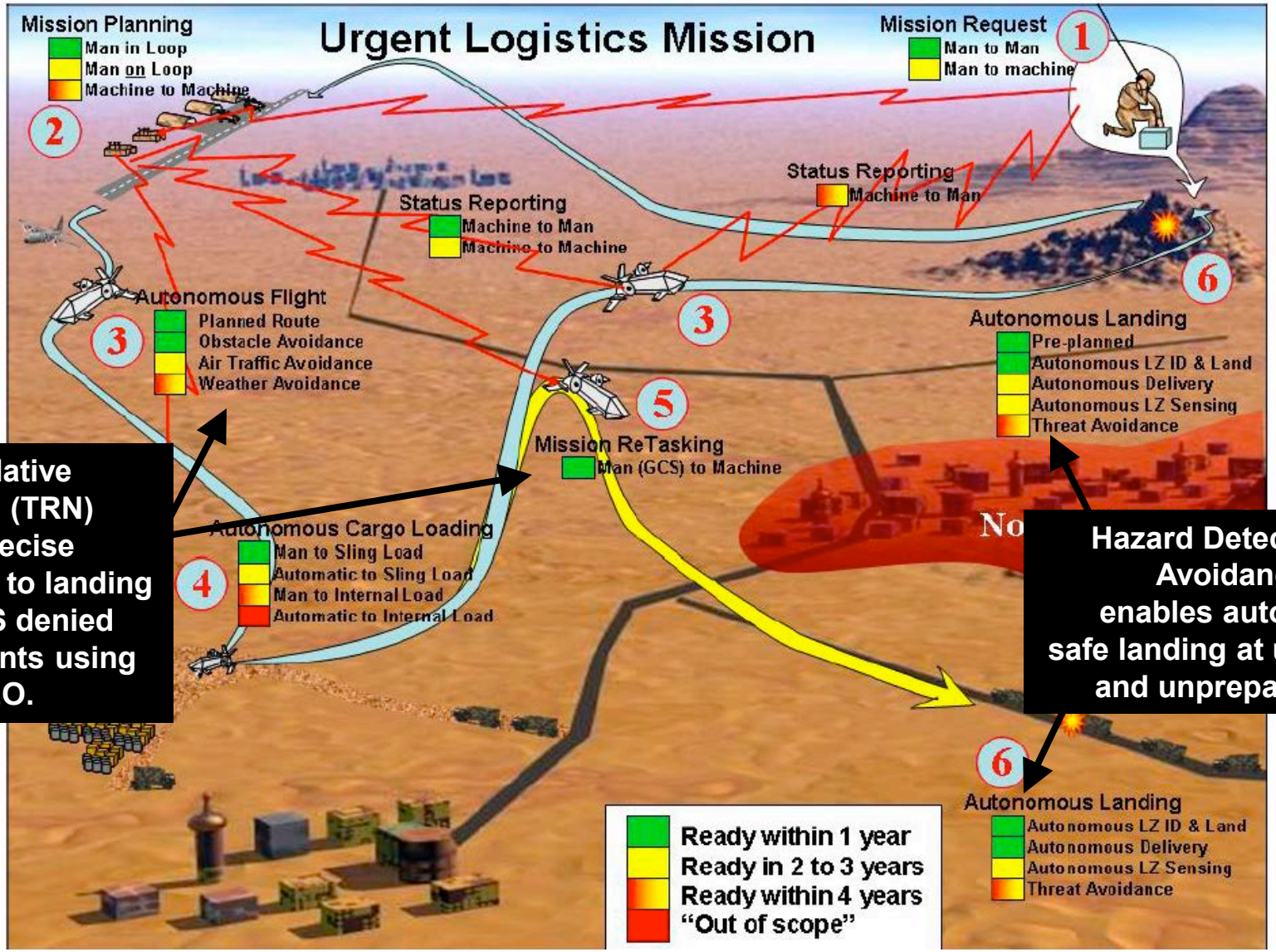


All Landmark views come from single image



Landmark views associated with a direction—allows code to search LMDB for closest view to current image pose

TRN and HD Application to Autonomous Aerial Cargo Utility Systems (AACUS)



Terrain Relative Navigation (TRN) enables precise navigation to landing site in GPS denied environments using lidar and EO.

Hazard Detection and Avoidance (HDA) enables autonomous safe landing at unknown and unprepared sites