ABSOLUTE AUTONOMOUS NAVIGATION IN LUNAR ORBIT

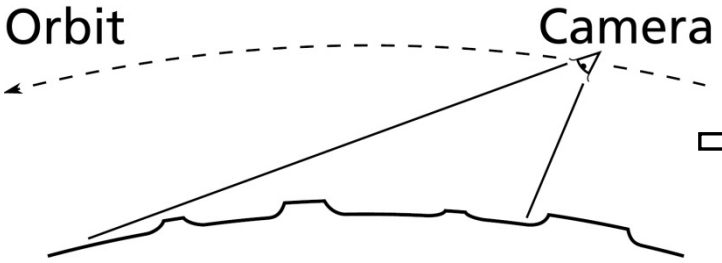
Hans Krüger, Bolko Maass, Stephan Theil

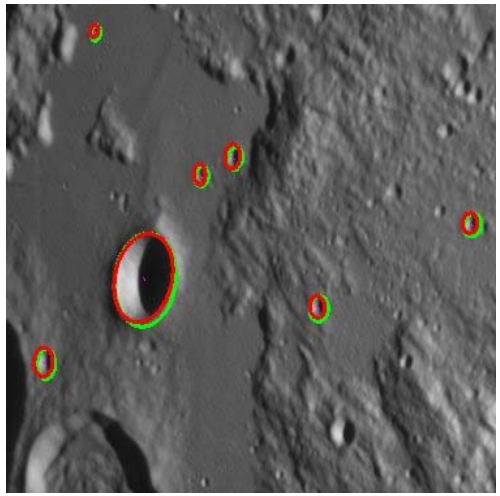
Goals of this presentation

- Give an overview of the navigation method
- Show results of characterization
- Show results of functional tests

Crater navigation method
Overview

- Sensor in lunar orbit
- Input: image of the lunar surface
- Processing image data and on-board data
  - Detecting craters, matching craters with on-board database
- Output: position and attitude of space craft in lunar orbit
- All necessary information on-board the sensor
- Works autonomously





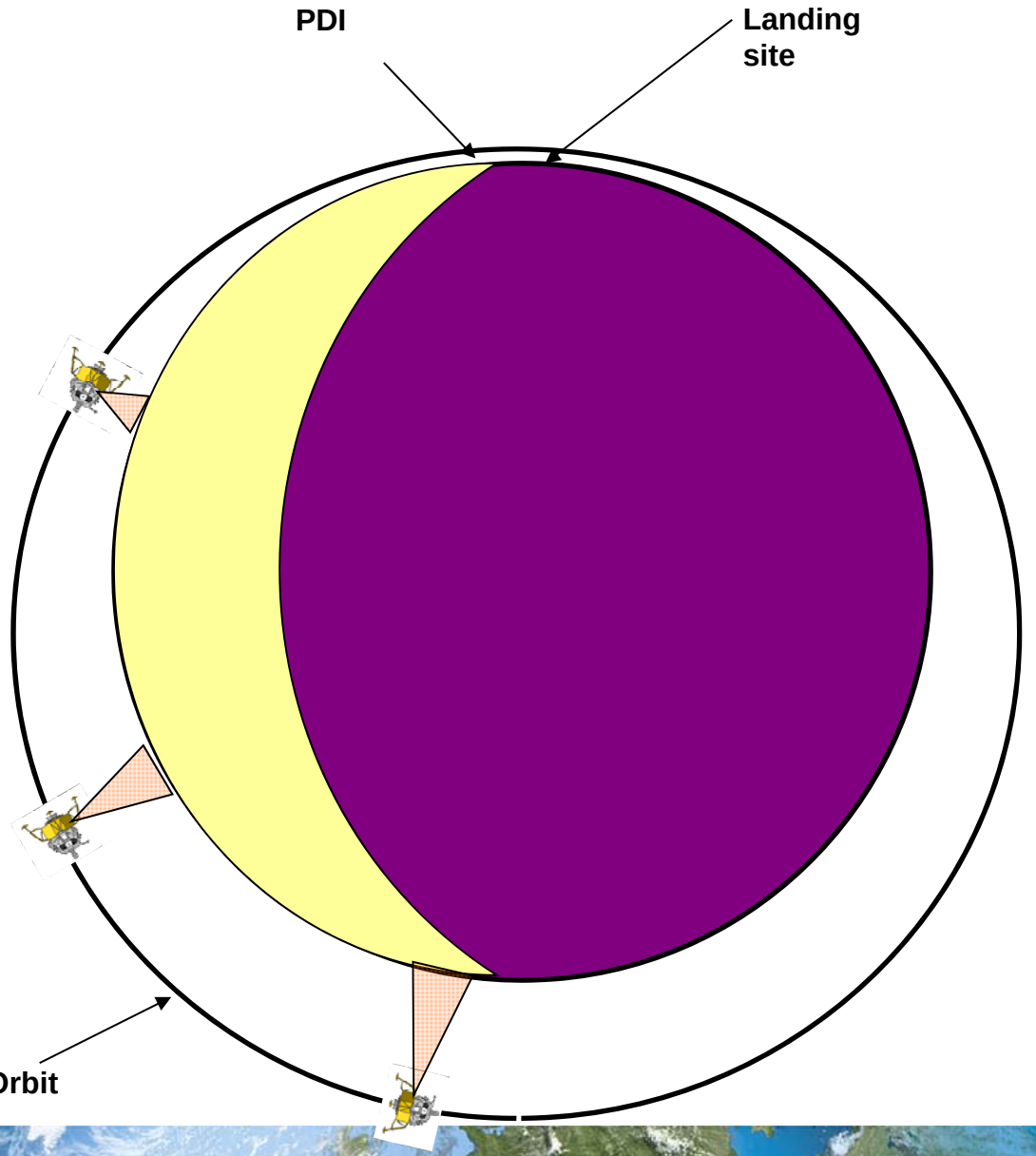
$$\boldsymbol{q} = \begin{pmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{pmatrix}$$

$$\boldsymbol{x} = \begin{pmatrix} x_0 \\ x_1 \\ x_2 \end{pmatrix}$$

Principle
Image acquisition

- Spacecraft in lunar orbit
- Sensor facing the surface
- Taking images

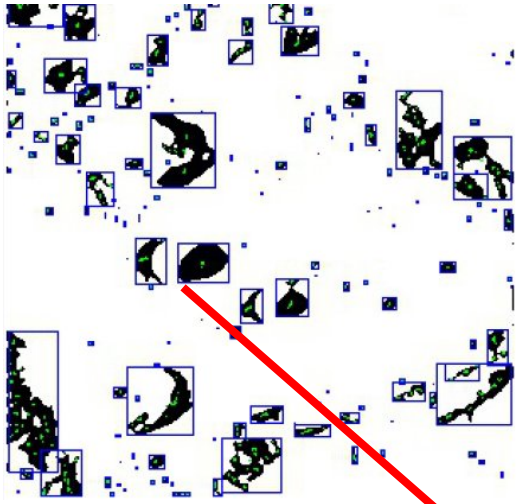
Images from DLR simulator



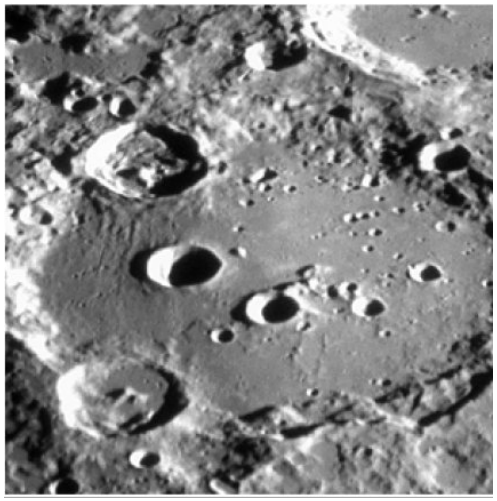
Principle overview
Blob analysis

For each image:

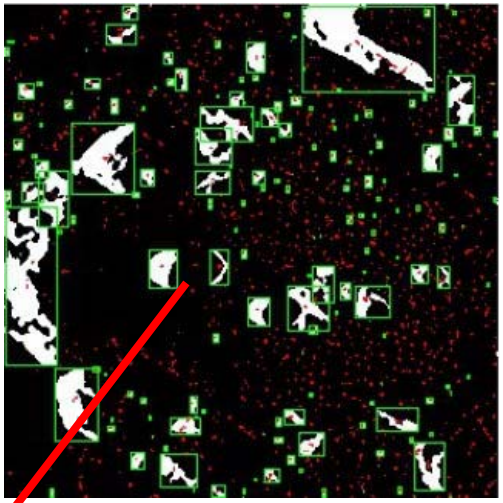
- Identification of blobs which are stable over a long range of gray levels
  - Shadow areas and bright areas
- Blob pair determination (supported by local light direction estimation)
- Ellipse fitting -> craters



Shadow blobs identification



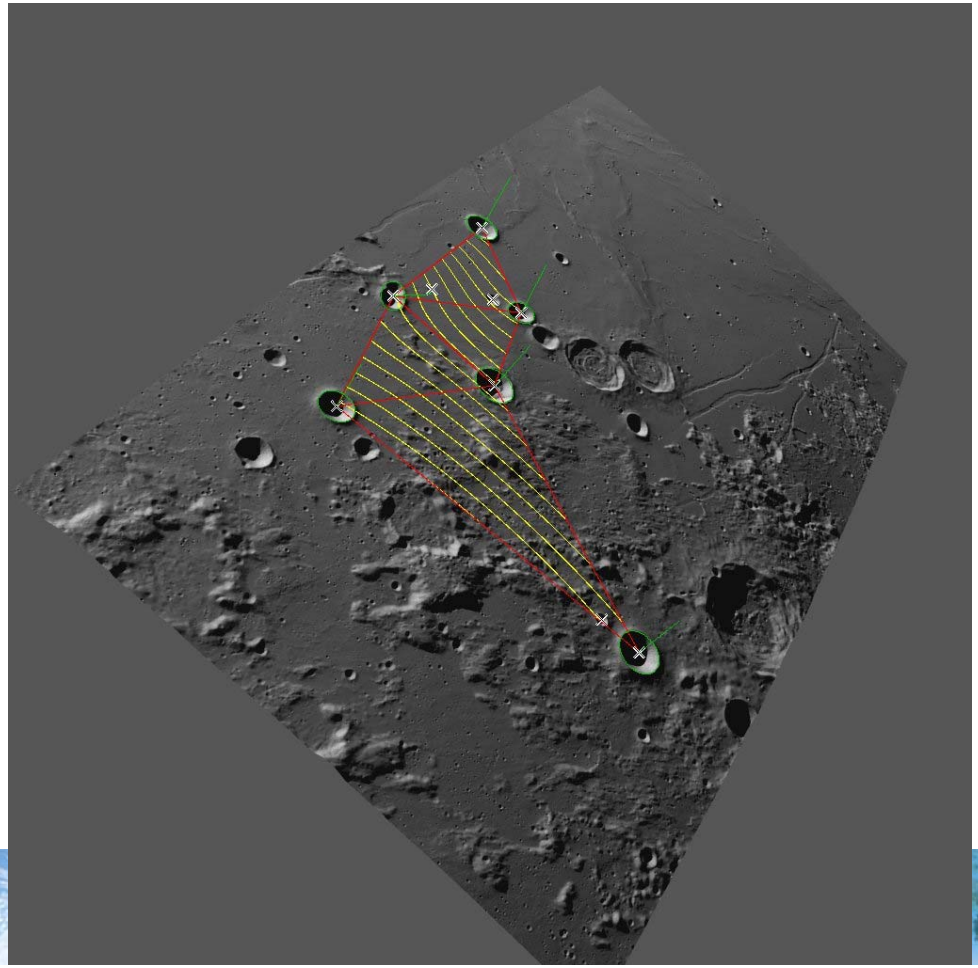
Original image



Bright area blobs identification

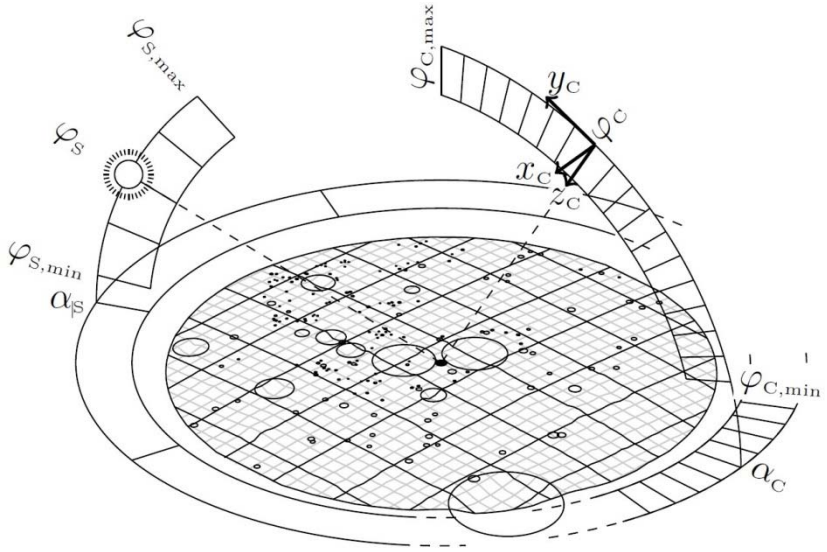
Principle overview
Surface reconstruction

- Goal: find relative angles & distances between crater triplets (for matching)
- for each crater we know normal vector in camera frame
- Interpolation of surface where the craters are embedded into
- Extraction of angles and distances from surface
- Ready for matching with database

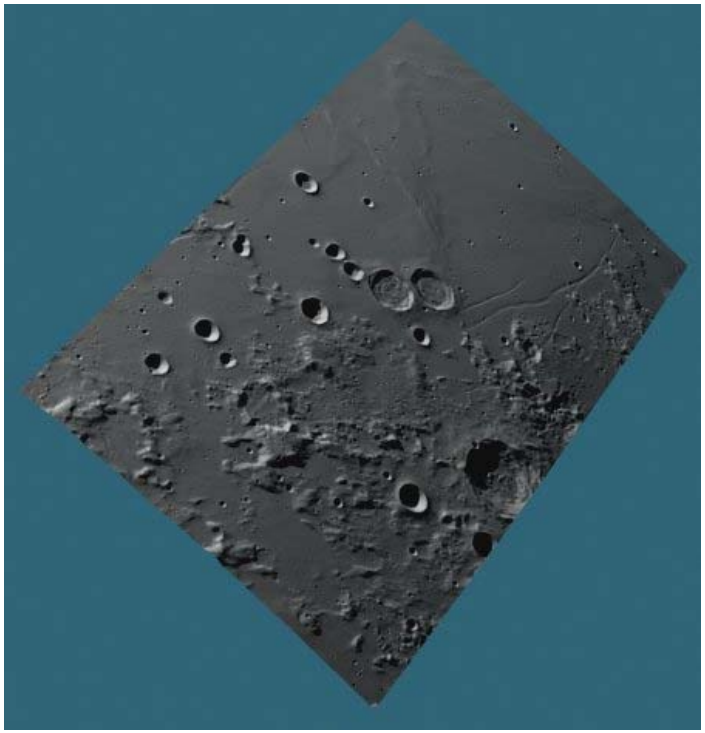


Tests
Characterization

- Characterization of the algorithm software-in-the-loop
- Question: How successful is the crater matching under different conditions?
  - varying camera elevation and azimuth
  - varying sun elevation and azimuth
- Processing of ≈ 130000 images
- DEM for rendering based on Kaguya data



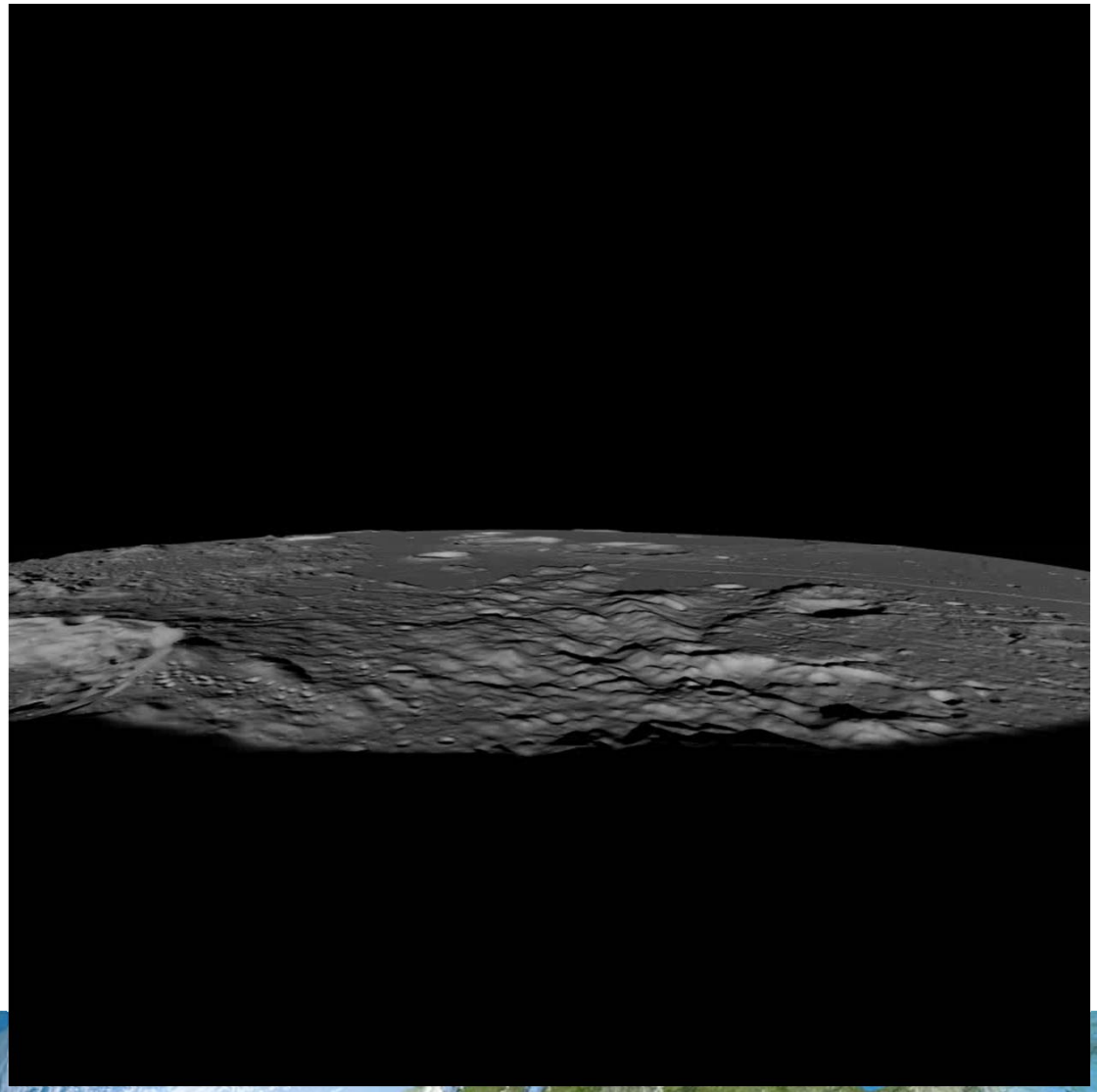
Variation of camera and sun in elevation and azimuth



DEM chosen for characterization

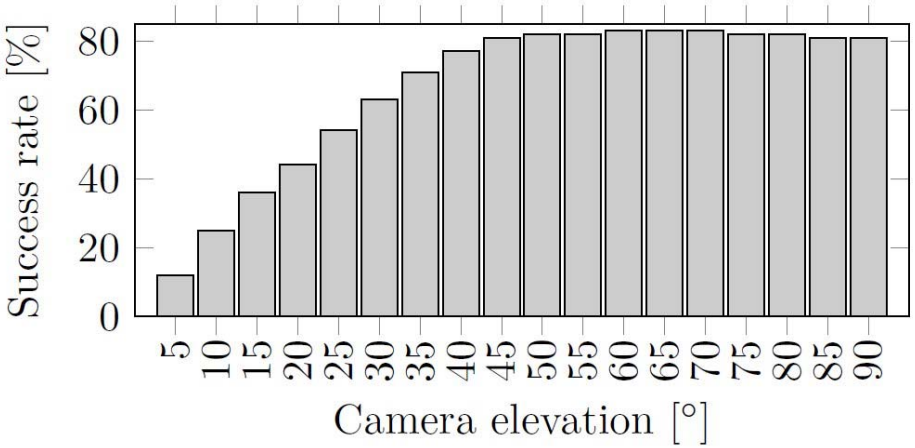
Tests
Characterization

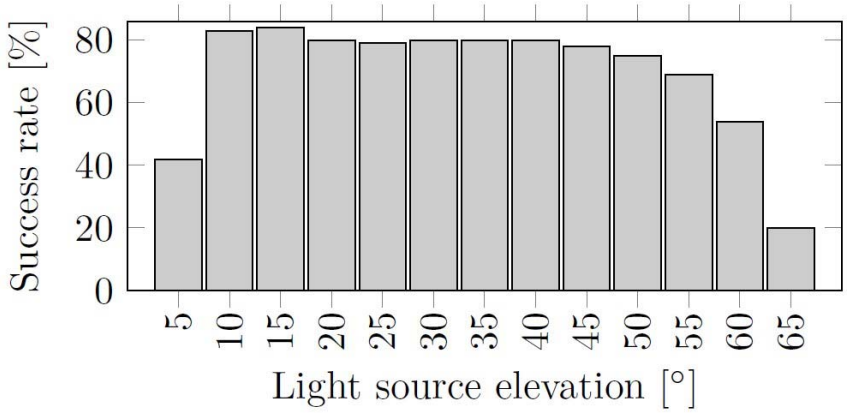
- Characterization images
  - 1 MPixel
  - FOV ≈ 66°



Test
Characterization results

- Result:
  - Crater navigation works over broad range of viewing and lighting conditions





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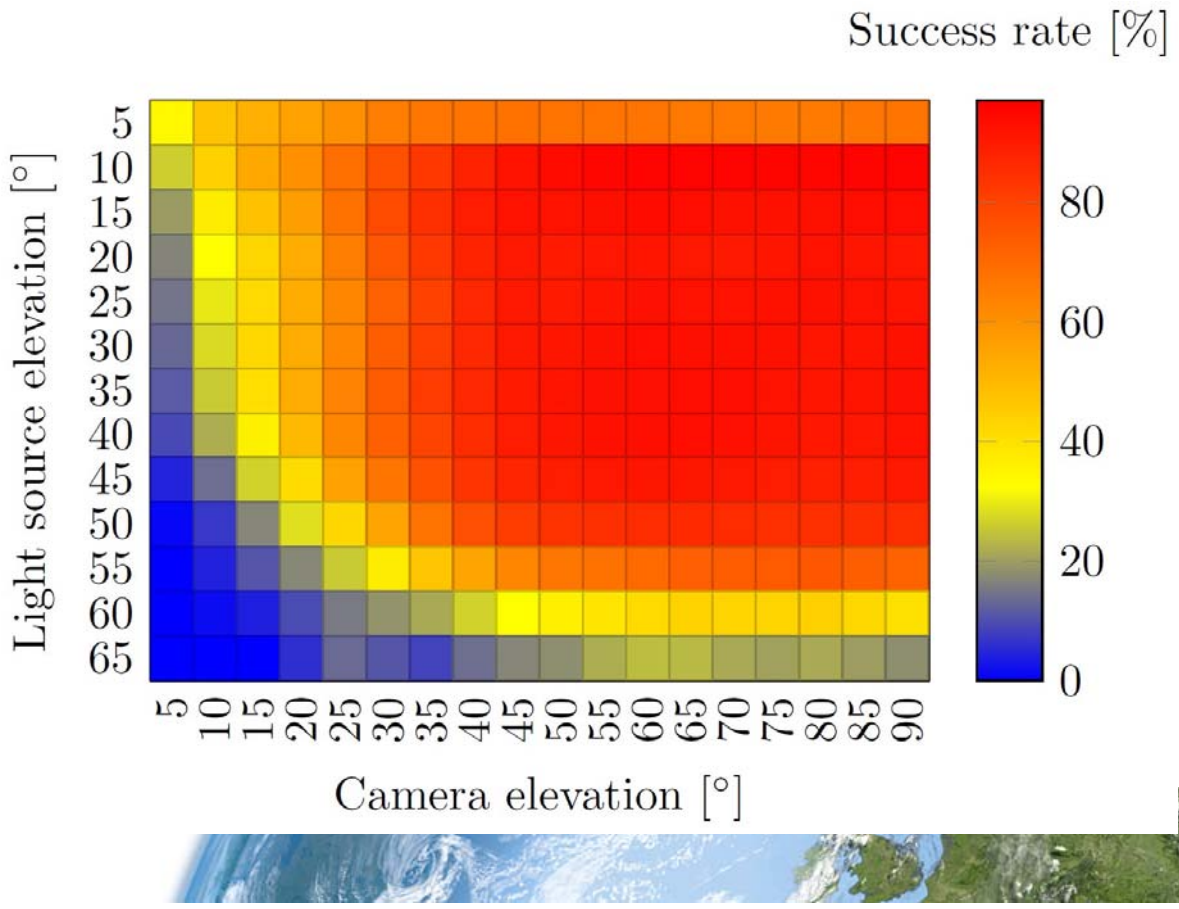
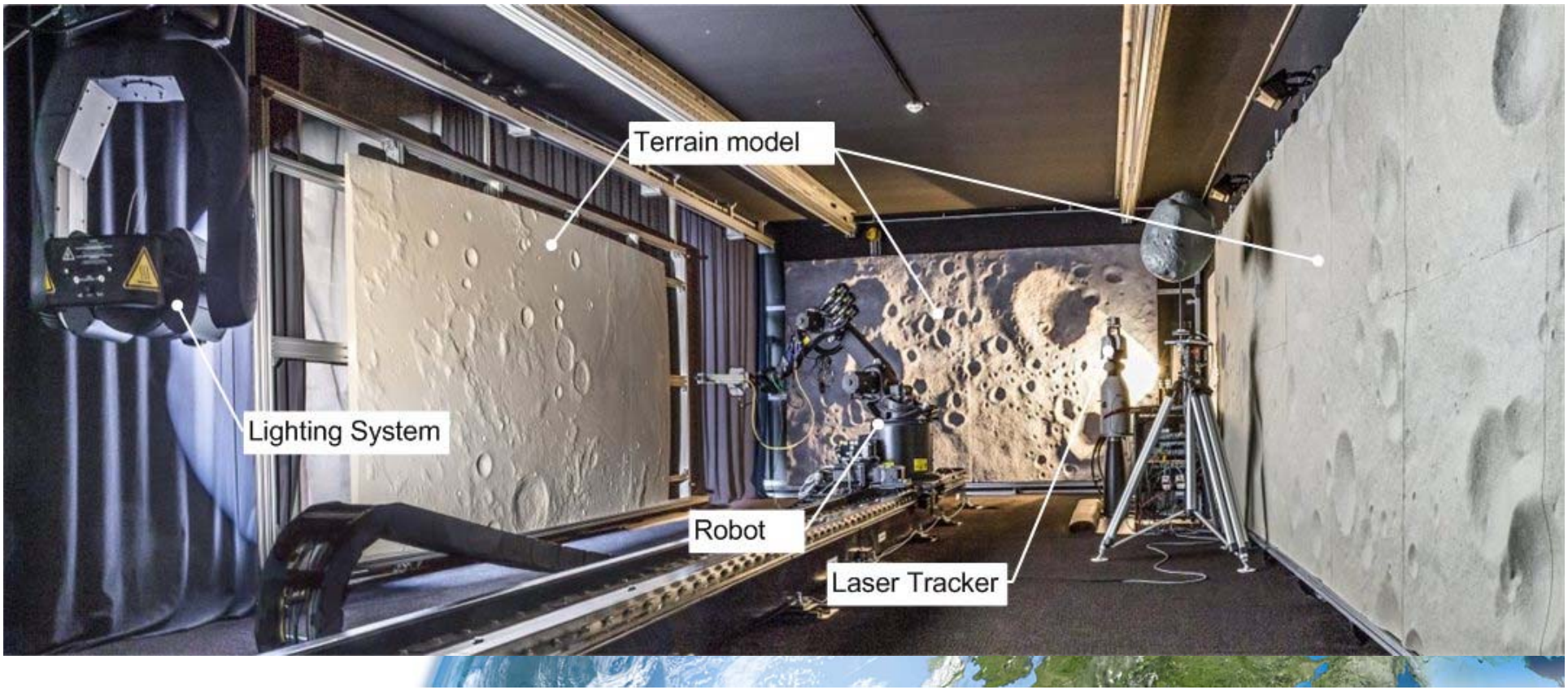


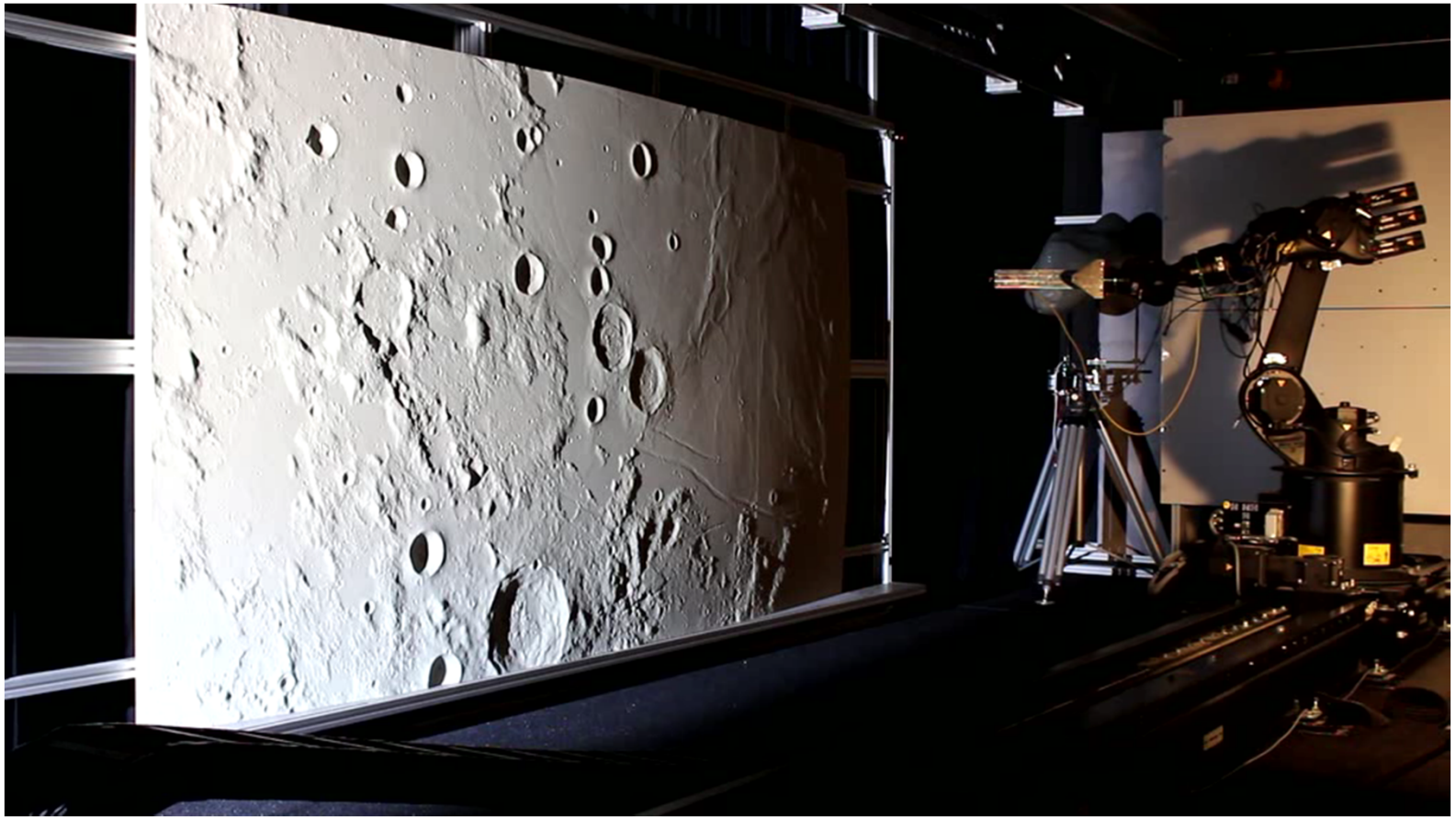
Test
Application test in TRON

- TRON provides environment for
  - developing algorithms
  - qualifying hardware up to TRL 6

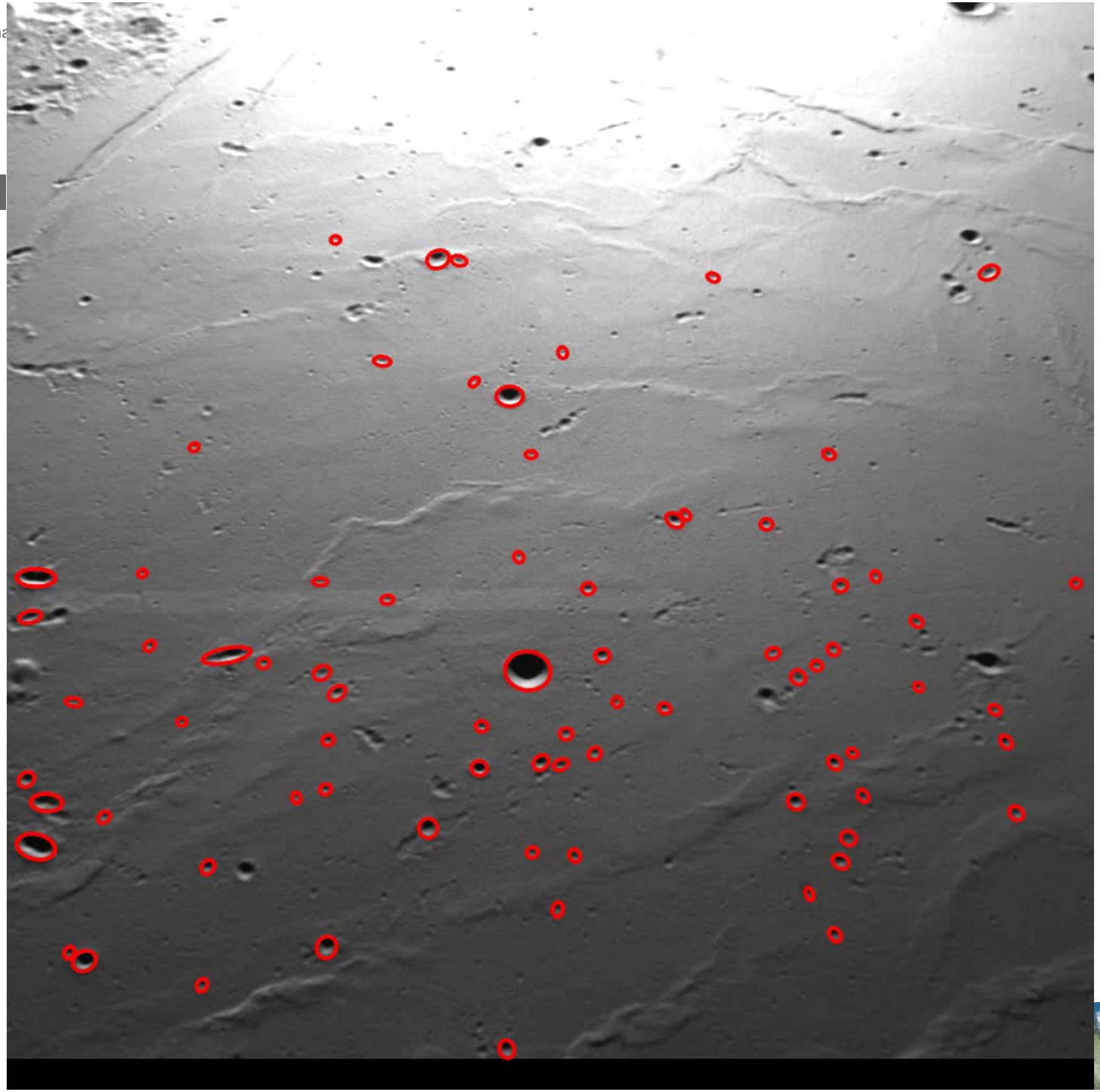


Test
Application test in TRON

- Test of navigation function in Descent orbit



Test
Appl



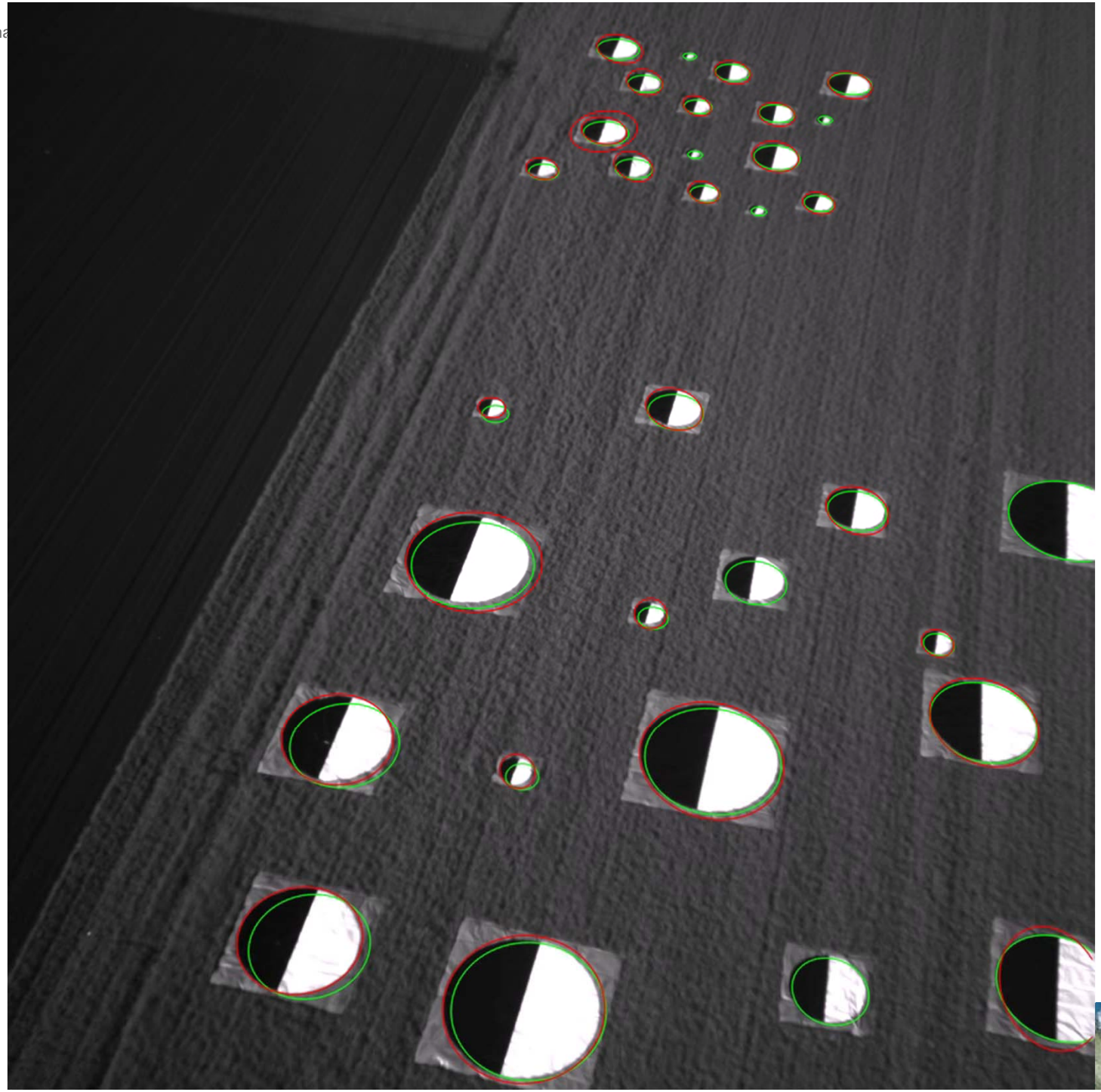
Test
Application test on helicopter

- Test of hybridization of IMU and Crater Navigation with real data
- Test setup
  - IMU and camera on helicopter
  - Planes as crater targets
  - Crater catalogue in GPS coordindates

Helicopter setup

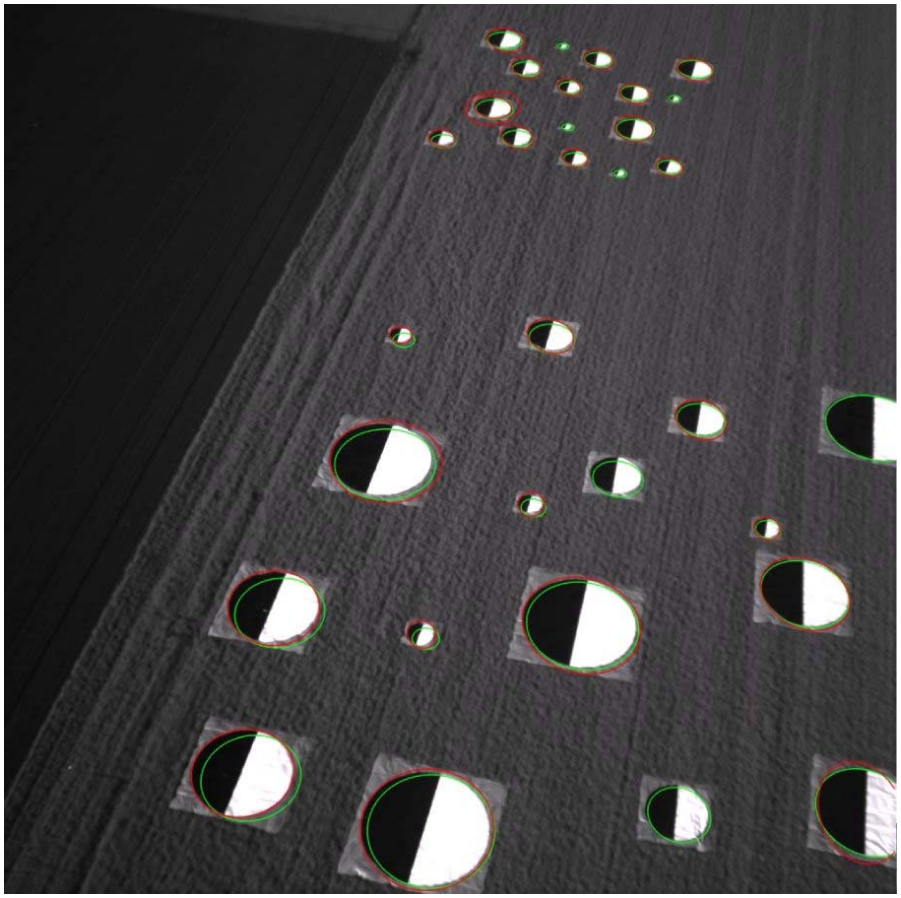
Zoom to camera sensor

Crater setup



Test
Application test on helicopter

- Hybridization of IMU and Crater Navigation works fine
- Also with real data



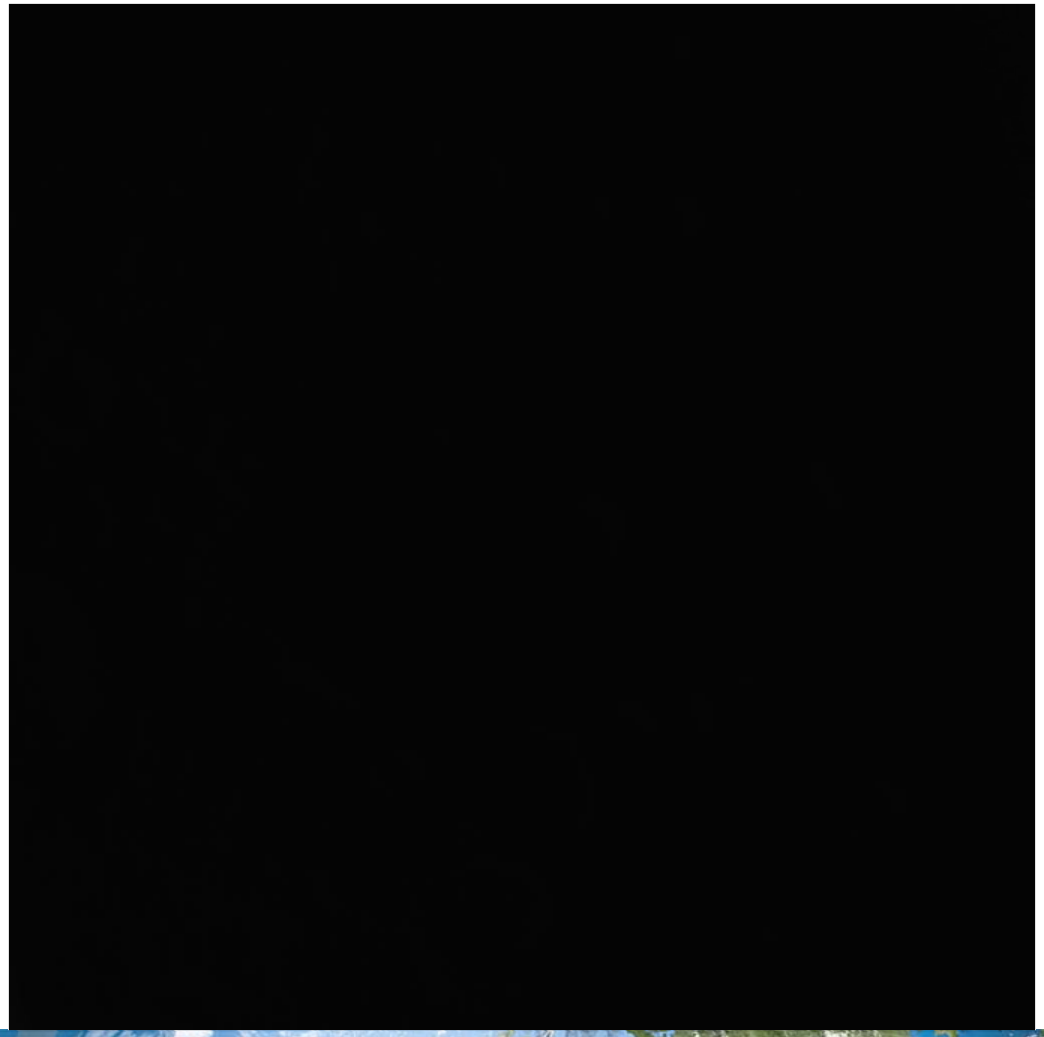
Conclusion

- Crater Navigation provides:
  - the capability of a global, real-time, lost-in-space, navigation solution
  - input to GNC system needed for precision landing
    - Identified craters (for predictor corrector)
    - lost-in-space position solution
- Robustness
  - no state knowledge needed
  - Broad range of viewing angles: 30° - Nadir (ca. 80% success)
  - Broad range of local sun elevation: 5° - 50° (ca. 80% success)

- Software can be applied on available space proven hardware
- Next step
  - Optimization of the code for FPGA

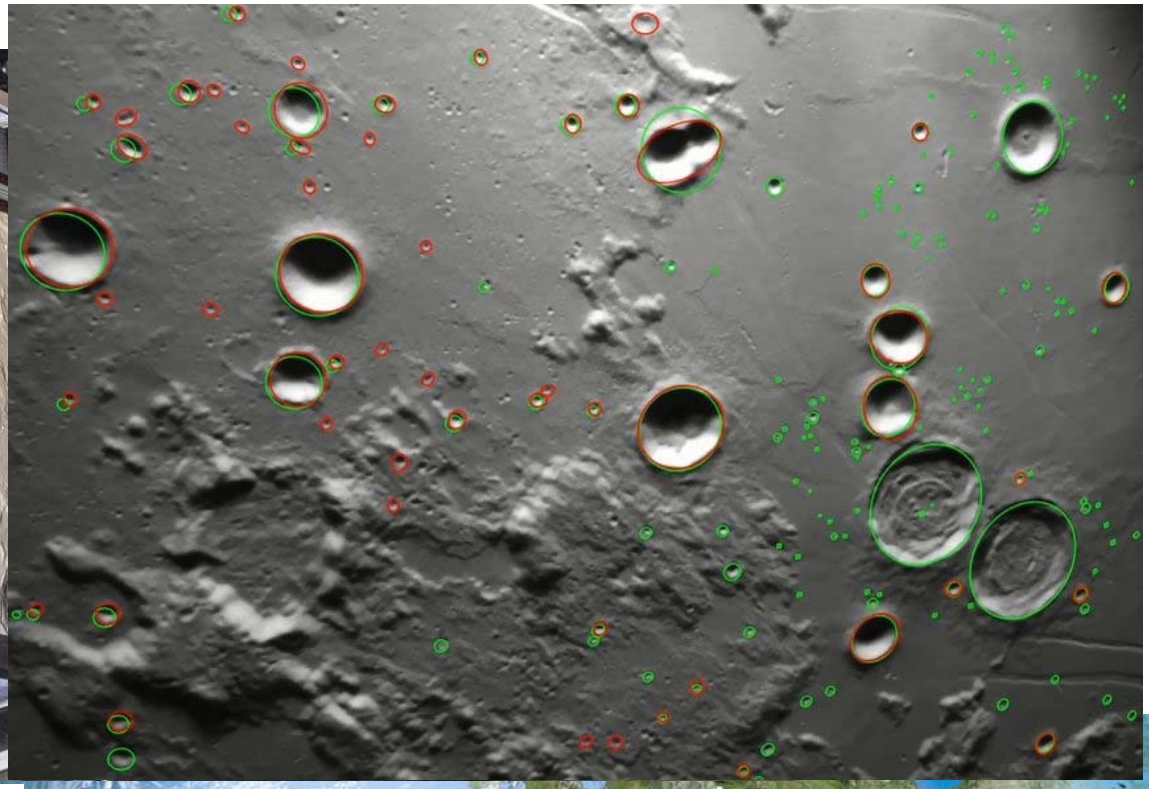
Backup

- Live demo backup



Introduction

- One of the goals of DLR is enhancing the capabilities of exploration missions
- A promising field is optical navigation
- DLR invested in test capabilities and algorithm development
- Successfully developed algorithm for autonomous, absolute positioning in lunar orbit



TRON – Testbed for Robotic Optical Navigation

Backup
Success criterion

- What is success?
  - craters detected in the image have been matched to database
  - projection of craters from catalogue into image