Pinpoint Landing Optical Navigation: Preliminary Hardware Validation

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Challenge

Pinpoint landing can significantly increase mission return. With no GPS nor radio aiding, a camera can recognize illuminated descent landmarks from orbital images.

Three major challenges lie in matching features from an orbital image with descent ones:

- Altitude and sensor changes,
- 3D topography of the terrain,
- Illumination changes.

Contributions

We detail in [1] an algorithm to identify mapped landmarks for accurate localization. Our main contributions are:

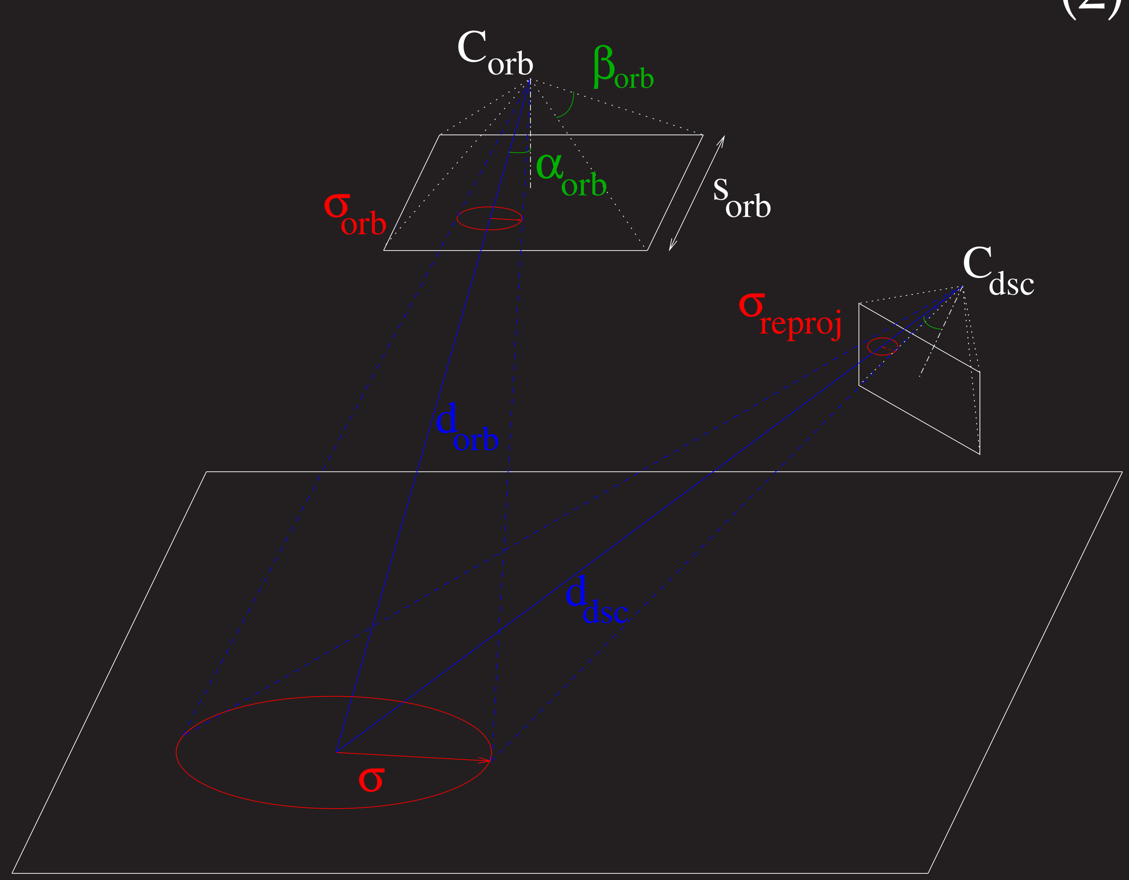
1. 3D-compatible geometric matching,
2. Use of characteristic landmark scale for better performance,
3. Tight IMU/Vision fusion

Image Feature Scale

Our landmarks are generic image corners. They can be described by their characteristic scale on the orbital image and the associated cornerness score extracted with the Harris-Laplace operator as in [2]. The former tells us at which image resolution the landmark should be looked for during descent, the latter allows for differentiating overlapping landmarks.

The scale of an orbital landmark in the descent image is predicted using *a priori* pose knowledge from the filter:

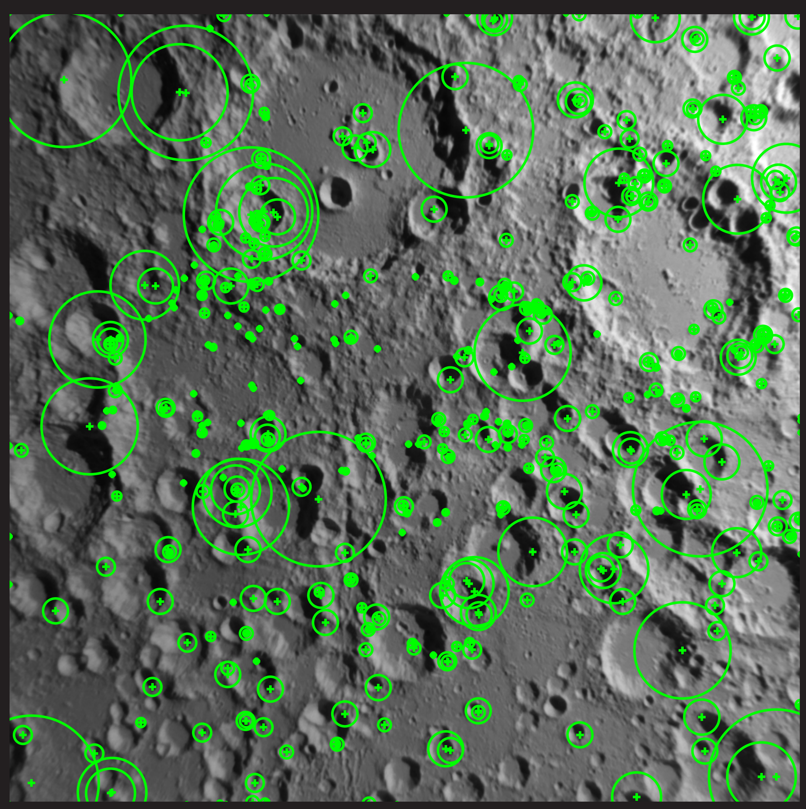
$$\sigma_{reproj} = \sigma_{orb} \frac{d_{orb}}{d_{dsc}} \frac{tan \frac{\beta_{orb}}{2}}{tan \frac{\beta_{dsc}}{2}} \frac{s_{dsc}}{s_{orb}} \frac{cos\,\alpha_{orb}}{cos\,\alpha_{dsc}} \quad (2)$$



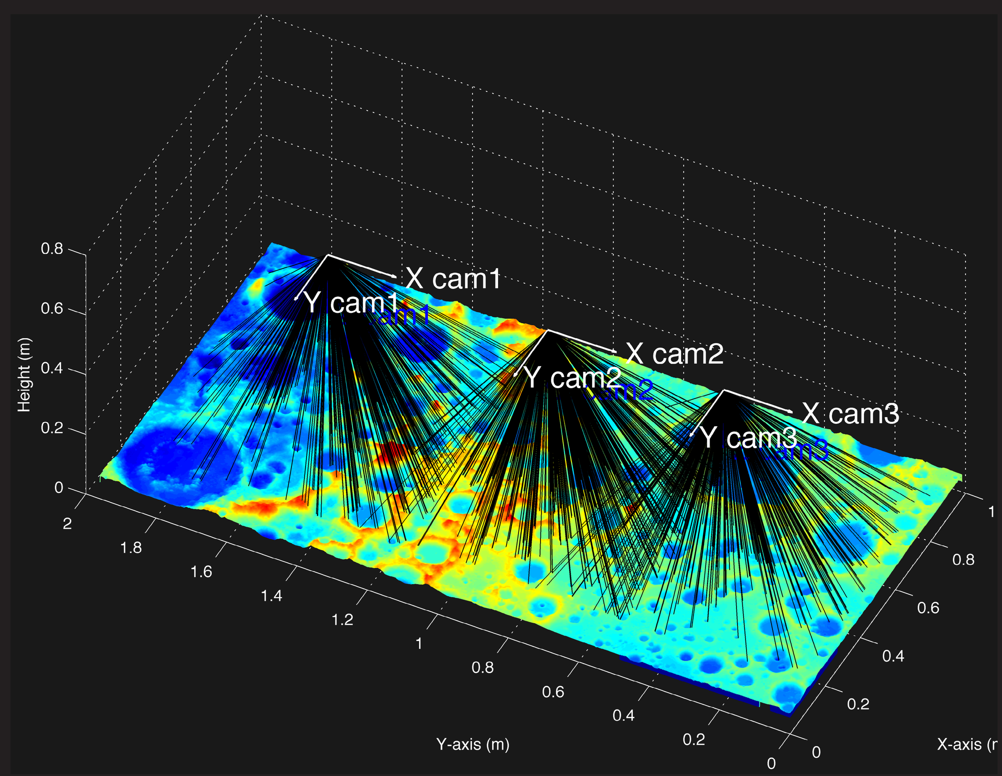
LION - Landing Inertial and Optical Navigation

Offline map generation is three-fold:

1. Harris-Laplace landmark extraction in orbital images



2. 3D coordinate interpolation from DEM



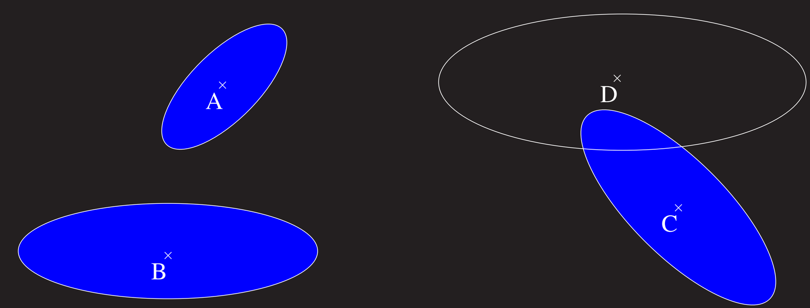
3. Map built as an Nx6 array: world coordinates, scale, cornerness score, orbital image tag.

Online landmark recognition has four steps:

1. Landmark prediction: The landmark position in descent image, its scale, and research area are computed from the *a priori* state estimates. The image position covariance P_j^I for landmark j is computed from the projection Jacobian J_j, state estimate P and image extraction noise Q:

$$P_j^I = J_j P J_j^t + Q \quad (1)$$

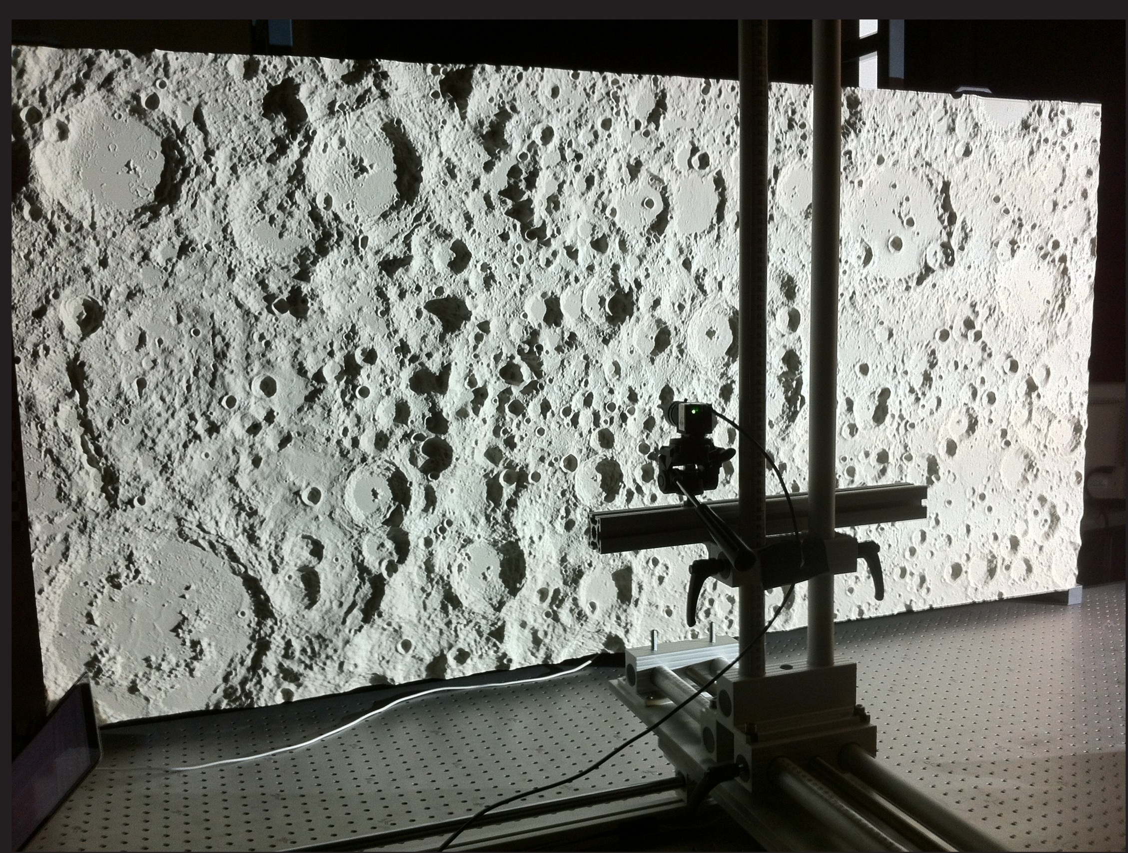
2. Landmark selection: Not all visible landmarks are considered suitable for matching.



Research ellipses of landmarks A and B are not overlapped, they are both selected. Landmark C and D overlap each other, only C is selected since it has the highest cornerness score.

3. Detection: Maximum of cornerness at scale σ_{reproj} within the research ellipse.
4. Outliers rejection: RANSAC scheme based on a P3P camera computation.

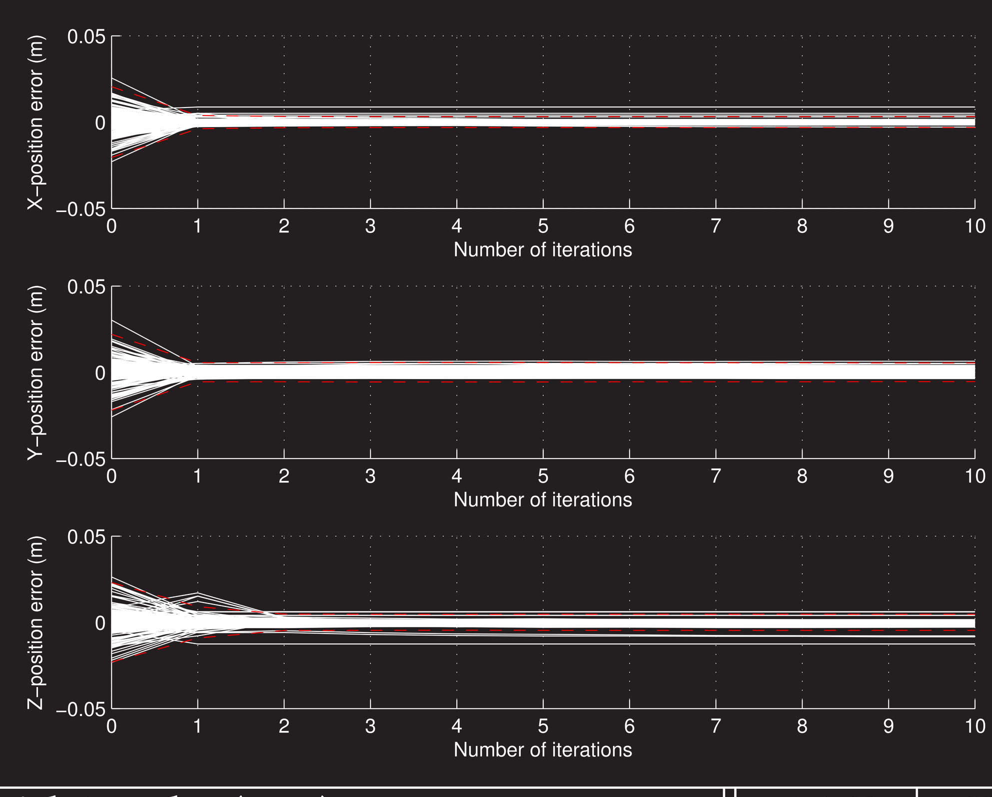
ESA Control Lab



A 2 m^2 planetary mock-up based on NASA LRO lunar altimetry data was designed and set up at ESA-ESTEC. A 1024x1024 USB camera mounted on a static support and equipped with a lens providing a 75-deg field of view was used for hardware-in-the-loop tests. Ground truth accuracy is 2.4 mm and 0.2 deg (3σ).

Performances

- 210 Monte Carlo runs on a sequence of 21 descent images;
- Orbital image altitude: 58.5 cm <=> 50 km (LRO-WAC, 100m/pixel);
- Similar illumination: orbital/descent. Sun elevation: 30 deg;
- Star tracker attitude initialization.



Altitude (cm)	46.5	70.5
Scaled Altitude (km)	40	60
Initial Position Error (mm, 3σ)	23.2	35.2
Scaled Initial Position Error (m, 3σ)	2000	3000
Final Position Error (mm, 3σ)	1.2	2.1
Scaled Final Position Error (m, 3σ)	103	180

Future Work

- Dynamic testing in a scale-representative lunar sequence,
- Test hardware robustness to illumination changes,
- Implement initialization method

References

[1] J. Delaune, G. Le Besnerais, M. Sanfourche, T. Voirin, C. Bourdarias, and J.-L. Farges. Optical Terrain Navigation for Pinpoint Landing: Image Scale and Position-Guided Landmark Matching. In *AAS GNC '12*

[2] K. Mikolajczyk and C. Schmid. Scale & Affine Invariant Interest Point Detectors. In *IJCV '04*