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Detector Validation of DLR Crater Navigation System for Autonomous Precise Lunar Landing

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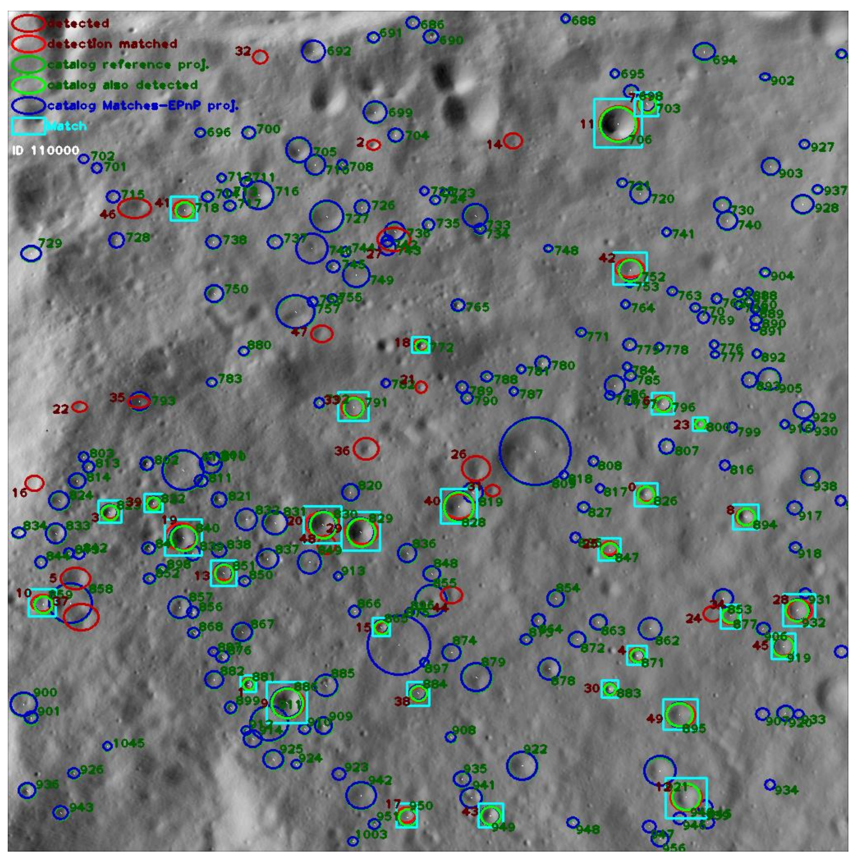
Introduction

DLR's **CNav** (Crater Navigation) is a terrain absolute navigation system that detects lunar craters in acquired images and matches them to an onboard database, allowing for accurate calculation of the lander's position and orientation, i.e., its pose, relative to the Moon-Centered-Moon-Fixed reference frame [1].



Sample Image of lunar surface on which CNav is applied. The image shows detected, catalog, and matched craters.

Goal

This work focuses on the V&V procedure applied to the **detector**, a CNav core function, which is also utilized independently for generating crater catalogs

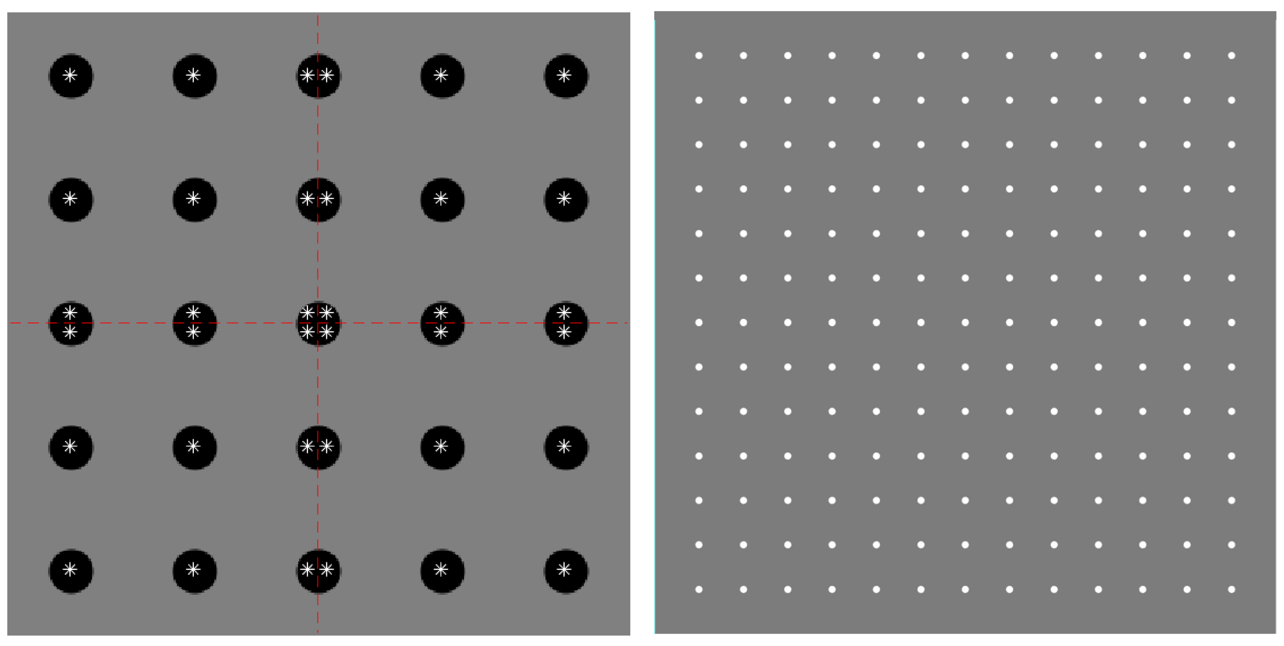
CNav Detector

The detector aims at extracting craters candidates from images. It works by recognizing for each crater its characteristic distribution of **contrast areas**, i.e., one darker and one lighter with respect to the surrounding [2,3].
Moreover, the detector supports **multi-core** processing by tiling images across cores.

Detector Verification

A large detector-level testing campaign, including **unit** and **system tests**, is conducted to verify the detector correct operational behavior.

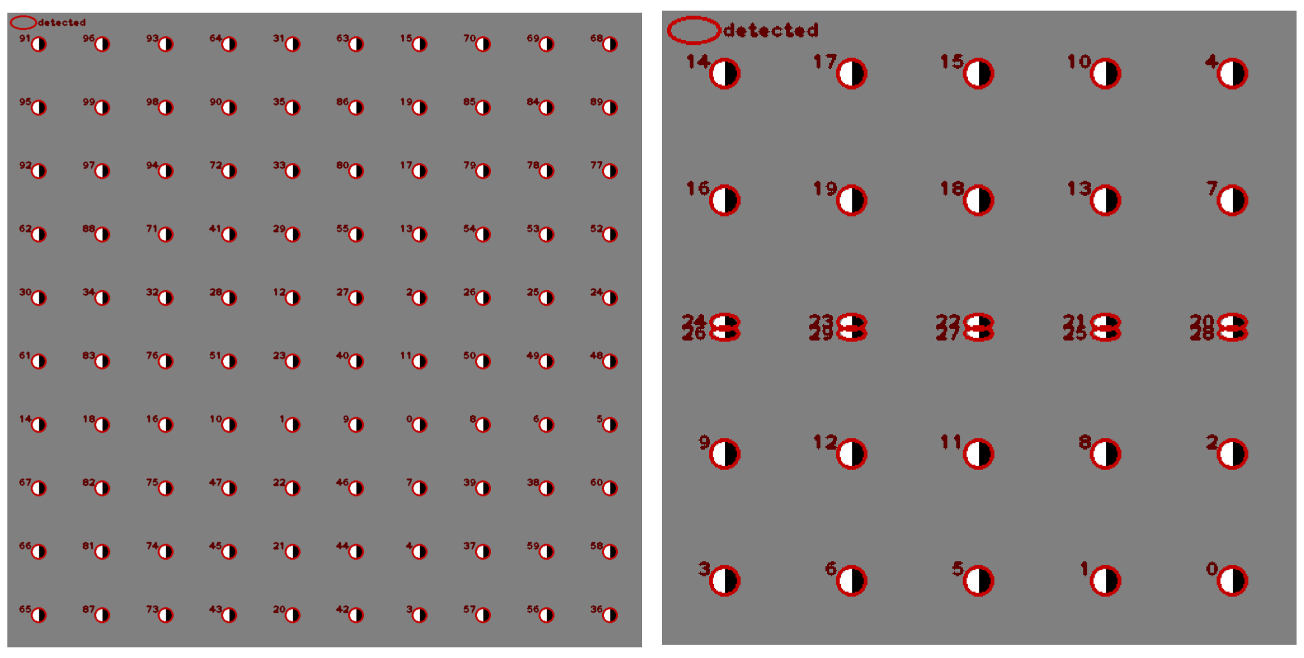
Unit tests assess the detection functionality of recognizing **bright** and **dark blobs**, focusing on edge cases such as: blobs located on tiling boundaries, detection limits for the smallest and largest possible blob sizes, and images with non-standard resolutions.



Left: Centroids of black blobs detected in an image divided into four tiles

Right: Smallest bright blobs eligible to be craters

System tests evaluate the detector ability to **match** bright and dark blobs and **fit an ellipse** on them. Multiple internal checks are performed to clean up candidates, and the system tests aim to verify the correctness of these procedures. Currently, the implemented system tests specifically focus on the detector behavior during the image tiling process.

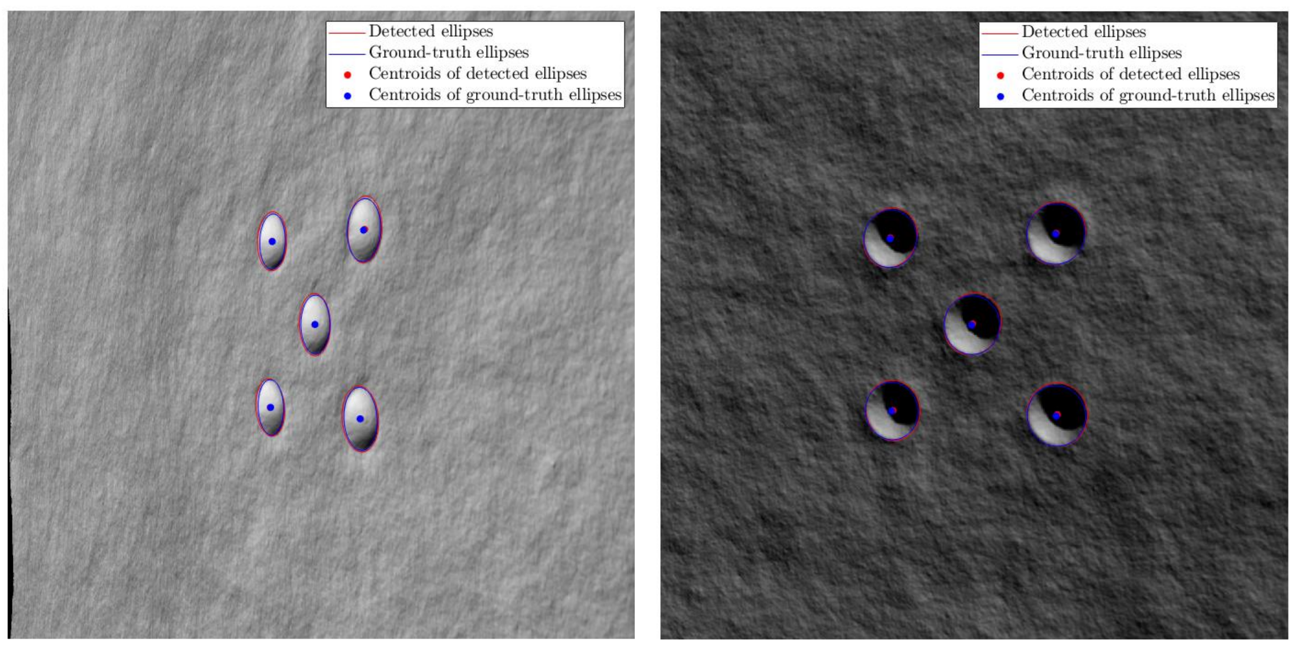


Left: Detected ellipses of ideal craters into a no-tiled image

Right: Detected ellipses of ideal craters in an image divided into four tiles

Detector Validation

The purpose of this validation is to assess the detector performance under relevant environmental conditions. Images are generated using PANGU [4] by varying **viewing direction, Sun position,** and **crater radius**. Each image contains five craters, which is the minimum number for detection. The main objective is to quantify how **accurately** the detector estimates the crater centroids, by comparing them to ground truth data across different illumination and observation scenarios.



Left: 35 deg of Sun elevation angle

Right: 15 deg of Sun elevation angle

Final Discussion and Future Works

The core functionalities of CNav detector have undergone extensive V&V and are performing as **expected** in most test scenarios.
Importantly, we have identified hidden **edge conditions** that highlight the need for dedicated edge-case testing beyond lunar surface simulations.
Moreover, the analysis highlights the need to extend testing to **realistic scenarios**, ensuring that detection accuracy remains robust under real-world conditions.

References

(1) Maass, Bolko, et al. "*Crater navigation system for autonomous precision landing on the moon.*" Journal of Guidance, Control, and Dynamics 43.8 (2020): 1414-1431.
(2) Maass, Bolko, et al. "*An edge-free, scale-, pose-and illumination-invariant approach to crater detection for spacecraft navigation.*" 2011 7th International Symposium on Image and Signal Processing and Analysis (ISPA). IEEE, 2011.
(3) Martin, Iain, et al. "*Planetary surface image generation for testing future space missions with pangu.*" 2nd RPI Space Imaging Workshop. Sensing, Estimation, and Automation Laboratory, 2019.

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