

Challenges in Planetary Mapping and Surface Navigation

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Navigation Challenges

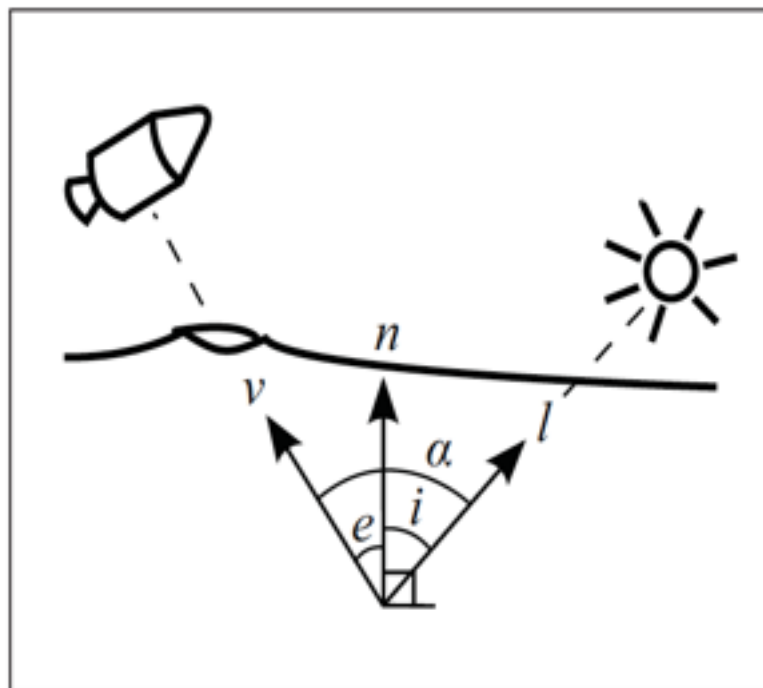
- Lack of surface imagery
- Low gravity
- Terrain uncertainty impacts
 - obstacle avoidance
 - direct communication with Earth
 - illumination conditions
- Lunar Polar reflectance conditions (albedo, reflectance models)
- Rock distribution
- Gaps in regolith and surface characterization
- Lunar temperature conditions
- Low computational complexity available
- Low power systems
- High radiation environment

Lunar Reflectance and Illumination

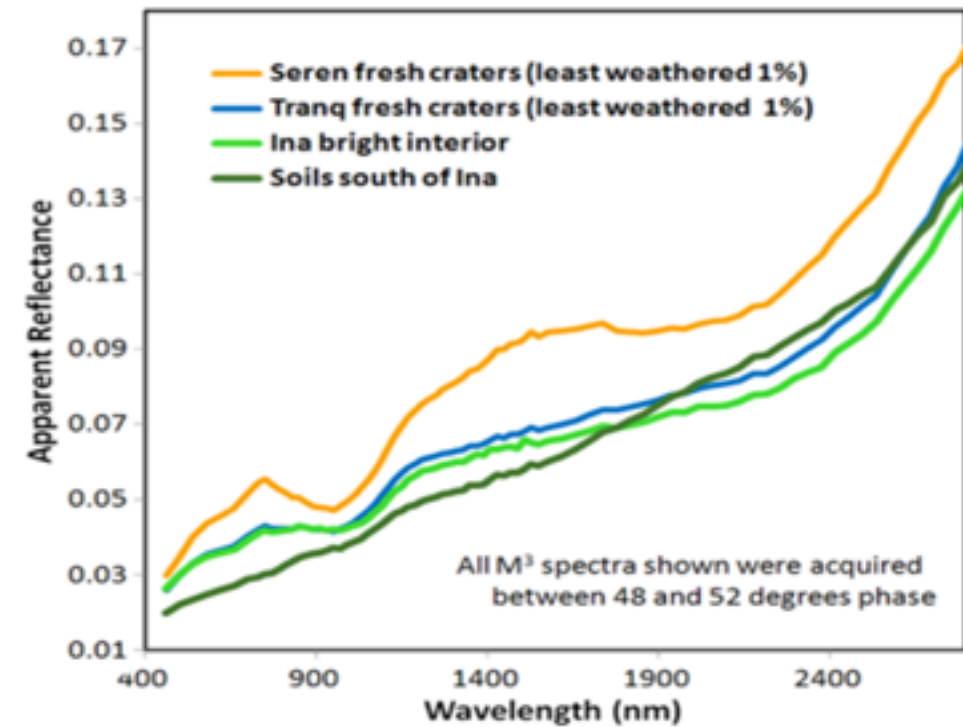
Lunar Albedo

Lunar Lambertian Reflectance Model

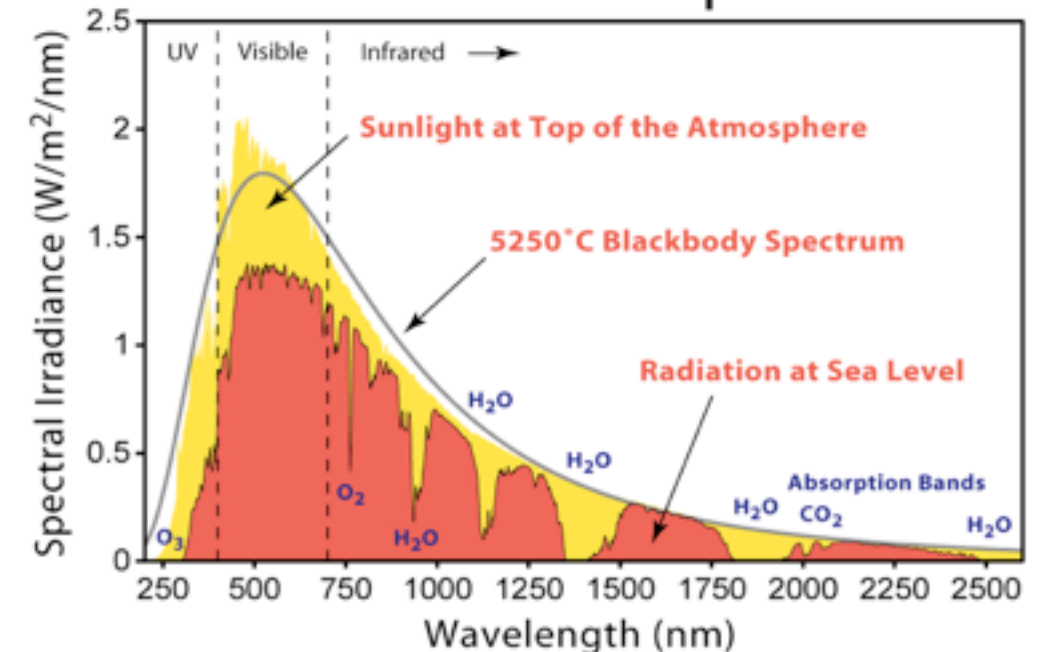
$$R = A \left[1 - L(\alpha) \cos(i) + 2L(\alpha) \frac{\cos(i)}{\cos(i) + \cos(e)} \right]$$



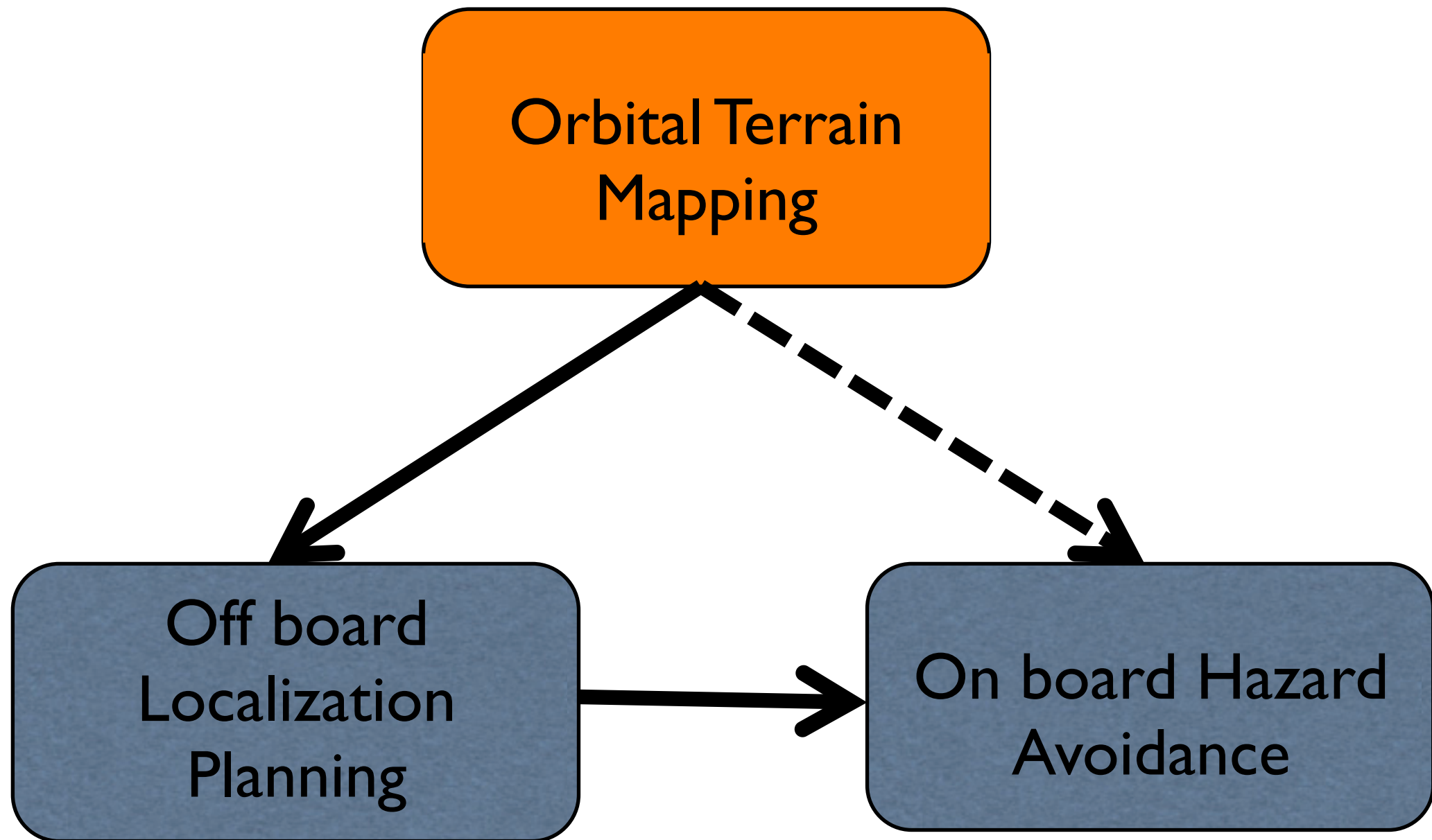
Incidence, emission and phase angles



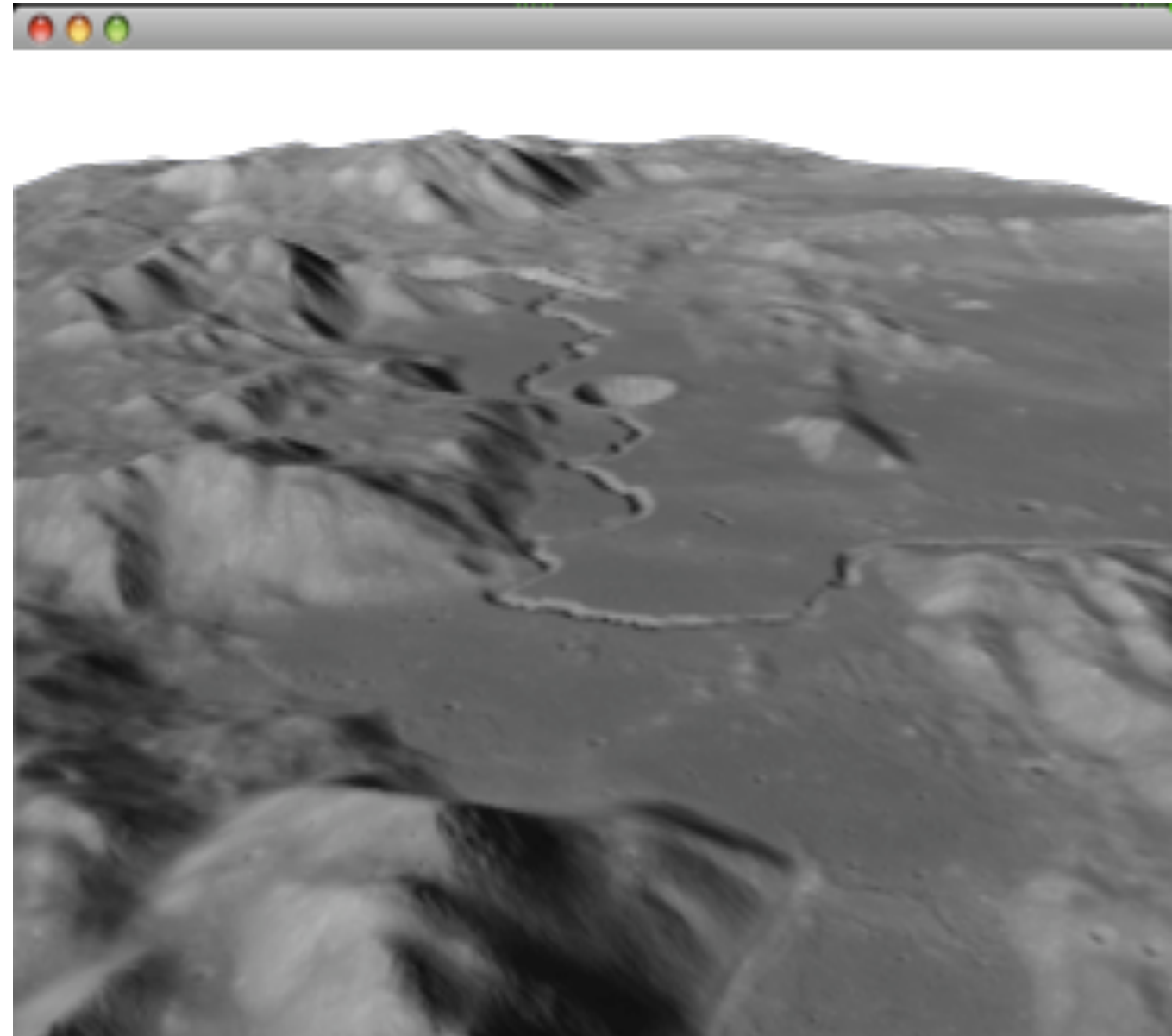
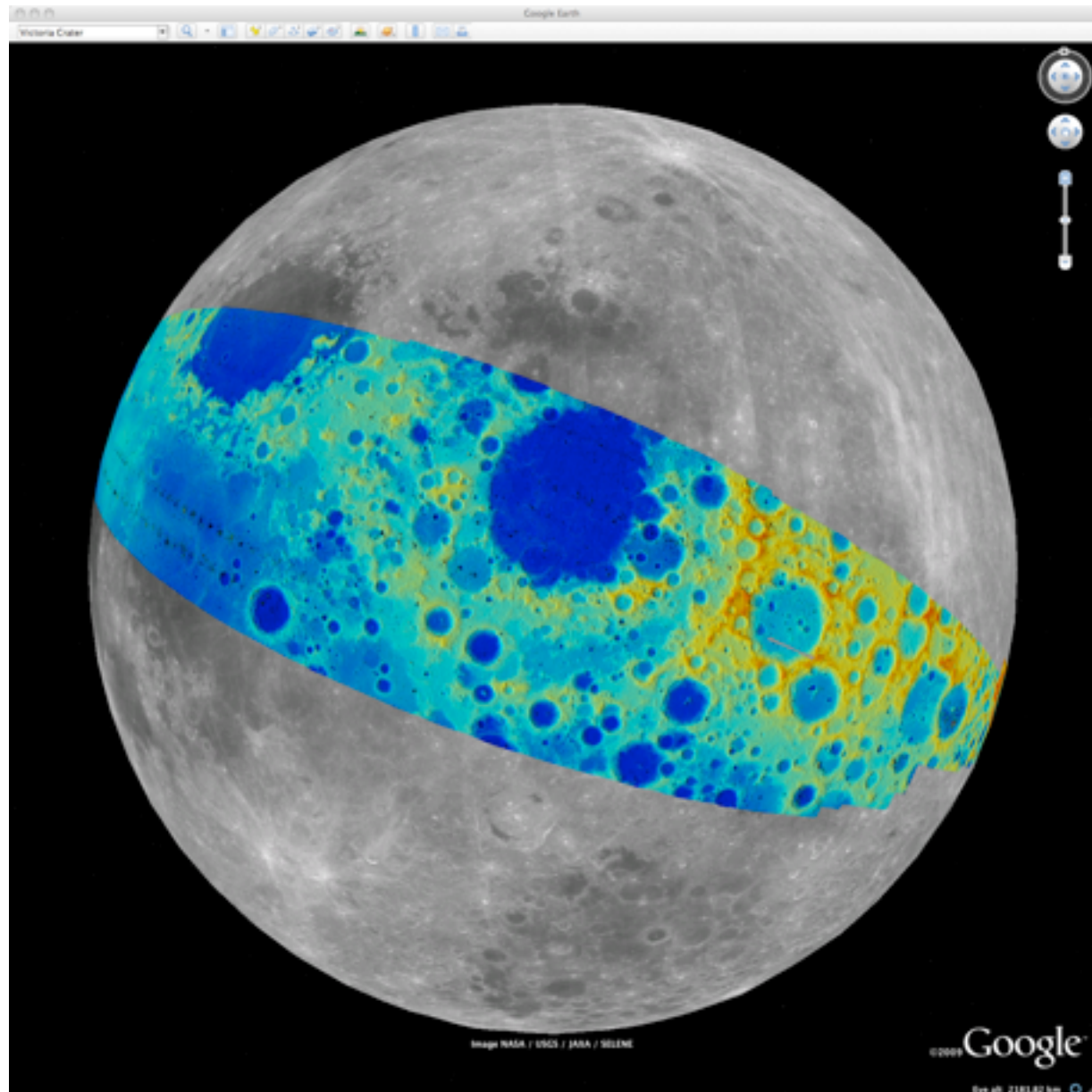
Solar Radiation Spectrum



Planetary Rover Navigation



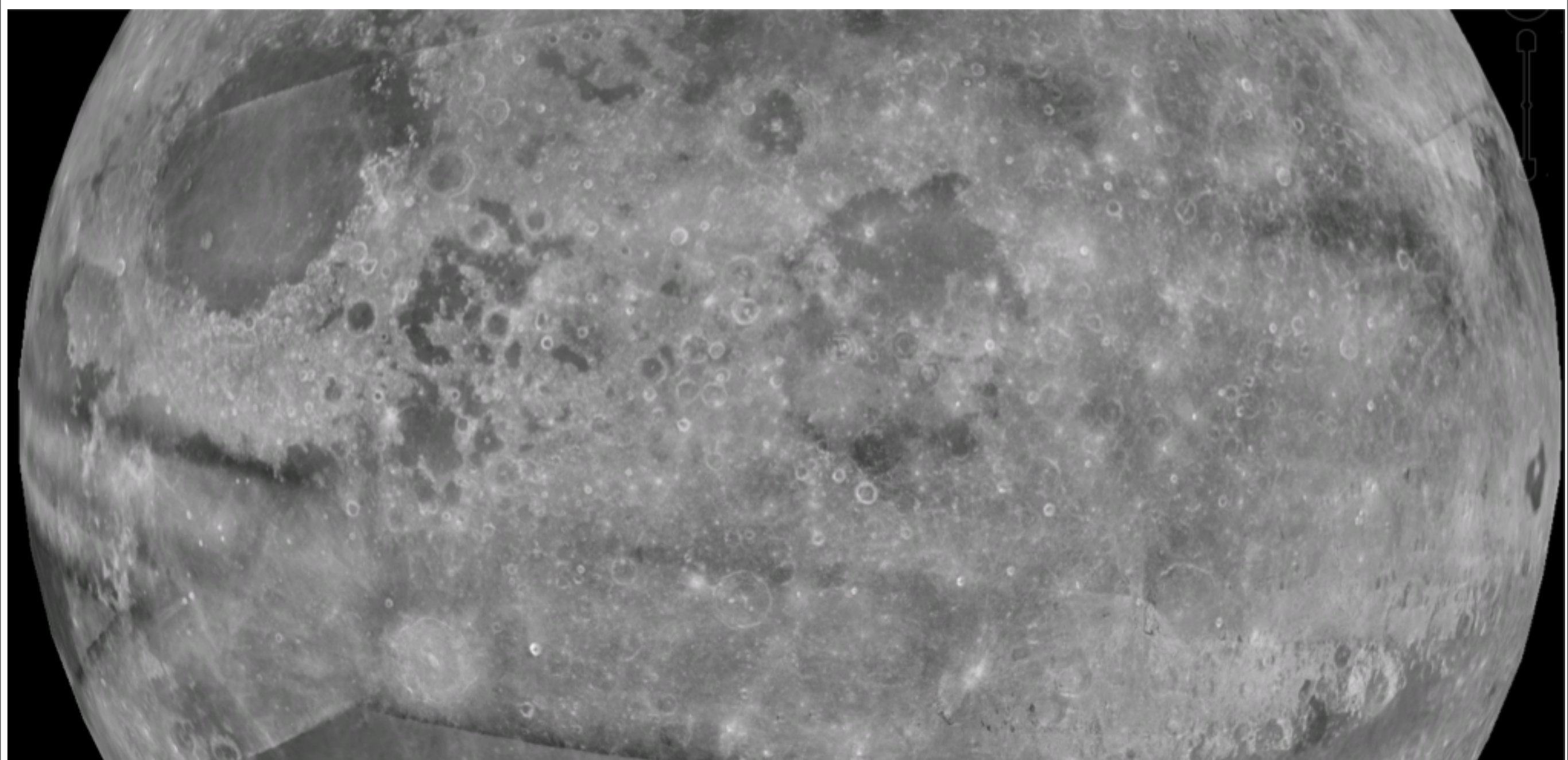
Stereo Reconstruction from Orbital Imagery



Apollo Zone reconstructed color shade over Clementine imagery in Google Earth (left) and reconstructed oblique view of Apollo landing site (right).

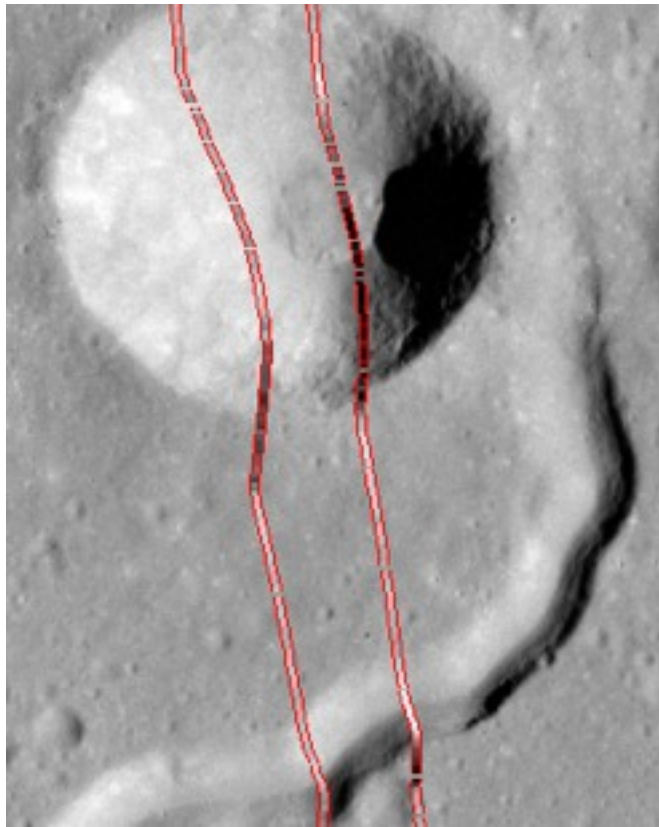
Albedo Reconstruction

http://byss.arc.nasa.gov/oleg/albedo_04_09_2012/albedo_04_09_2012.kml

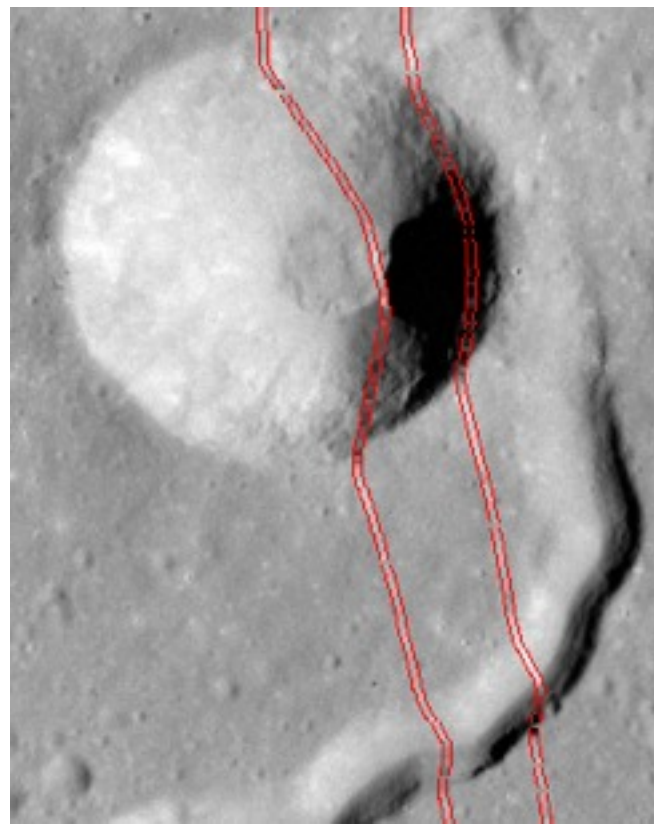


Apollo Zone reconstructed albedo over Clemntine imagery (Google Earth)

LOLA to Image Coregistration

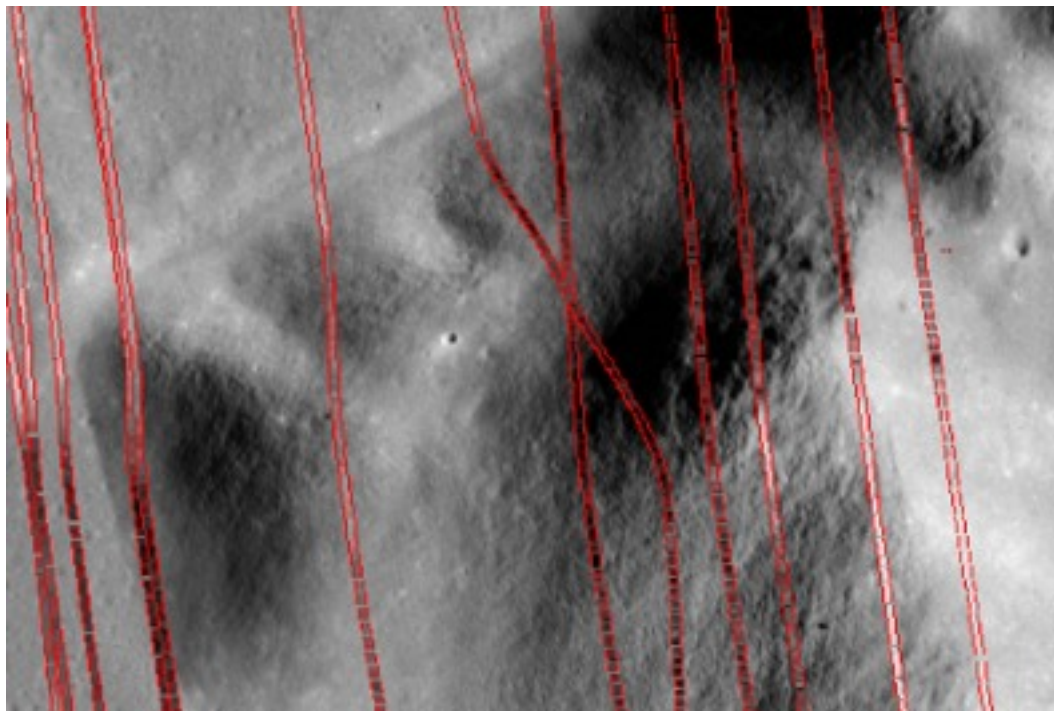


Original

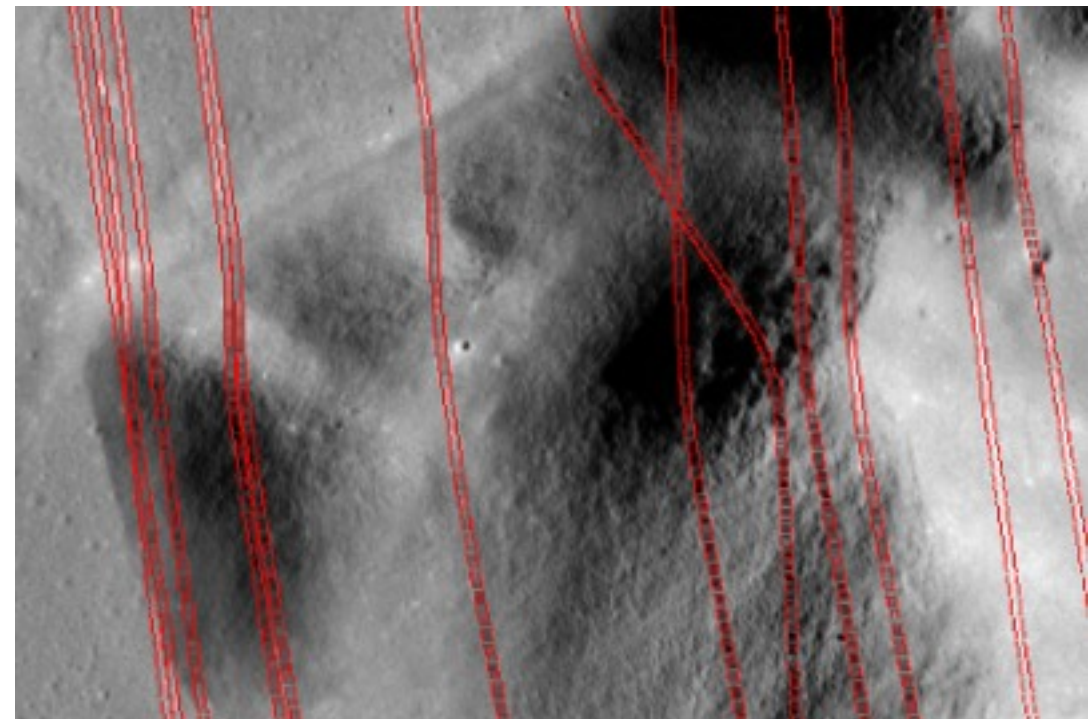


Adjusted

Alignment of LOLA altimetry data to Apollo Imagery using the Lunar Lambertian reflectance model.

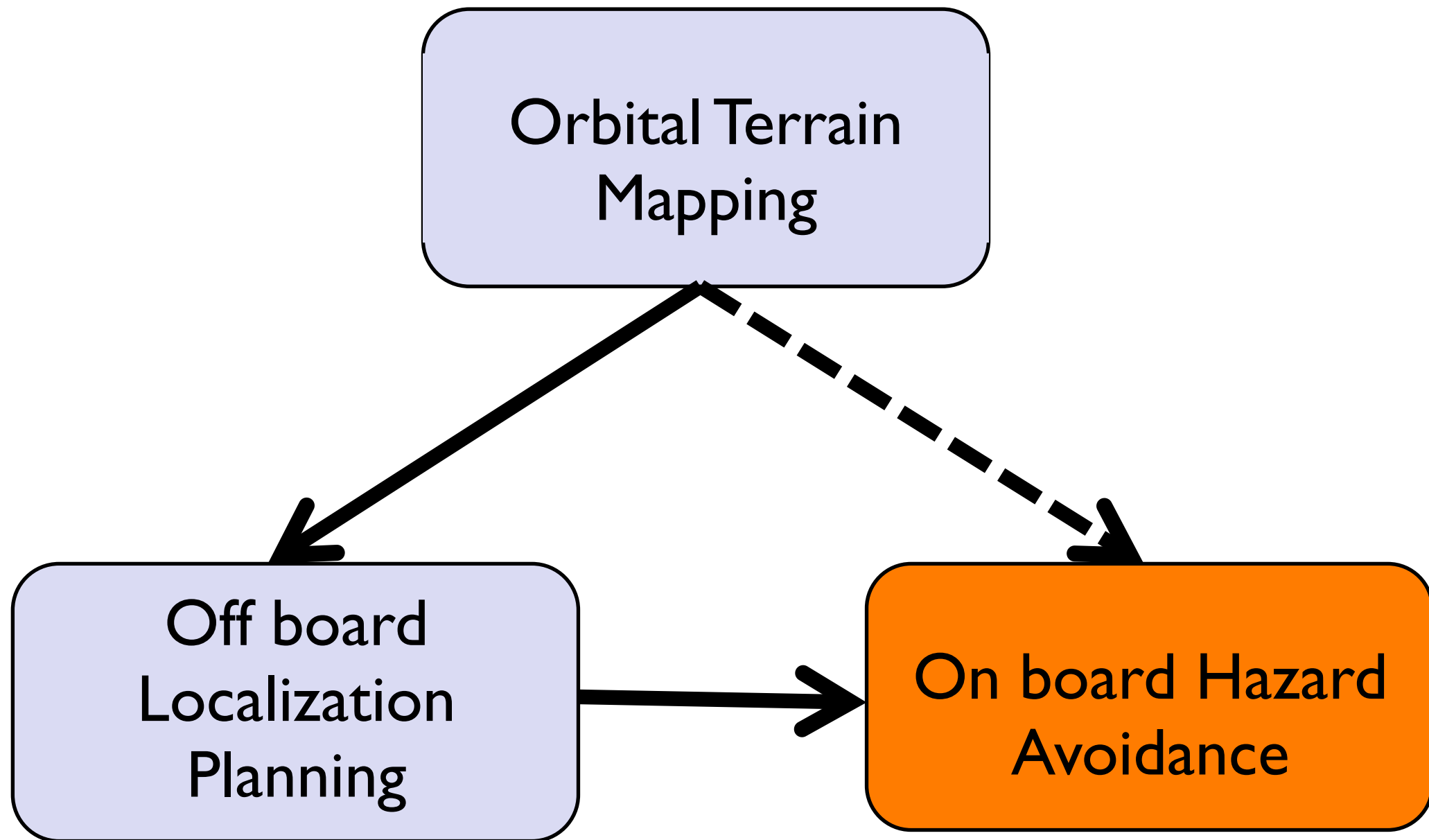


Original

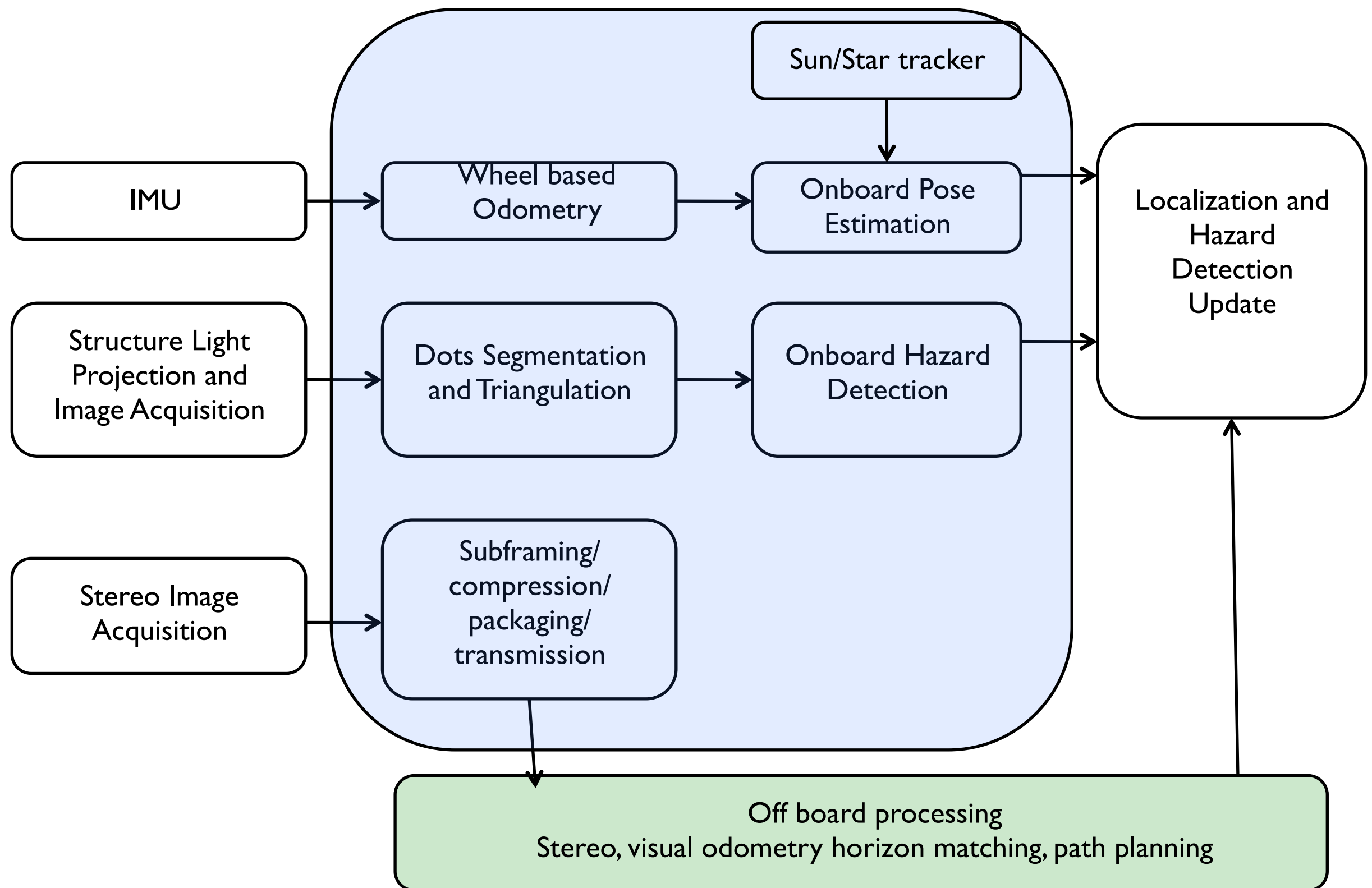


Adjusted

Planetary Rover Navigation



On-board Navigation

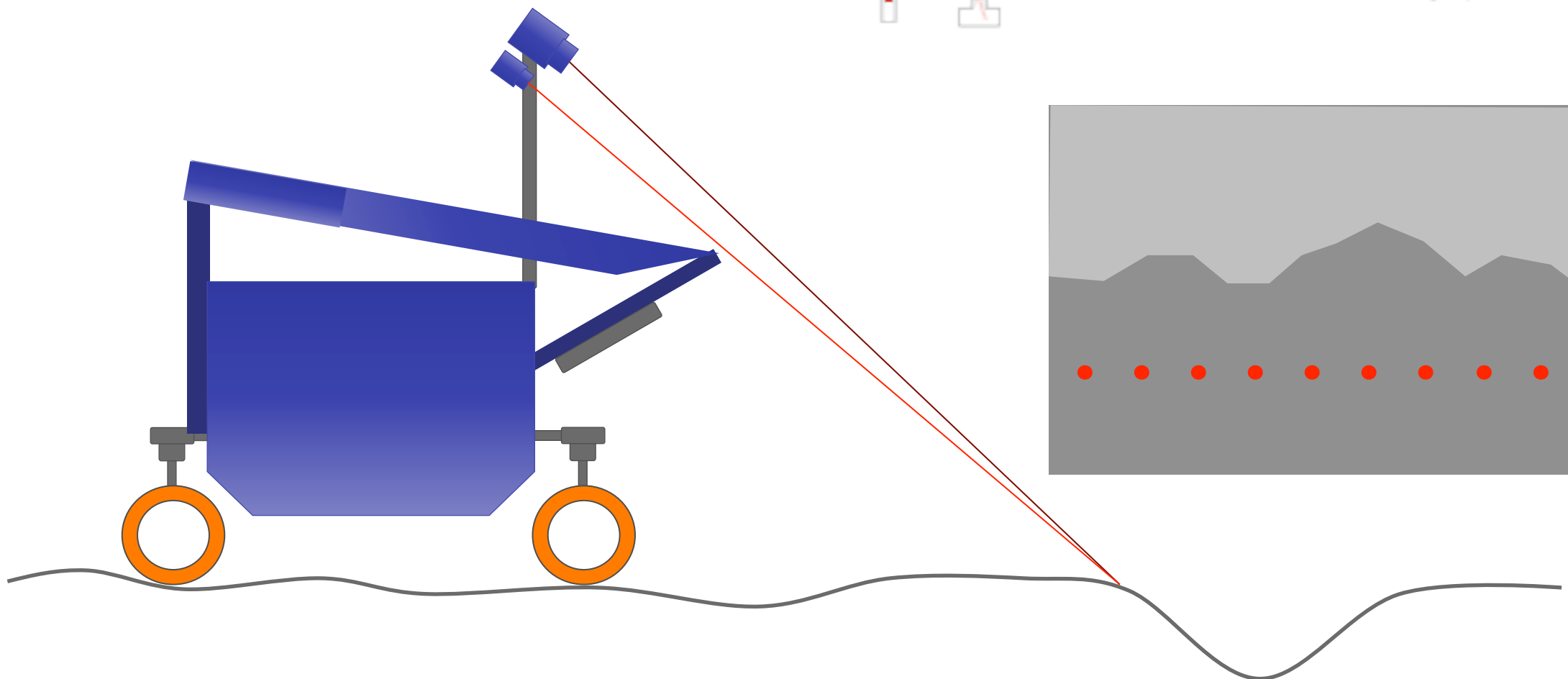
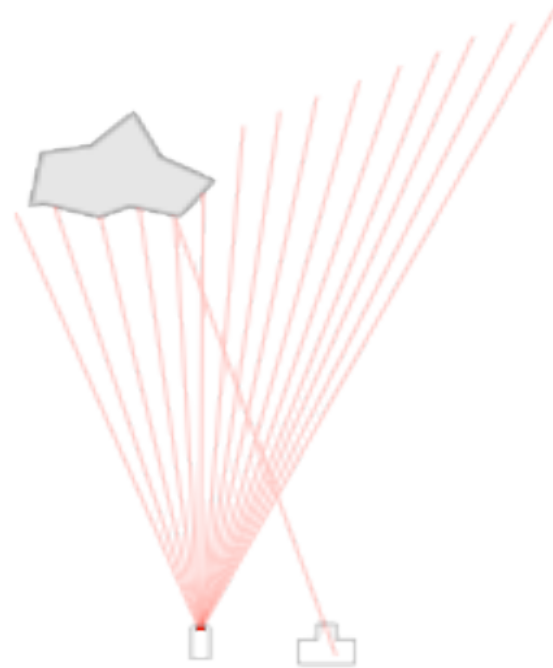


Structured Light: Onboard Hazard Detection

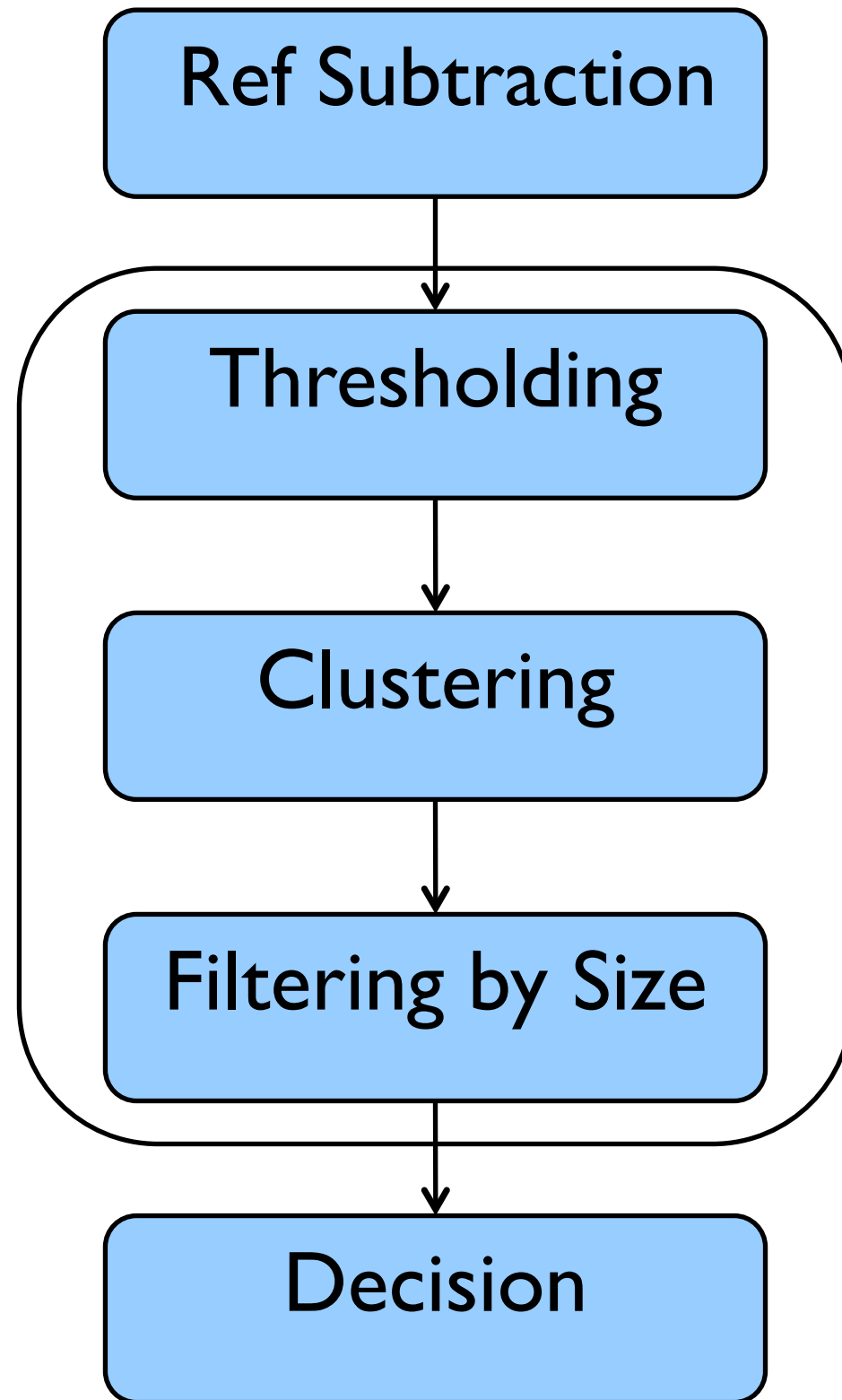
“Virtual Bumper”

Uses projected dots

Triangulation



Structured Light: Onboard Hazard Detection



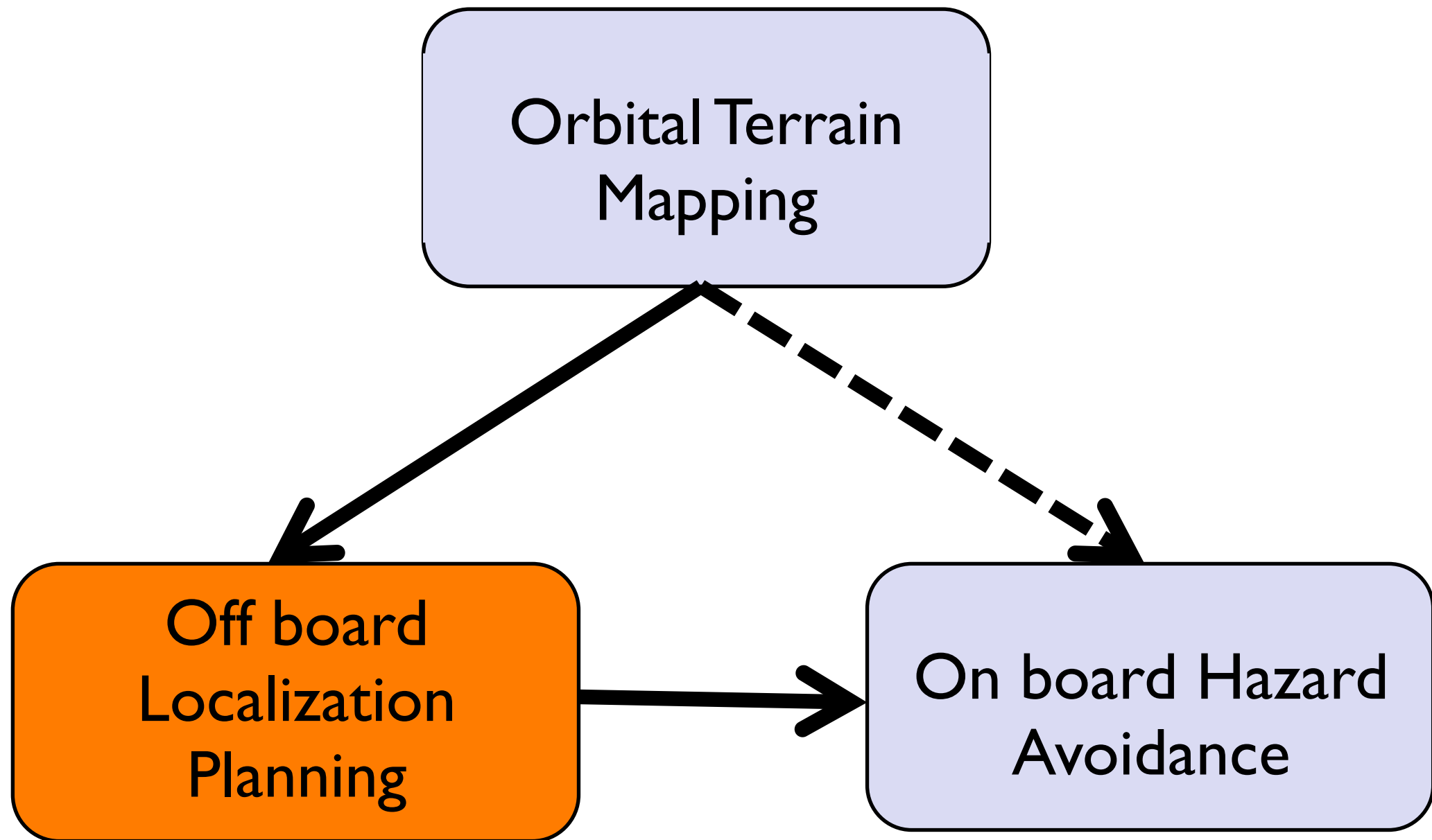
Structure Light Day Time with Color Filter



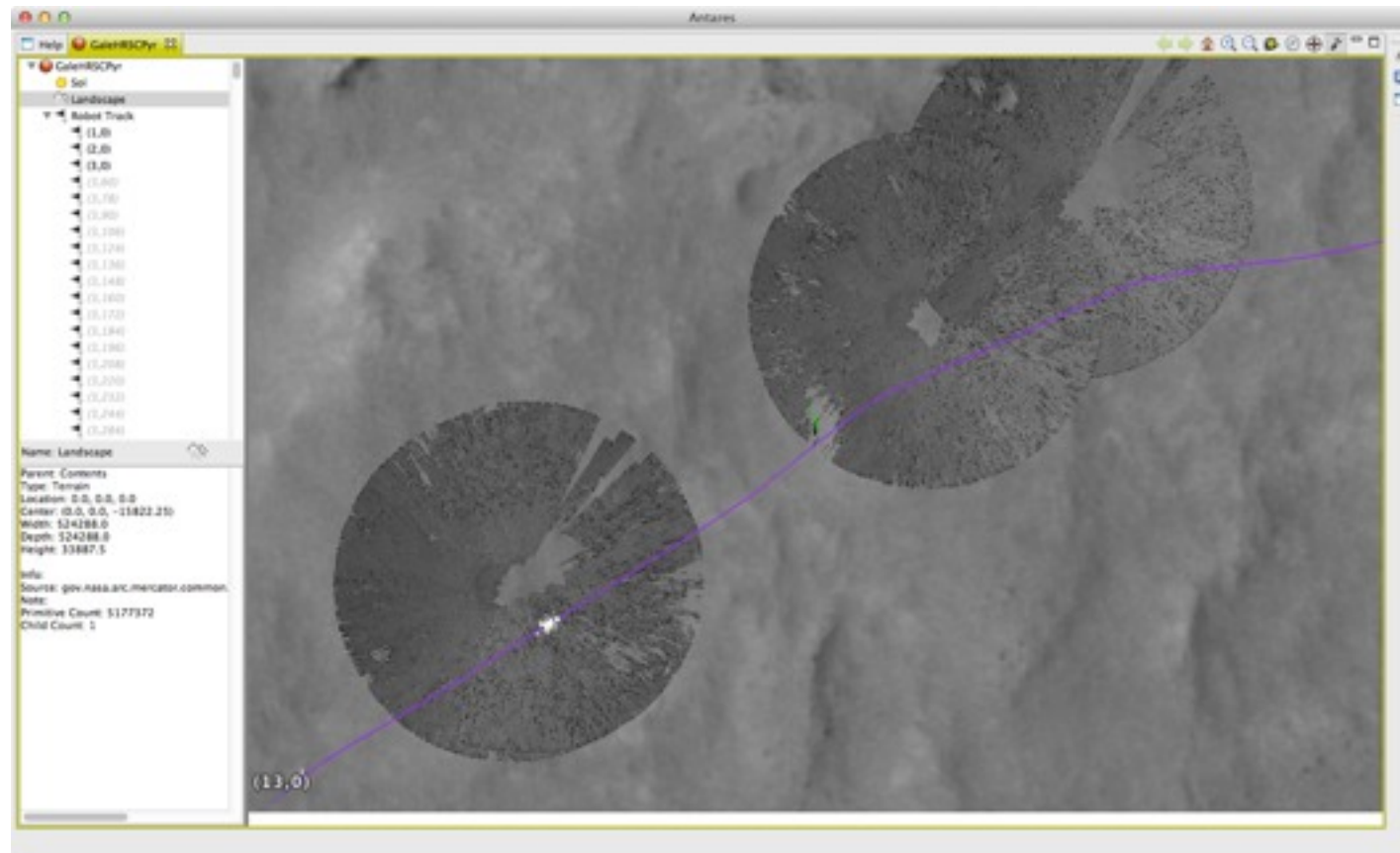
Structure Light at Night Time



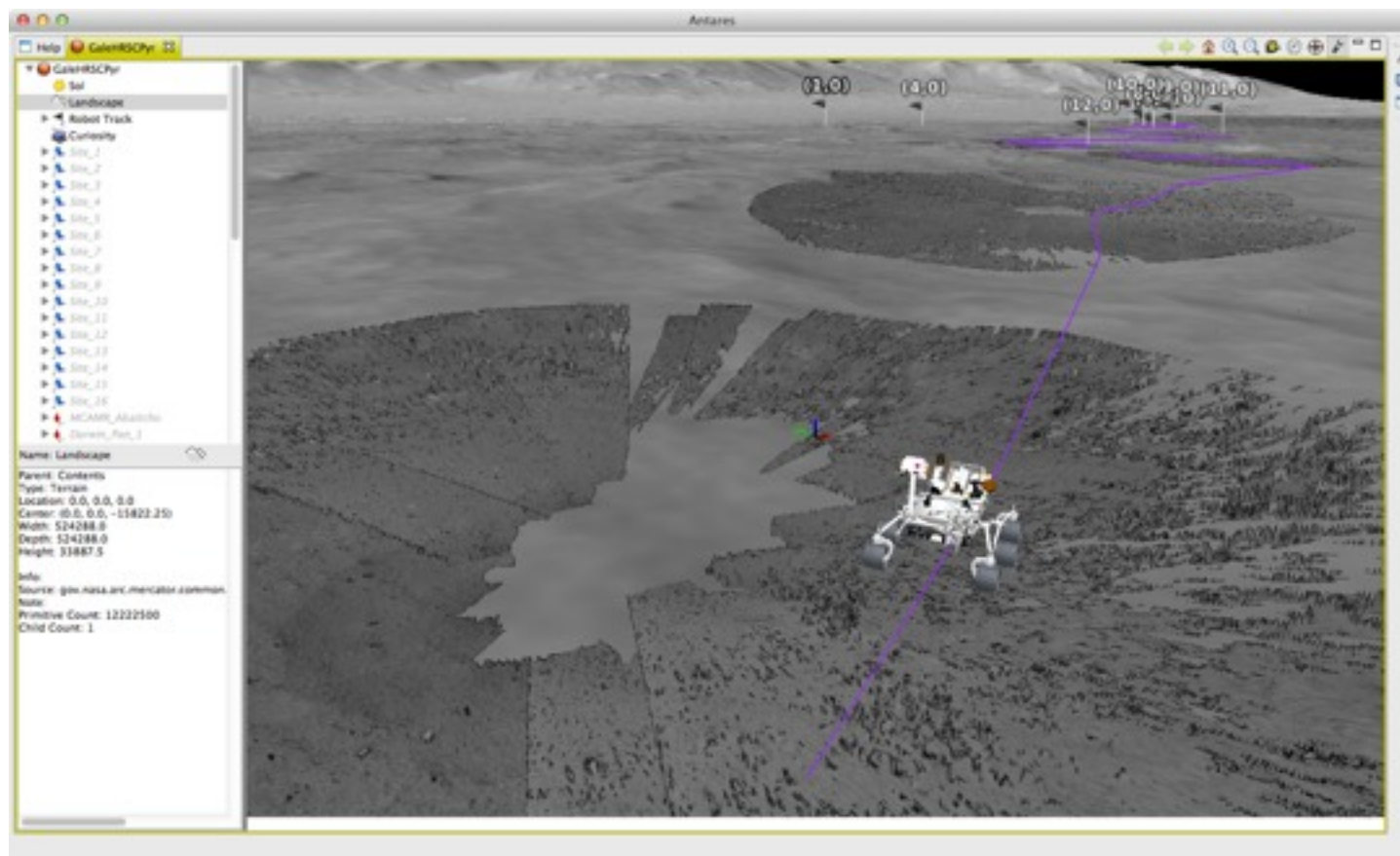
Planetary Rover Navigation



Mars Science Lab



Top view of MSL rover panoramas over Gale Crater HiRISE terrain



Oblique view of MSL rover panoramas over Gale Crater HiRISE terrain

Impact on automatic localization for planetary rover missions

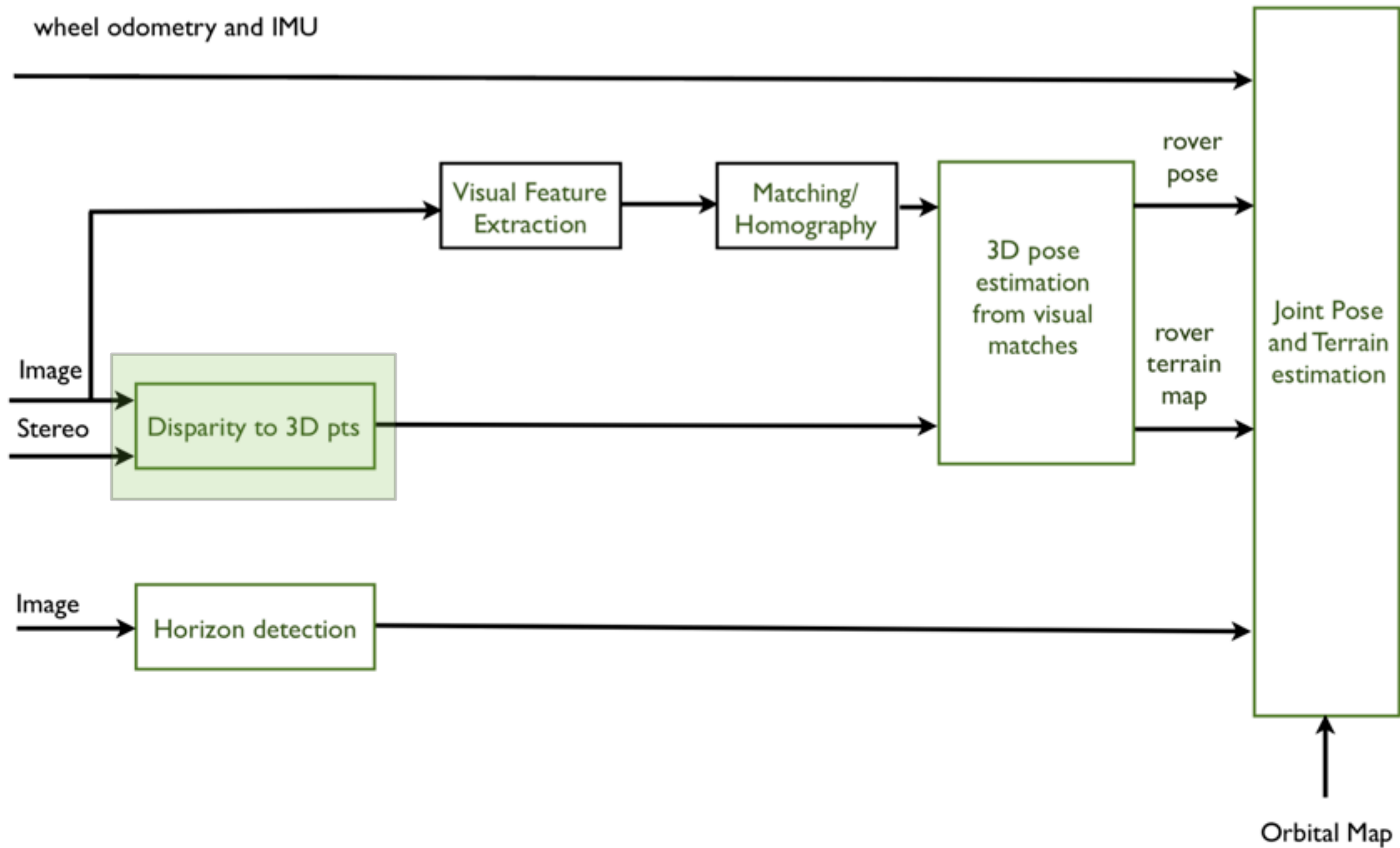
MSL mission localization through odometry is shown in purple lines in both top (top) and oblique (bottom) views.

The final partially automatic localization is shown by the rover panorama positions over the Gale crater HiRISE terrain.

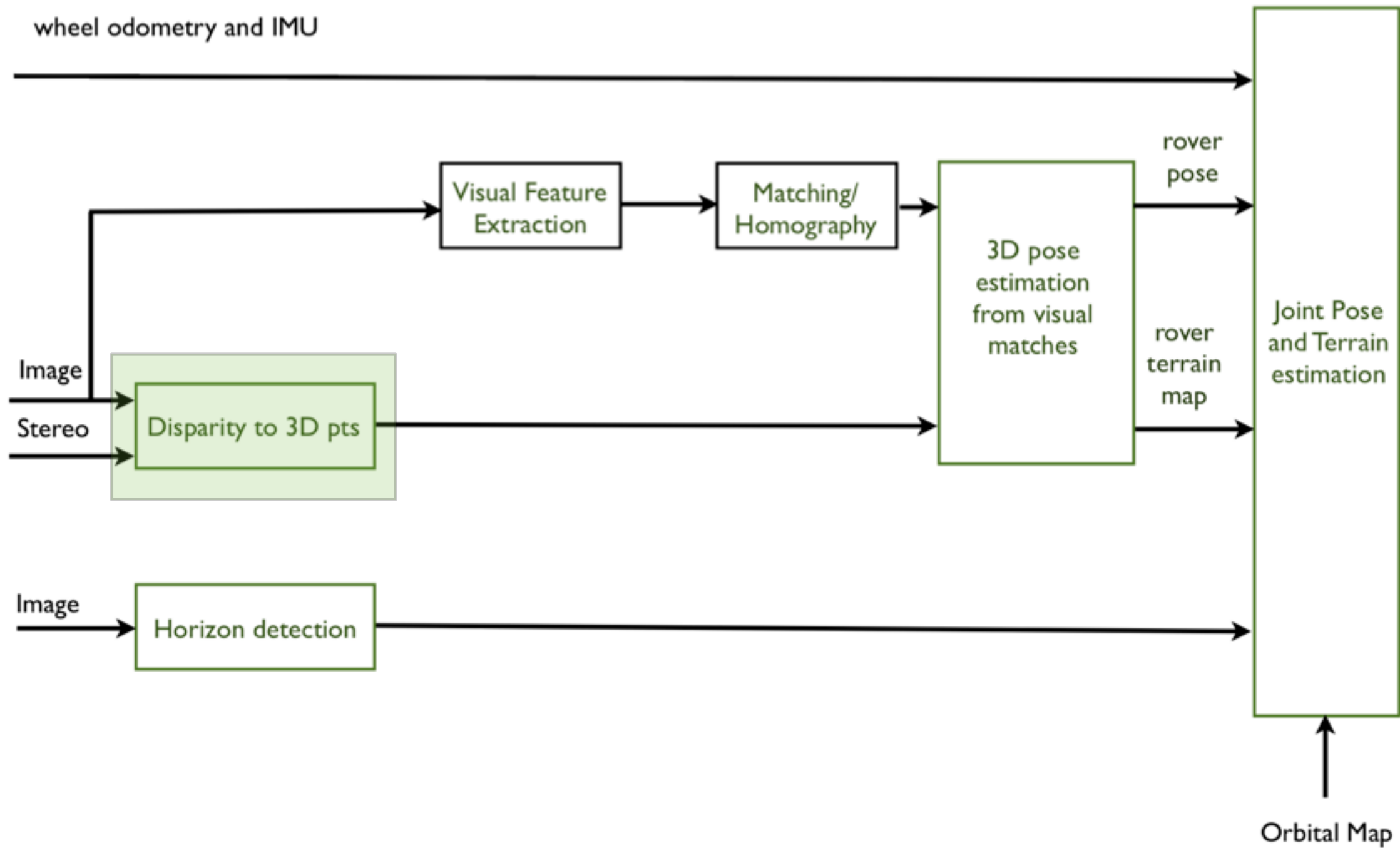
The offset between odometry and final rover localization is generally of about **10-20m.**

Fully or partially automatic localization using the system prototyped here will allow MSL and future missions for rapid turn around localization and support long traverse autonomous navigation.

Off board Localization System



Off board Localization System



Stereo Processing



Rectified left image



Disparity map

calibration package using OpenCV

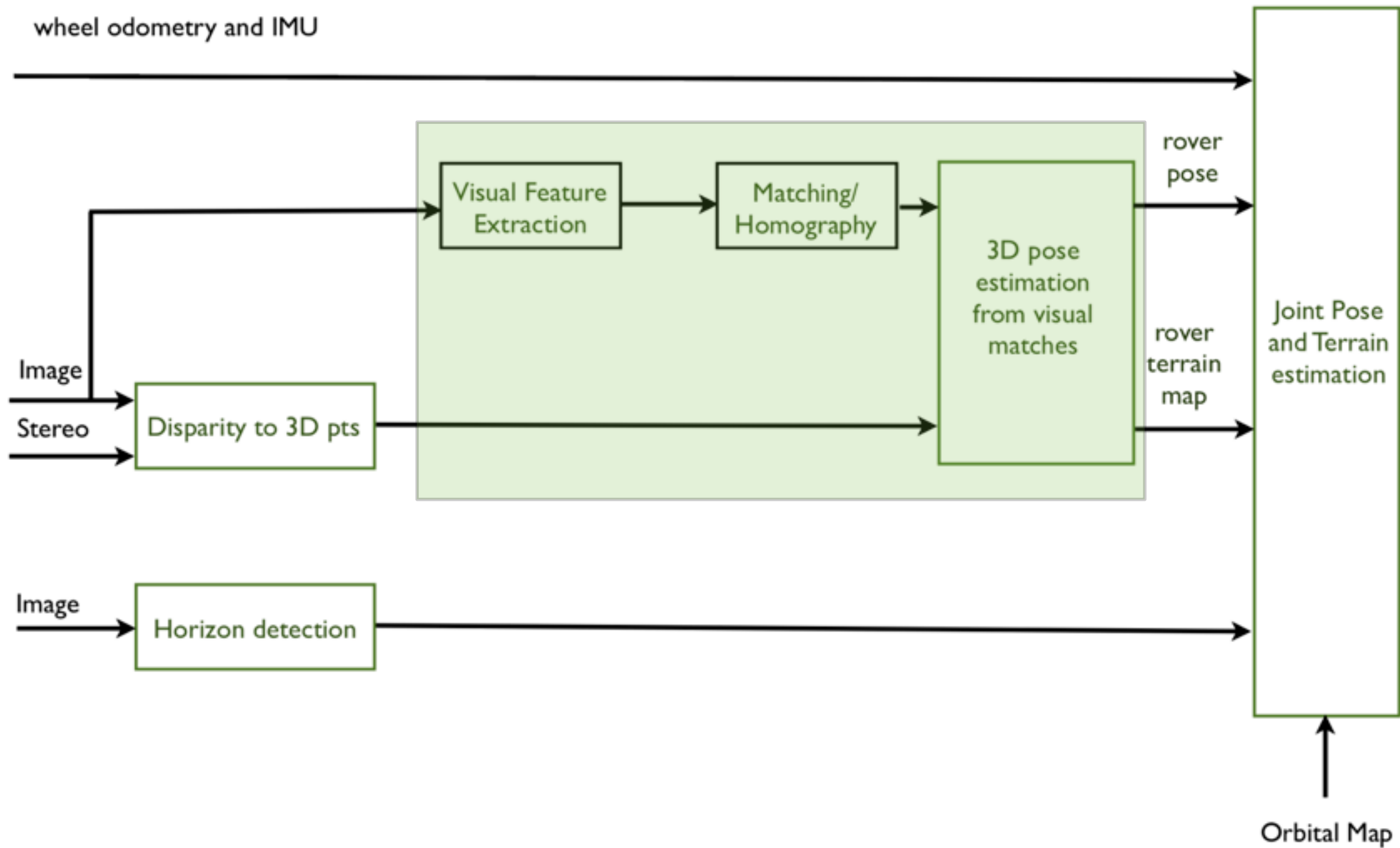
block matching based disparity computation OpenCV

outlier rejection using morphological filtering

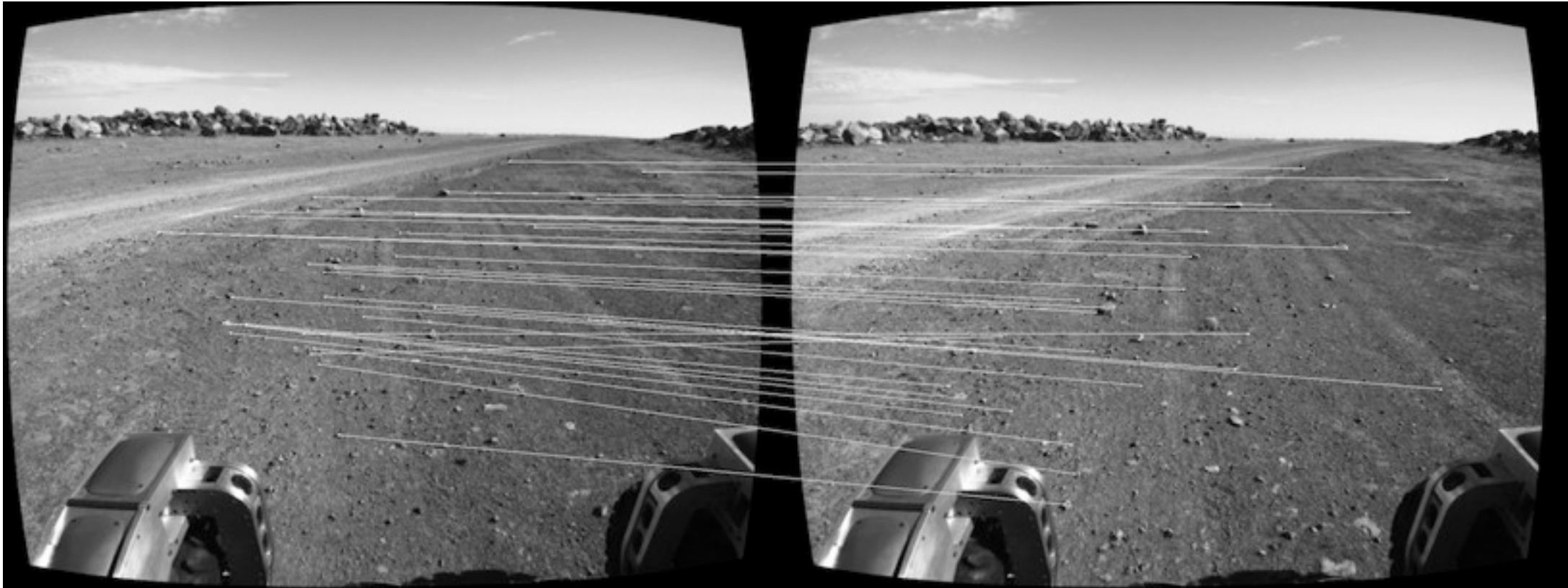
run time 6 fps

terrain reconstruction at 40m, 30cm baseline, 1388x1088 image size

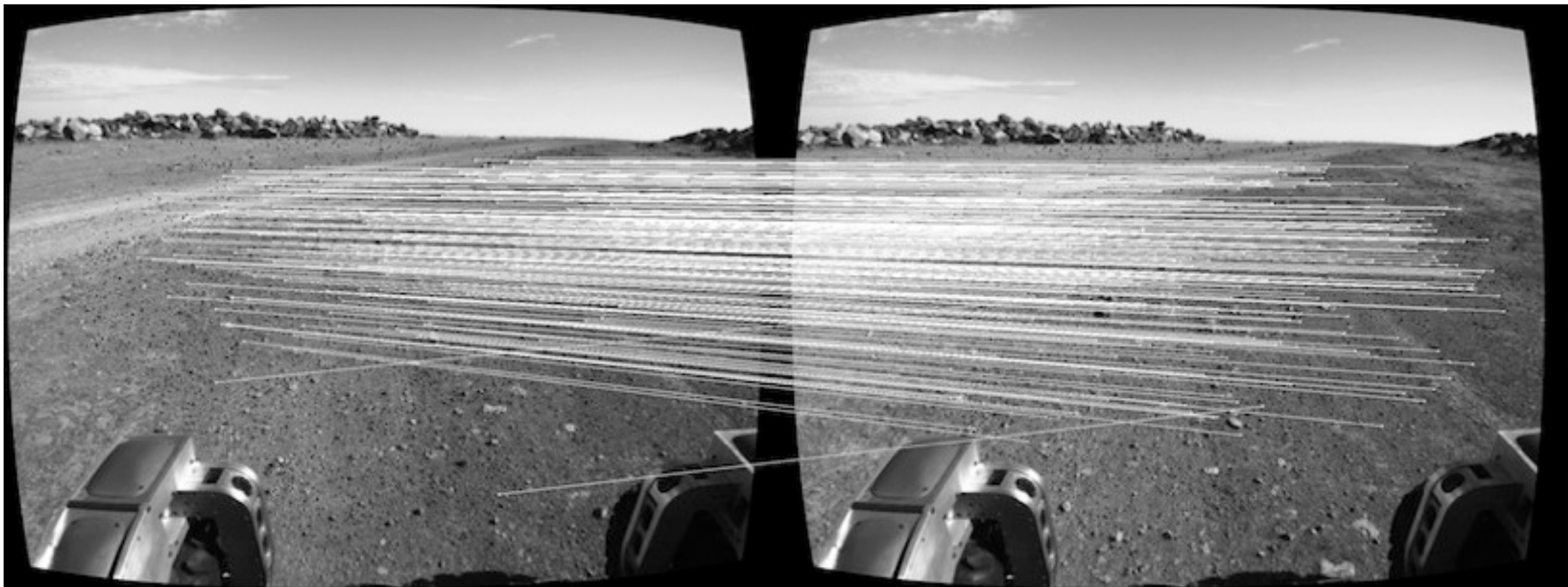
Off board Localization System



Stereo Visual Odometry

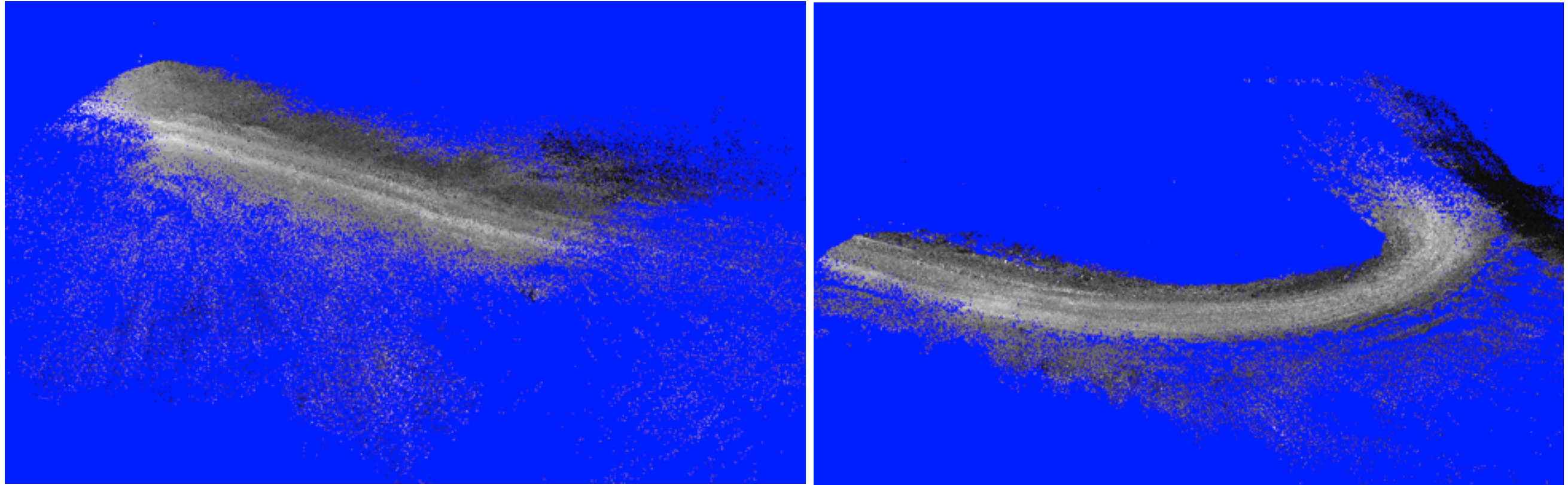


BRISK Visual Feature Matching.



SURF Visual Feature Matching.

Stereo Visual Odometry



Mapping results of the stereo visual odometry system.

Uses stereo reconstructed terrain.

Visual feature extraction SIFT, SURF, **BRISK**, ORB.

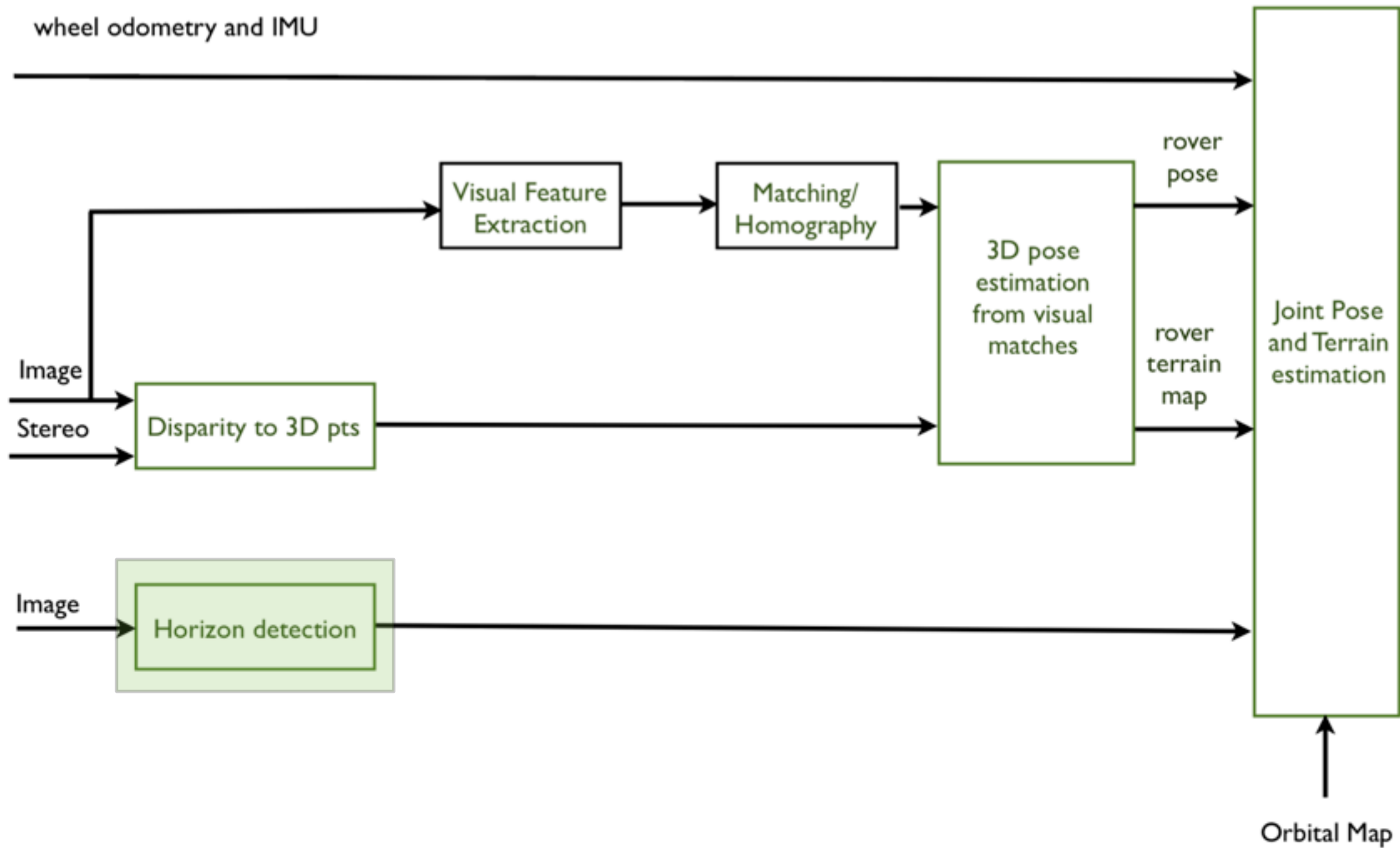
Descriptor matching using FLANN, homography based outlier detection (RANSAC).

Pairwise 3D pose estimation using stereo results.

3D outlier rejection

Running time: 8 fps (BRISK)

Off board Localization System

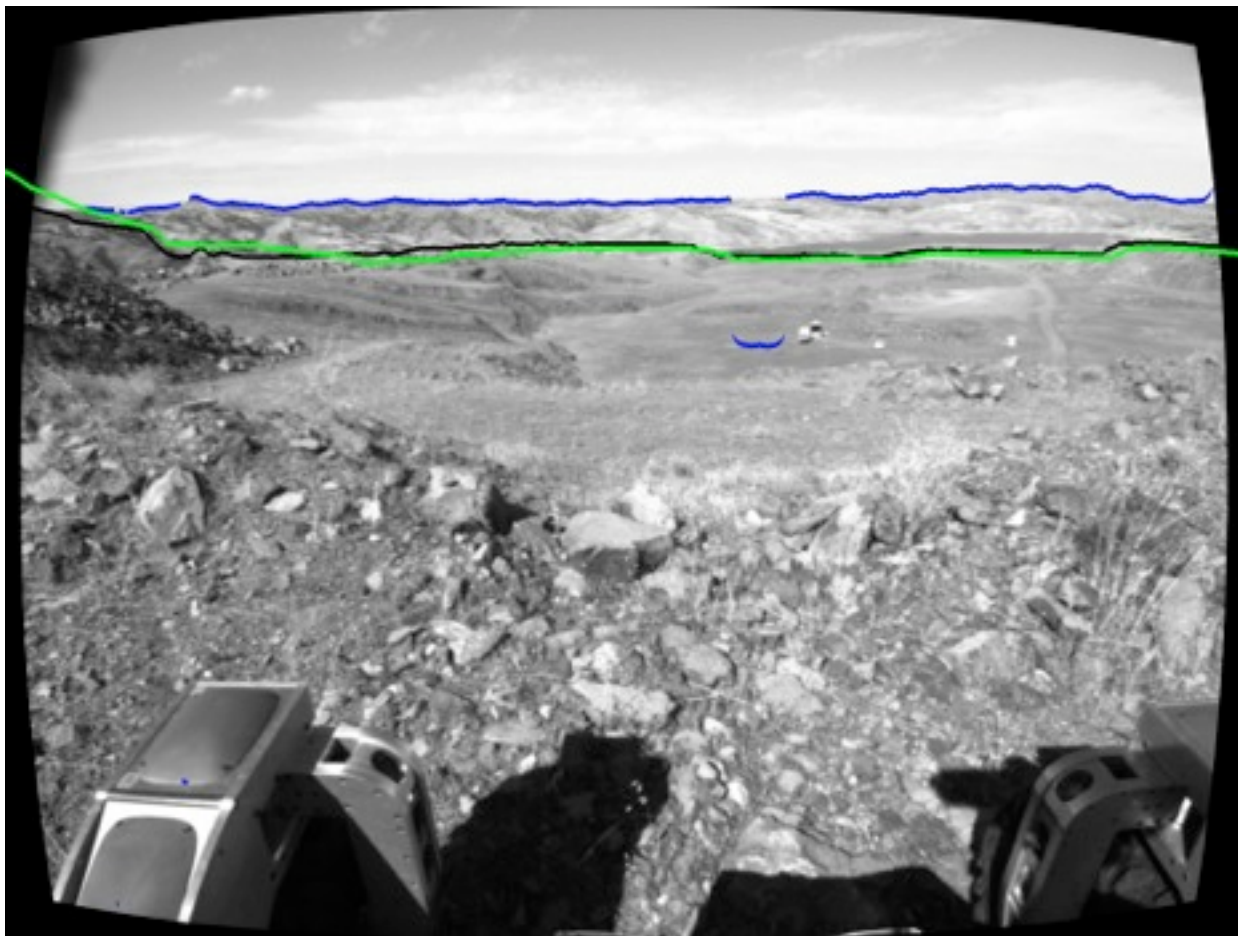


Horizon Detection

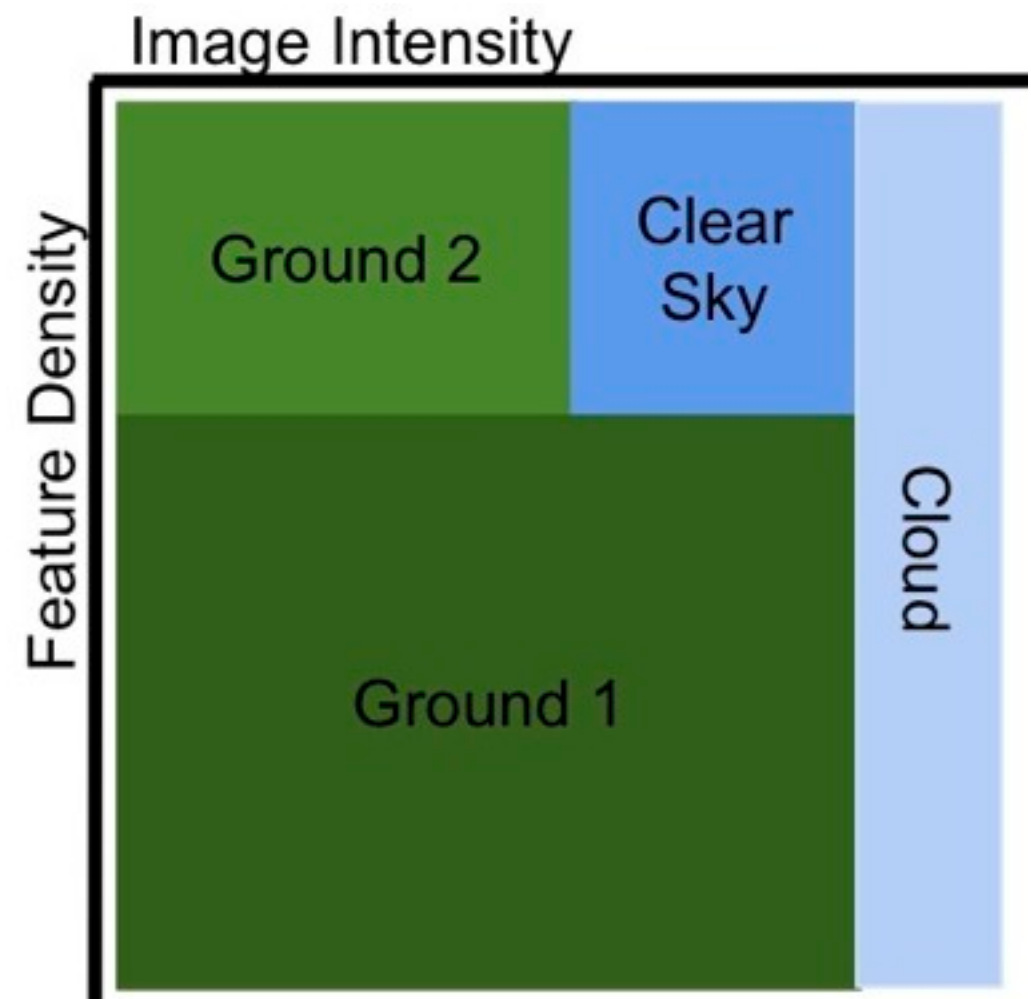
Real time horizon detection.

Method for gray scale imagery to be used in various planetary environments.

No training set imagery is used.

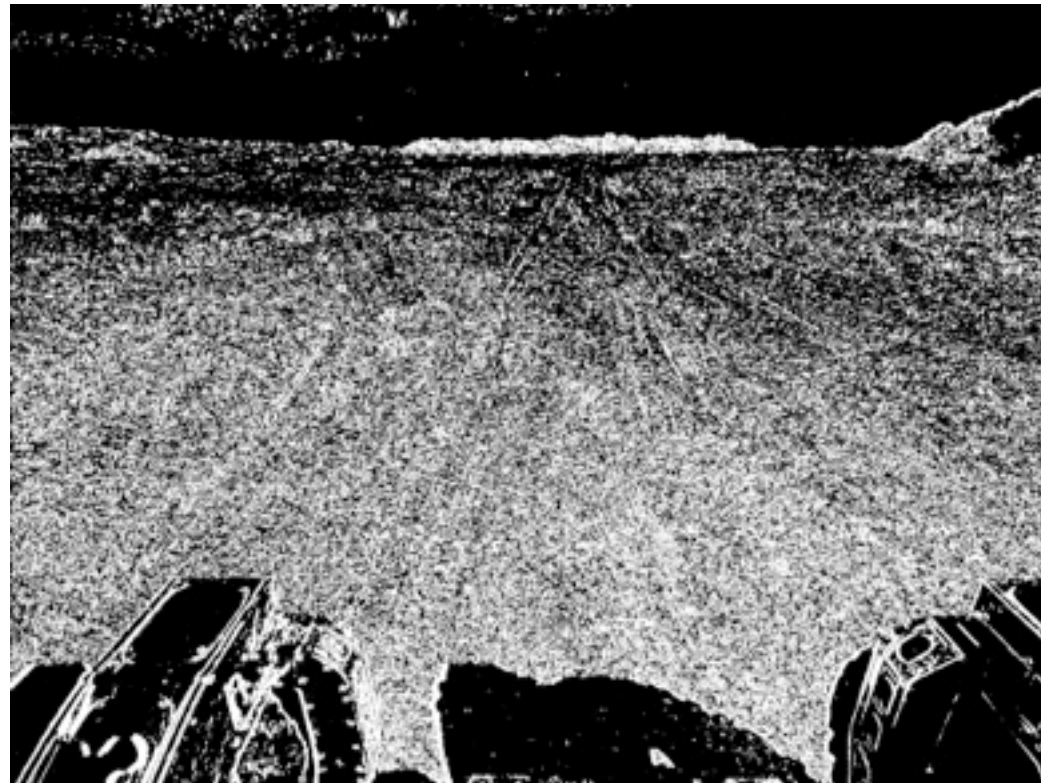


Rectified rover image



Sky and ground distribution

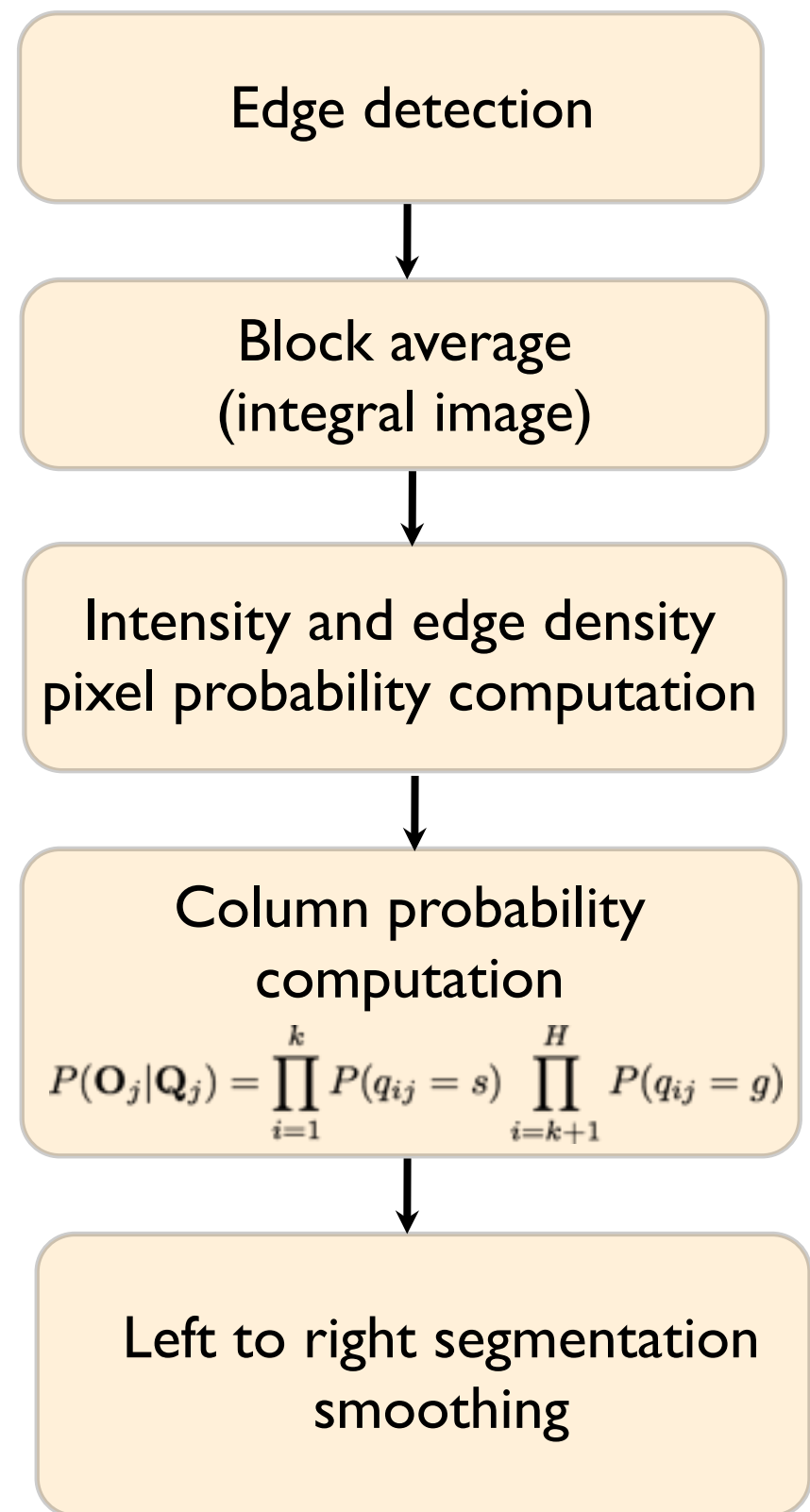
Horizon Detection



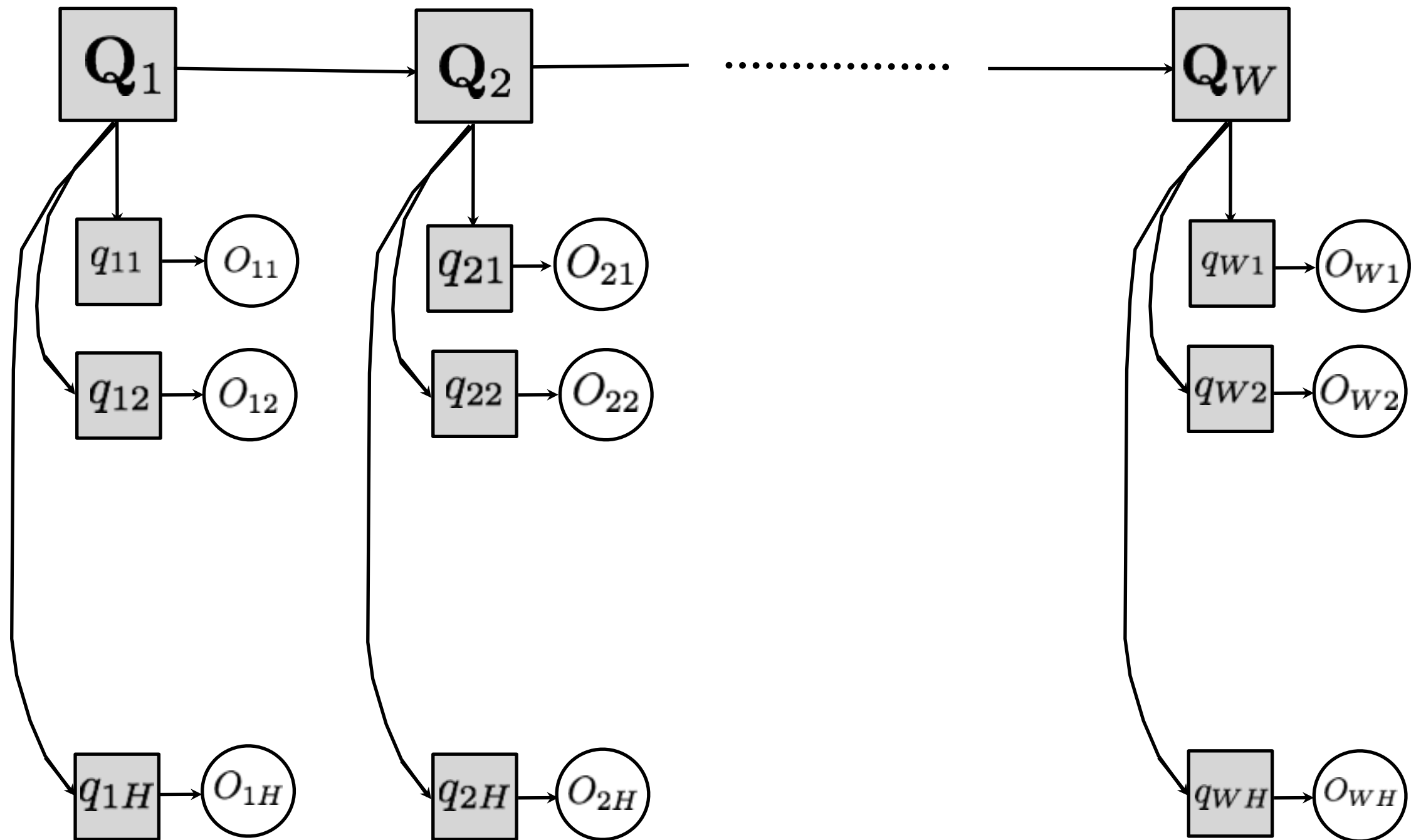
Edge detection response.



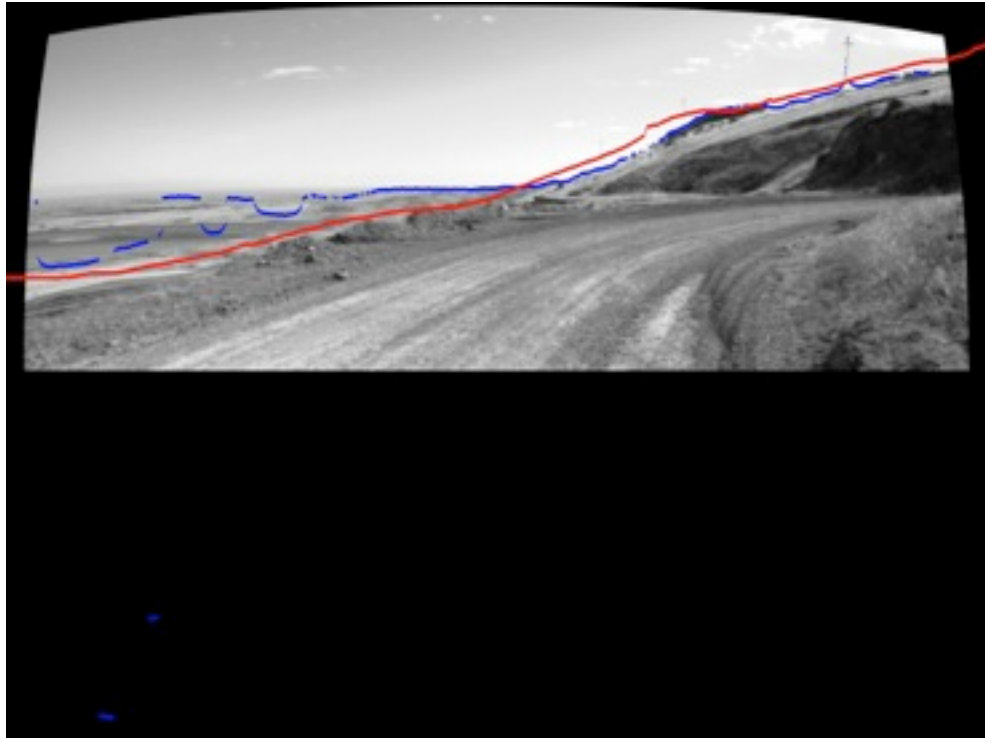
Intensity and edge density pixel segmentation



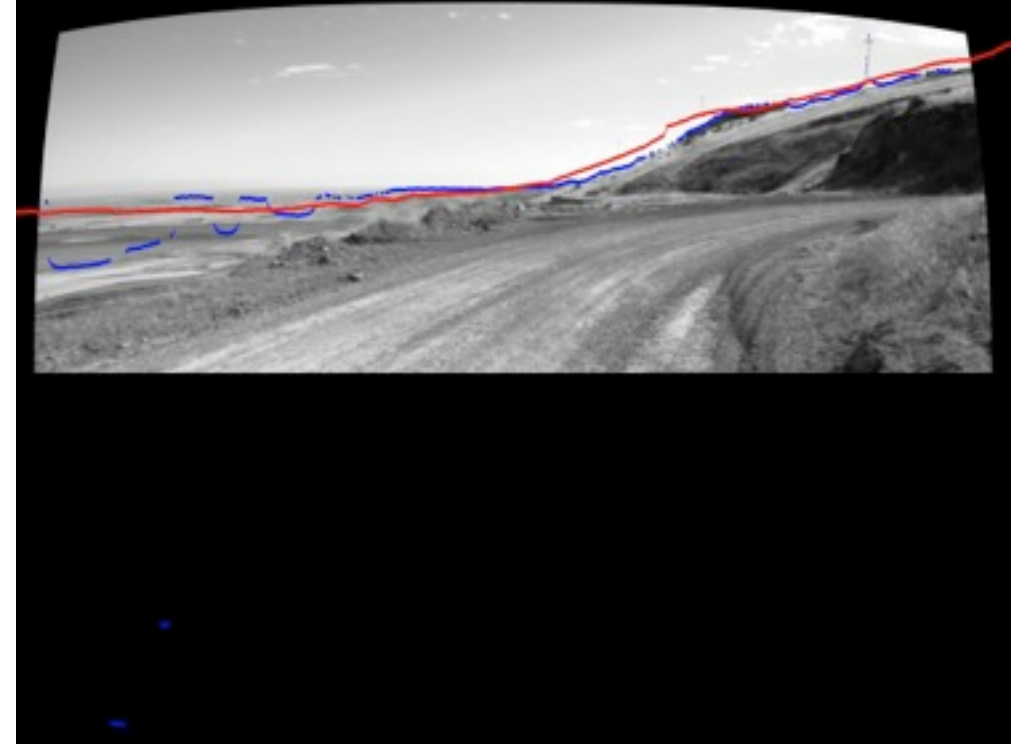
Horizon Detection



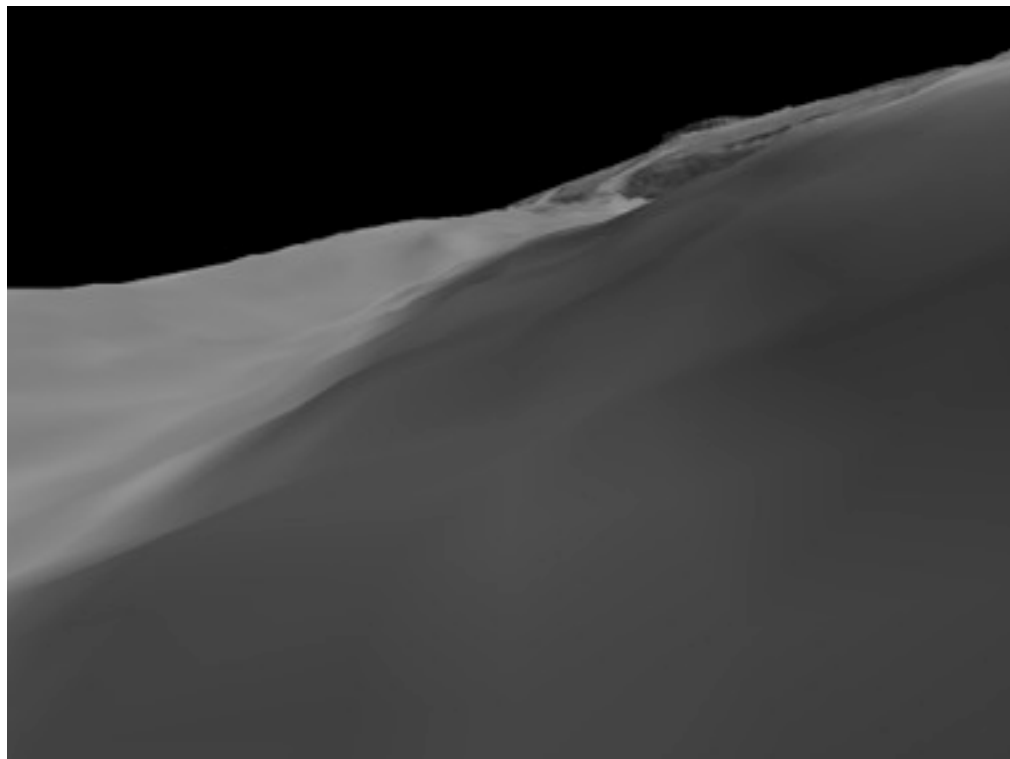
Horizon Rendering



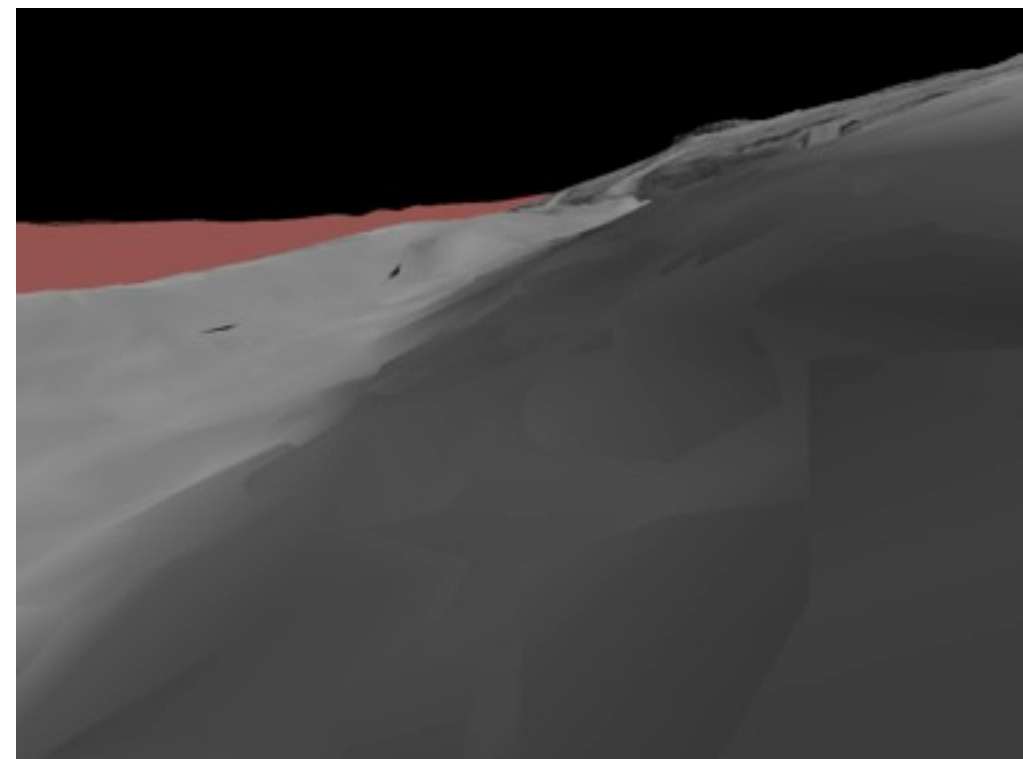
rendered (red) horizon from rover pose and high res low coverage terrain



rendered (red) horizon from rover pose and high res low coverage + low res high coverage terrain

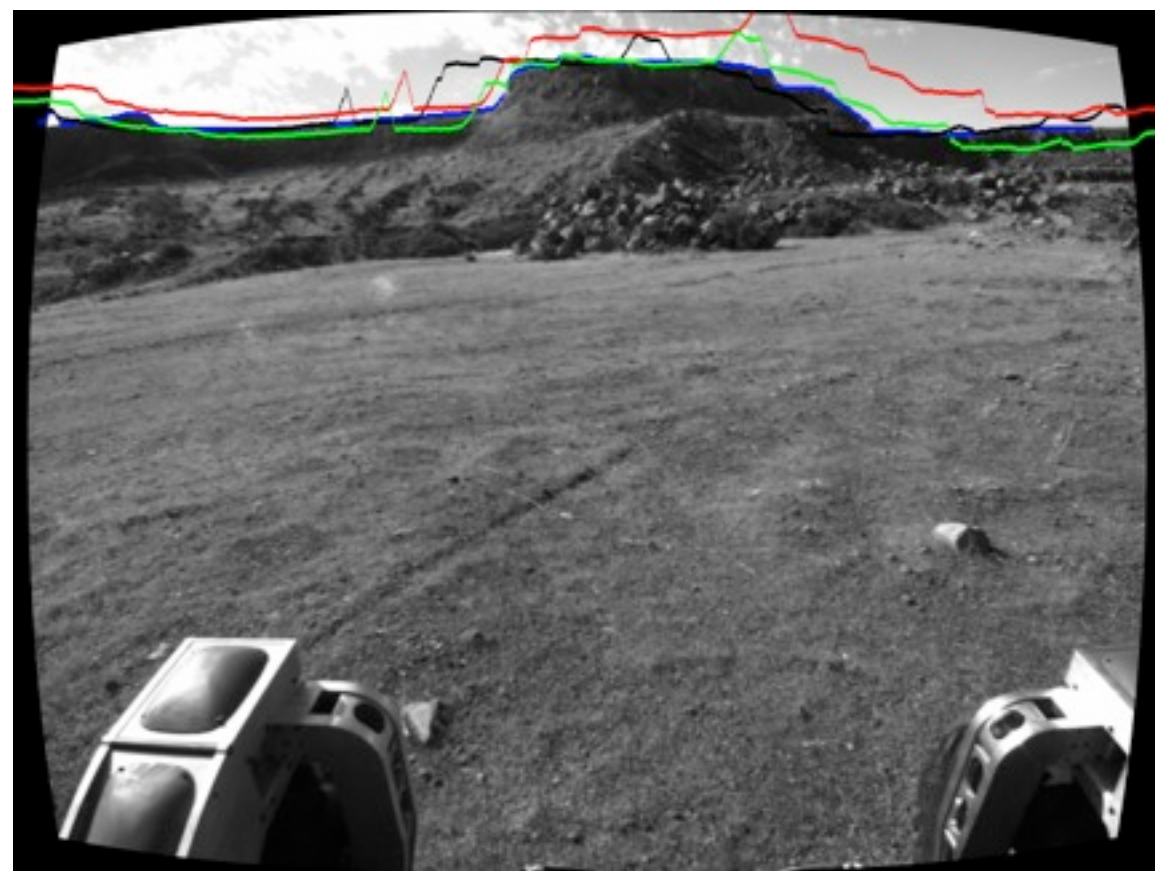
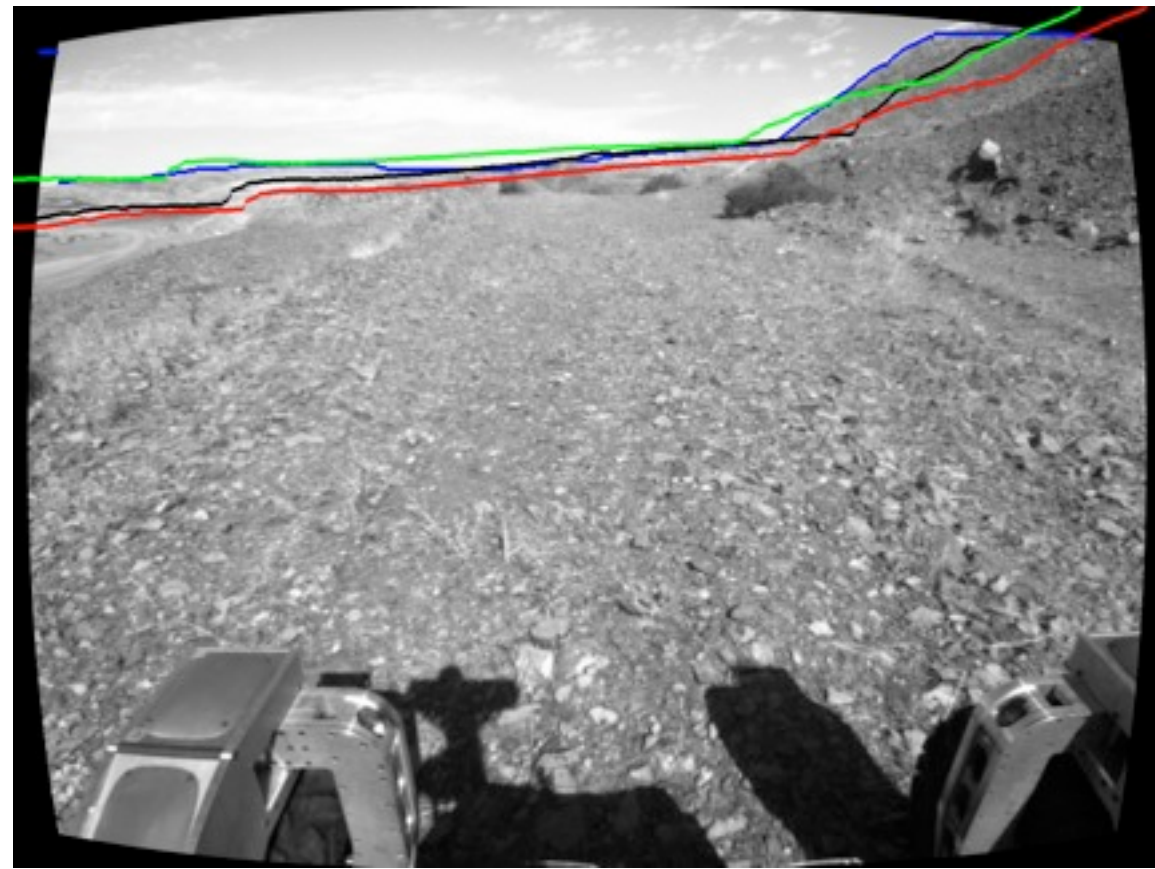
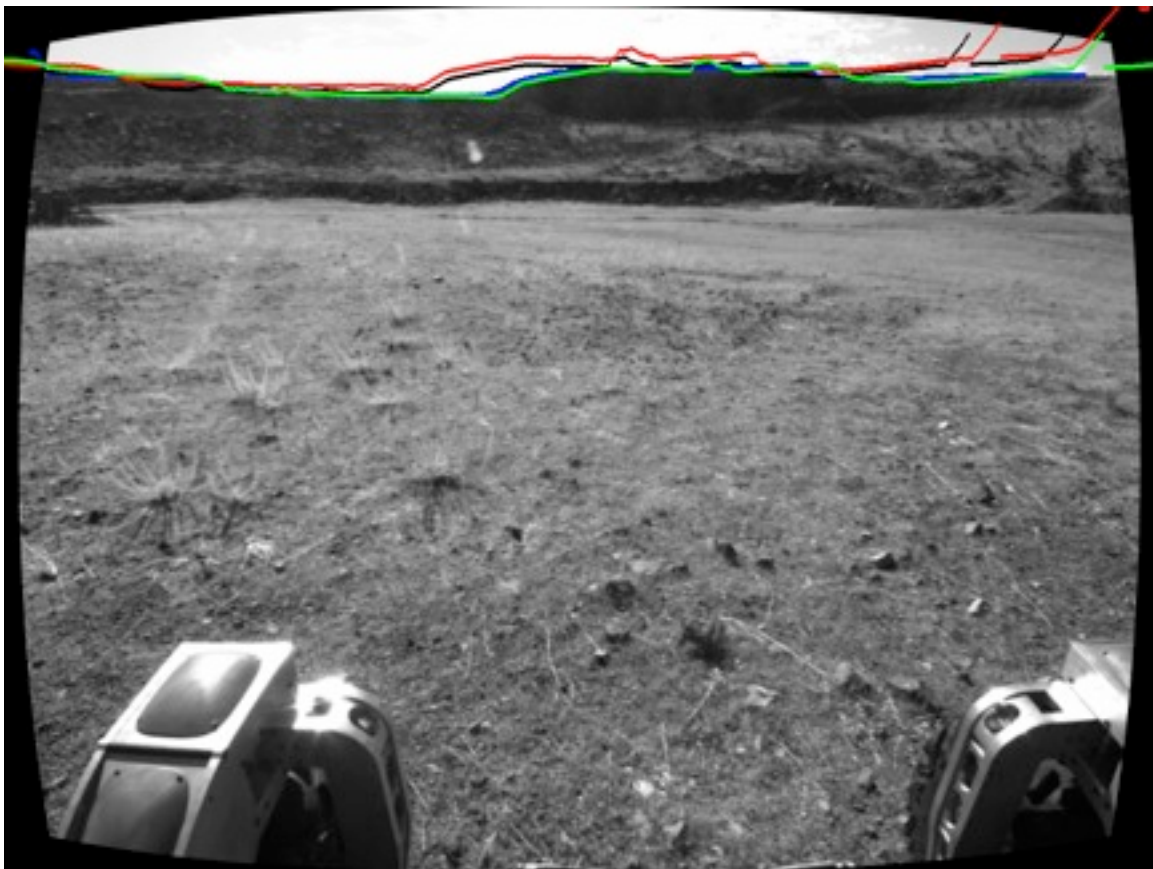


rendered rover view from rover pose and high res low coverage terrain



rendered rover view from rover pose and high res low coverage + low res high coverage (red) terrain

Horizon Matching



Horizon Rendering and Matching

Horizon Matching Cost Function $Q_h(\mathbf{R}, \mathbf{T}) = \sum_i (Hd_i - Hr_i(\mathbf{R}, \mathbf{T}))^2$

i is the image column

Hd_i, Hr_i are the rows corresponding to the detected and rendered horizon.

- multiple restart solution
- number of restarts increases over time to account for accumulated errors
- every 500 frames, <5s/frame.

$$Conf(\mathbf{R}, \mathbf{T}) = \frac{Q_h(\mathbf{R}, \mathbf{T})}{\sum_k Q_h(\mathbf{R}_k, \mathbf{T}_k)}$$

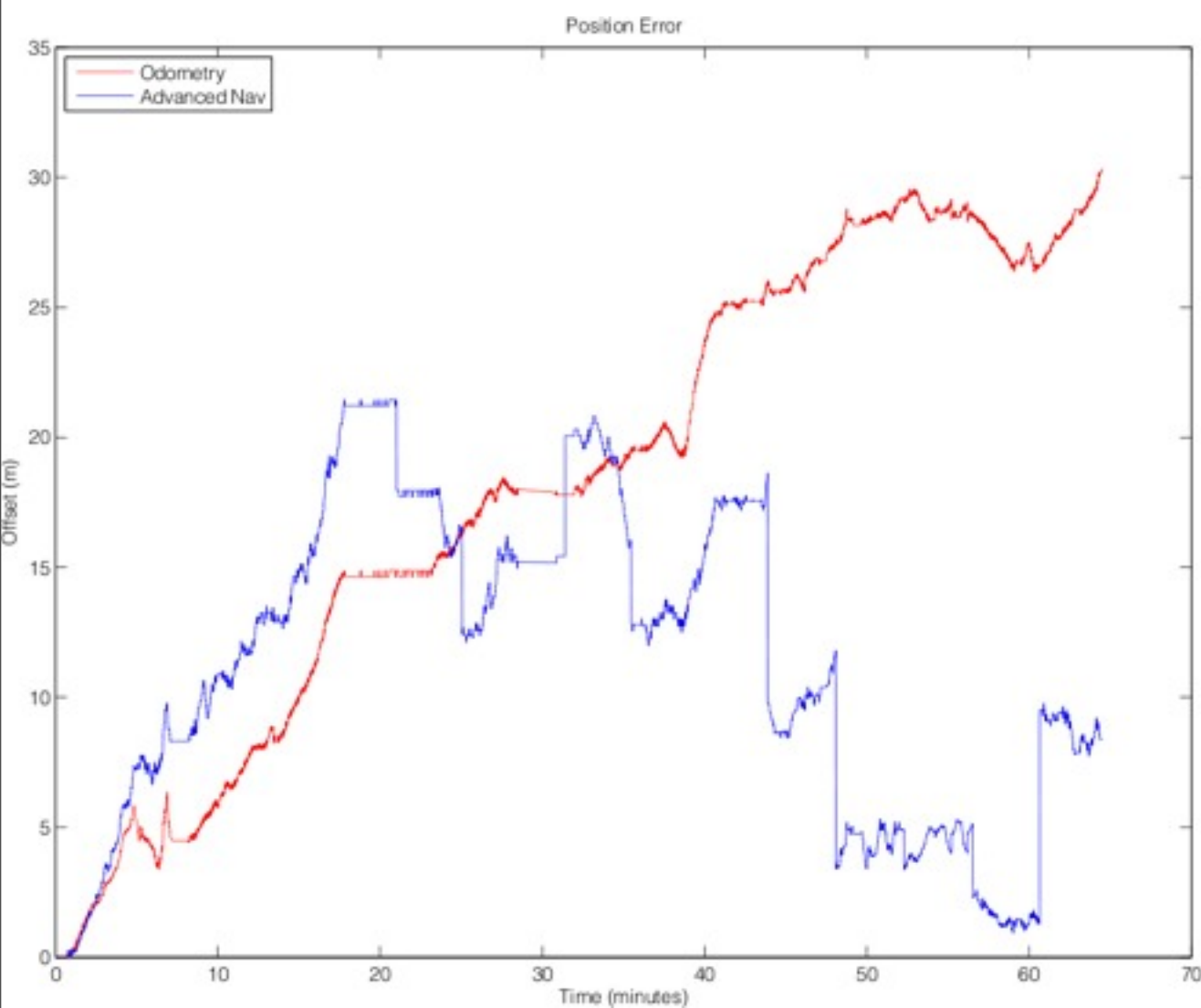
Horizon Rendering

Orbital Terrain Generation Ames Stereo Pipeline from Digital Globe Imagery 0.5m/pixel

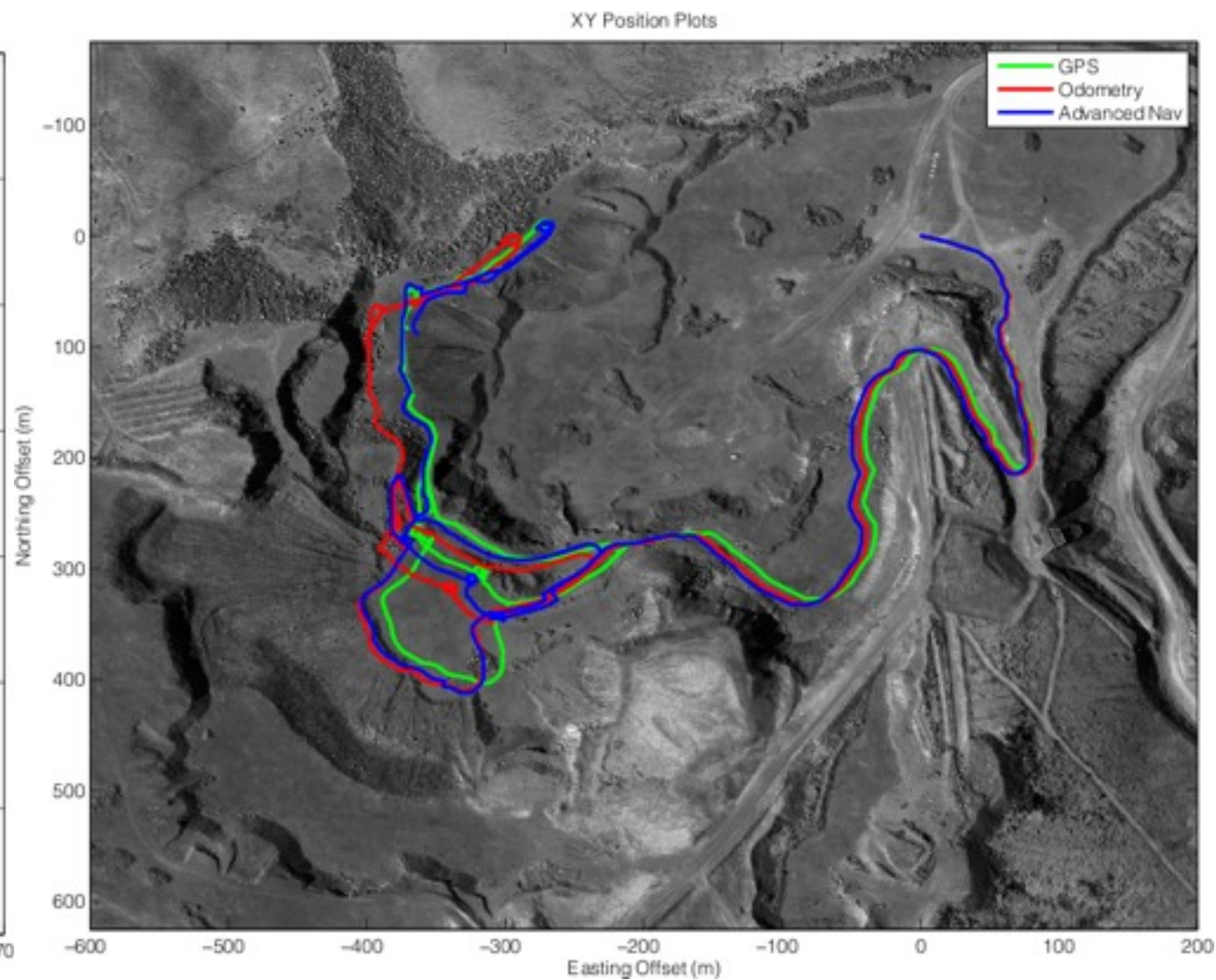
Overlay over USGS Terrain models at 10m/pixel.

OpenGL or Mesa based solution for terrain rendering.

Localization Results



Localization errors wheel odometry (red) vs advanced navigation (blue)



Estimated traverse tracks over Basalt Hills area



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