The PERIGEO project: Inertial and Imaging sensors Processing, Integration and Validation on UAV platforms for Space Navigation

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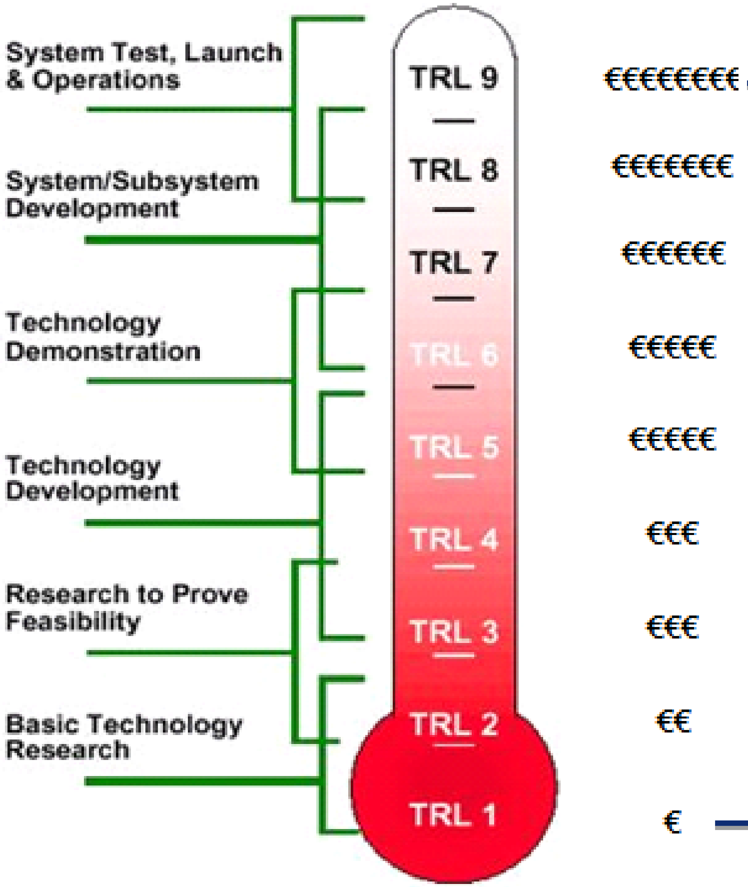
Summary

1. PERIGEO project
   - Goals and Scenarios
   - Validation and testing: from simulation to UAVs
2. Inertial- and Imaging-based Navigation
   - Relative navigation based on features extraction and matching
   - Absolute navigation based on craters detection and matching
3. Results

Why PERIGEO?


System Test, Launch & Operations

System/Subsystem Development

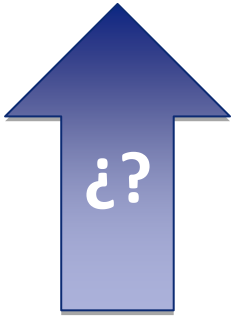
Technology Demonstration

Technology Development

Research to Prove Feasibility

Basic Technology Research

TRL 9	€€€€€€€€€
TRL 8	€€€€€€€€
TRL 7	€€€€€€
TRL 6	€€€€€
TRL 5	€€€€€
TRL 4	€€€
TRL 3	€€€
TRL 2	€€
TRL 1	€



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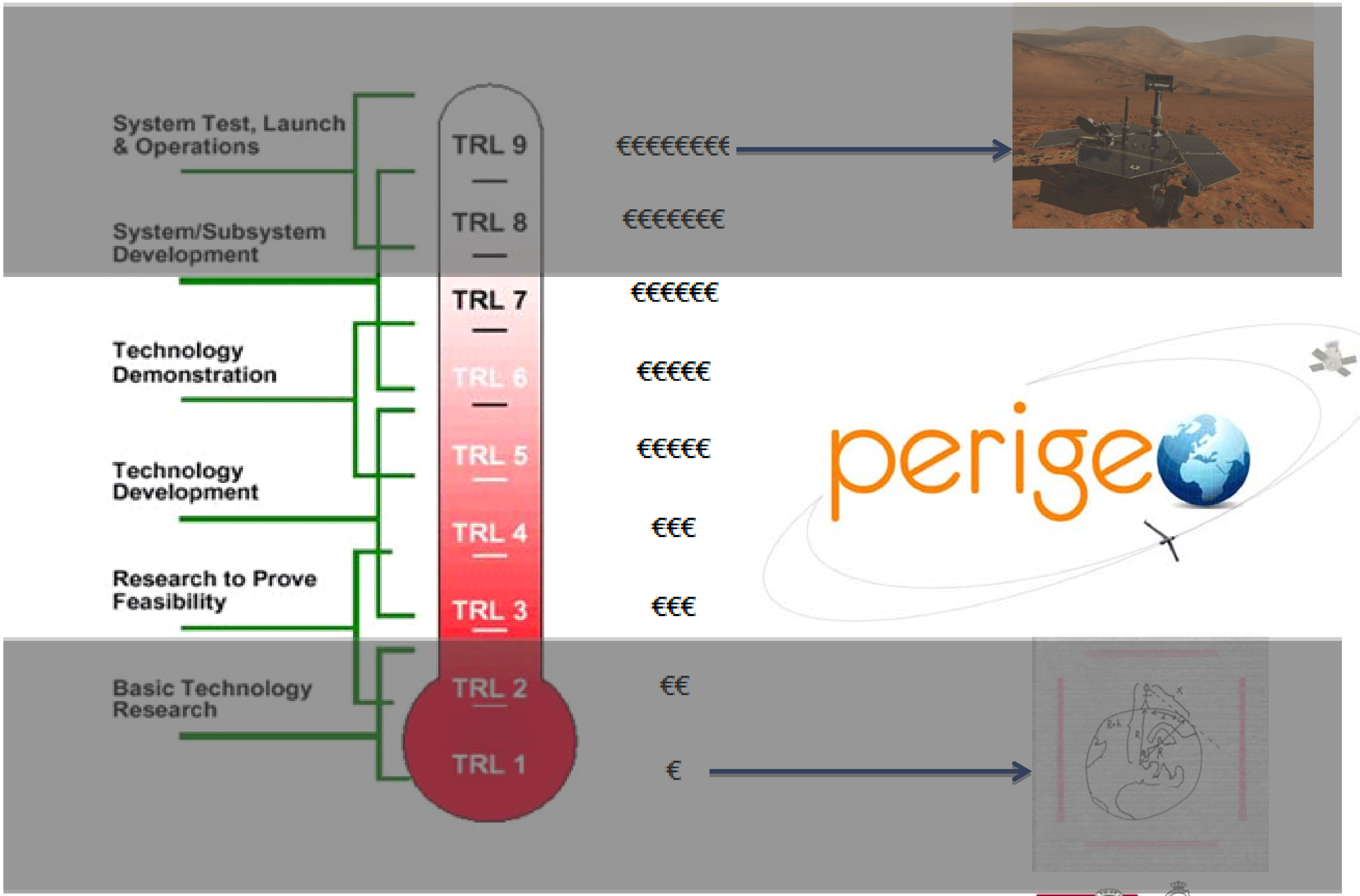

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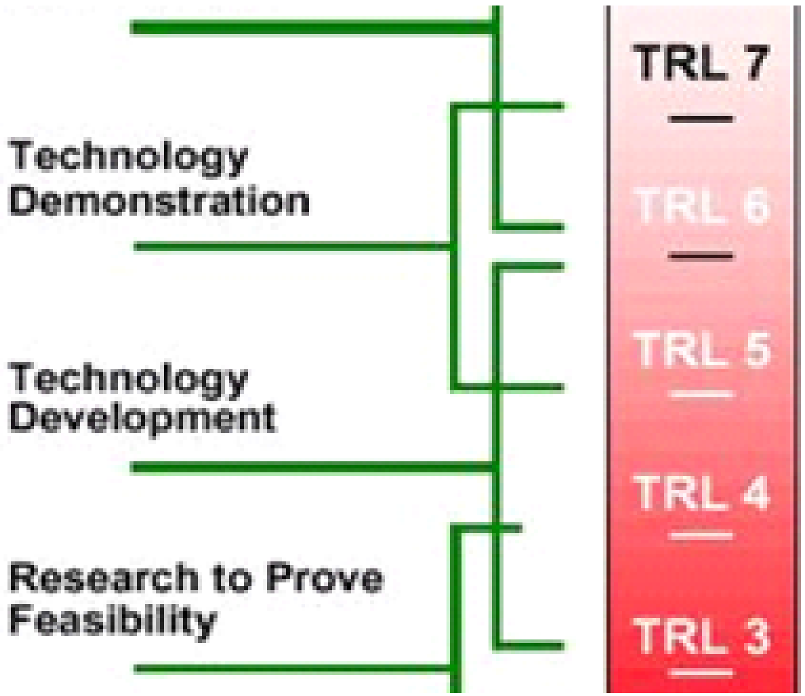
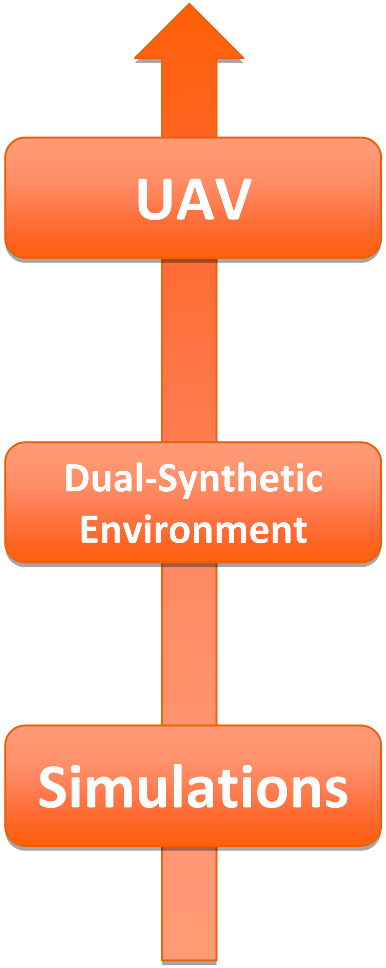




UAV

Dual-Synthetic Environment

Simulations

Scenarios, Missions and Technologies

Scenarios and Missions:

EARTH OBSERVATION

Satellites

ATMOSPHERIC FLIGHT

Titan and Earth (re-entry)

INTERPLANETARY

NEO characterization

ENTRY, DESCENDING AND LANDING

Mars, Moon and NEO

Technologies:

OPTIMAL DESIGN

ADVANCED CONTROL

AUTONOMOUS NAVIGATION

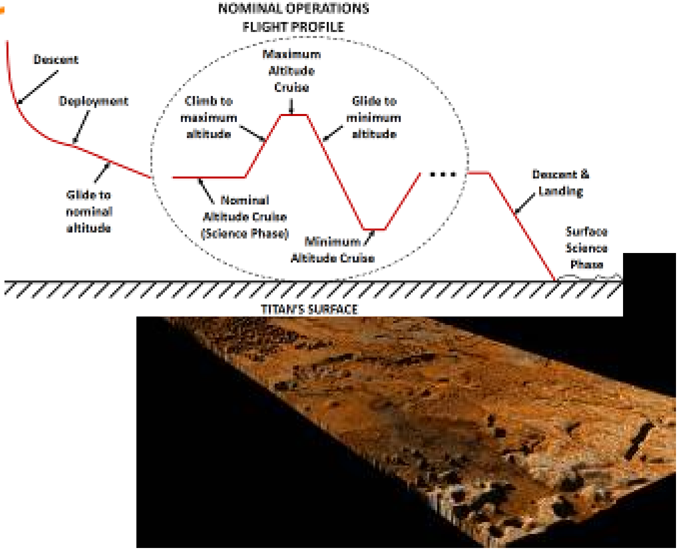
RESEARCH AND DESIGN INTEGRATED PROCESS

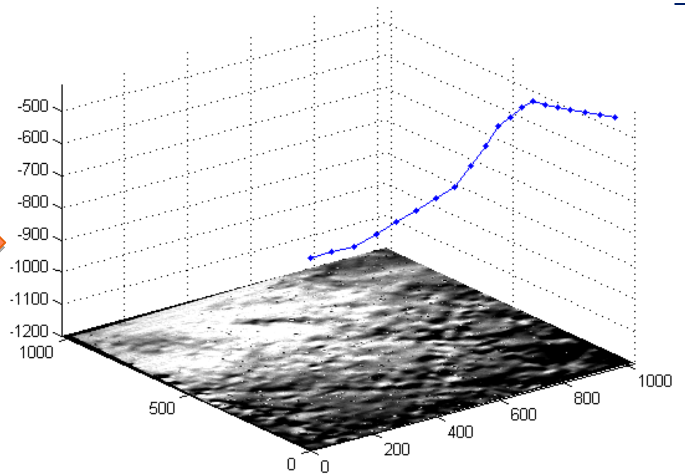
Atmospheric Flight on Titan

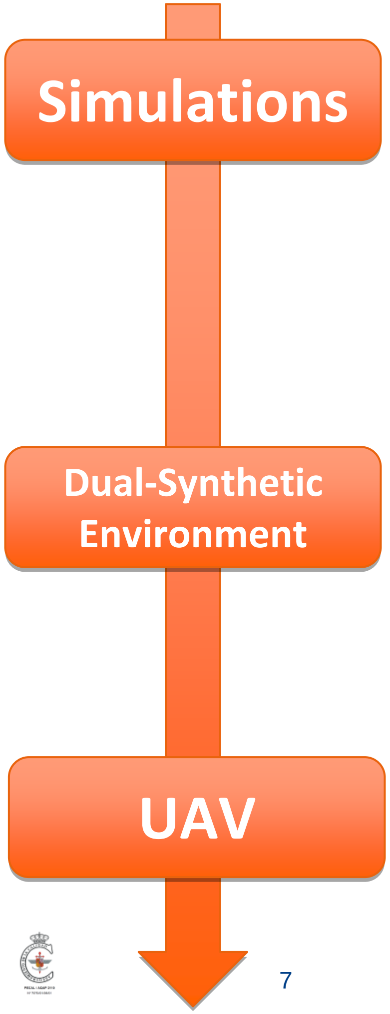
SPACE MISSION

PERIGEO

Tests are representative and scalable

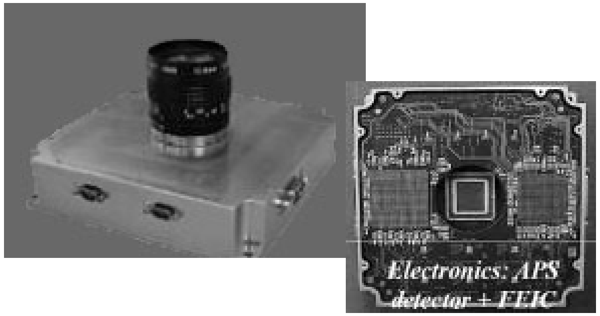


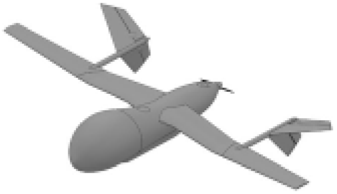


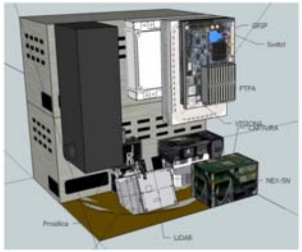

Simulations

Dual-Synthetic Environment

UAV







Key requirements

Reqs Sensors

Flight Platform Reqs

Mission Reqs

Entorno Espacial

Camera: FOV, resolution, fps, pixel-size, etc.

Trayectory: manoeuvre, payload, consumo, profile, etc.

Environment: morphological characteristics, illumination, etc.

Technology Key requirements

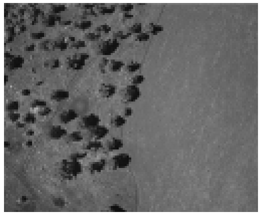
Pixel-size

Profile

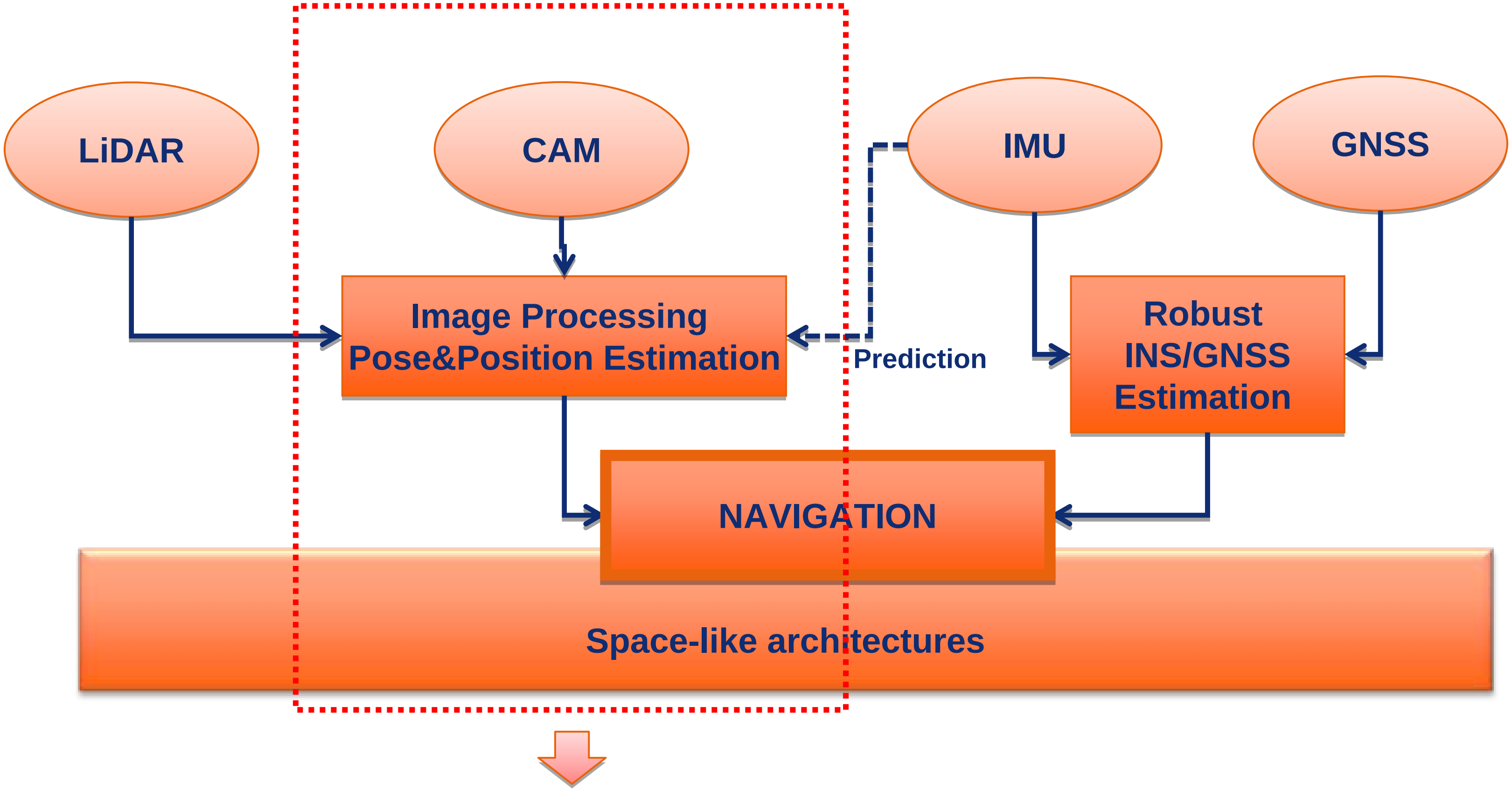
Characteristics

ESD

Entorno Terrestre



Technology: relative and absolute navigation



LiDAR

CAM

IMU

GNSS

Image Processing
Pose&Position Estimation

Prediction

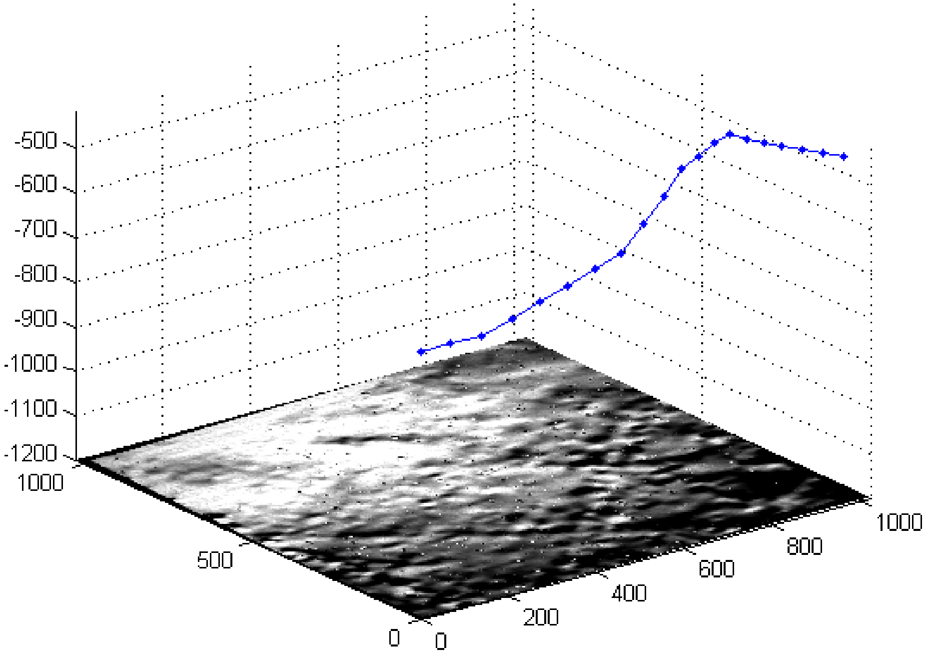
Robust
INS/GNSS
Estimation

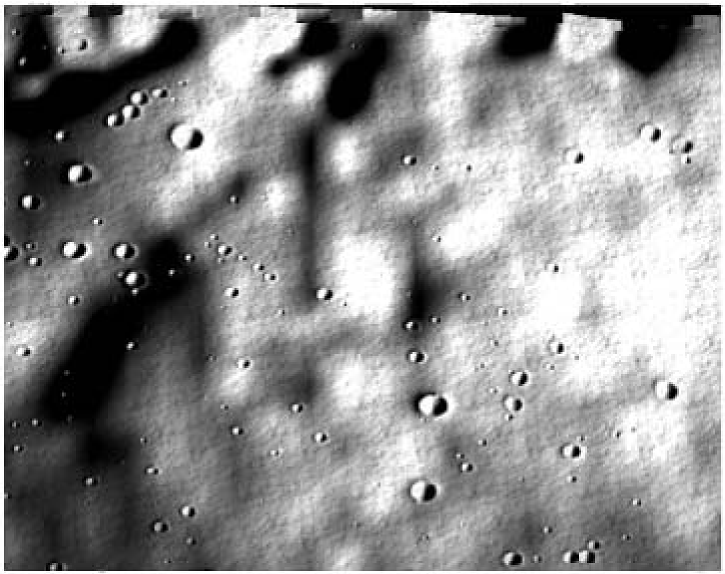
NAVIGATION

Space-like architectures

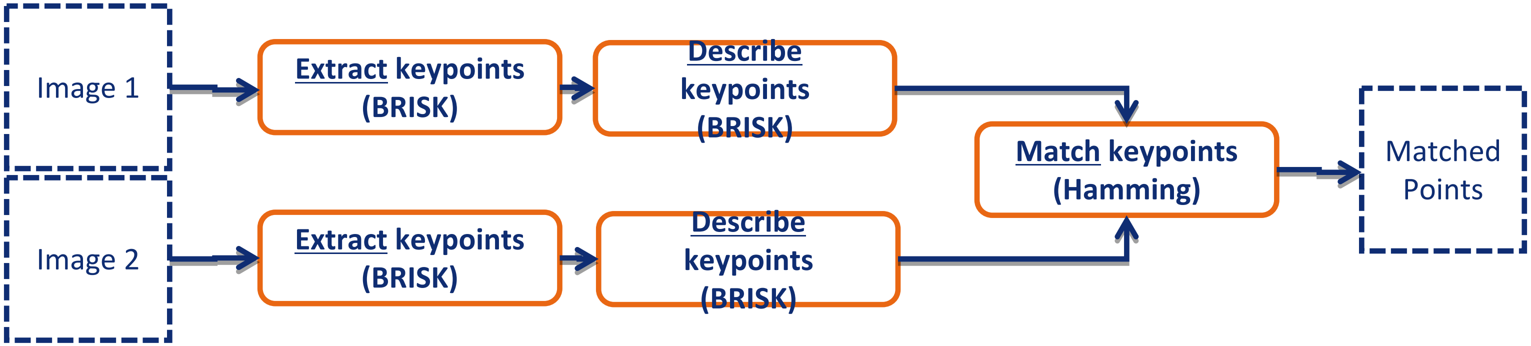
Optical Absolute and Relative Navigation based on Camera Images

Trajectory Example





Vision-based Relative Navigation

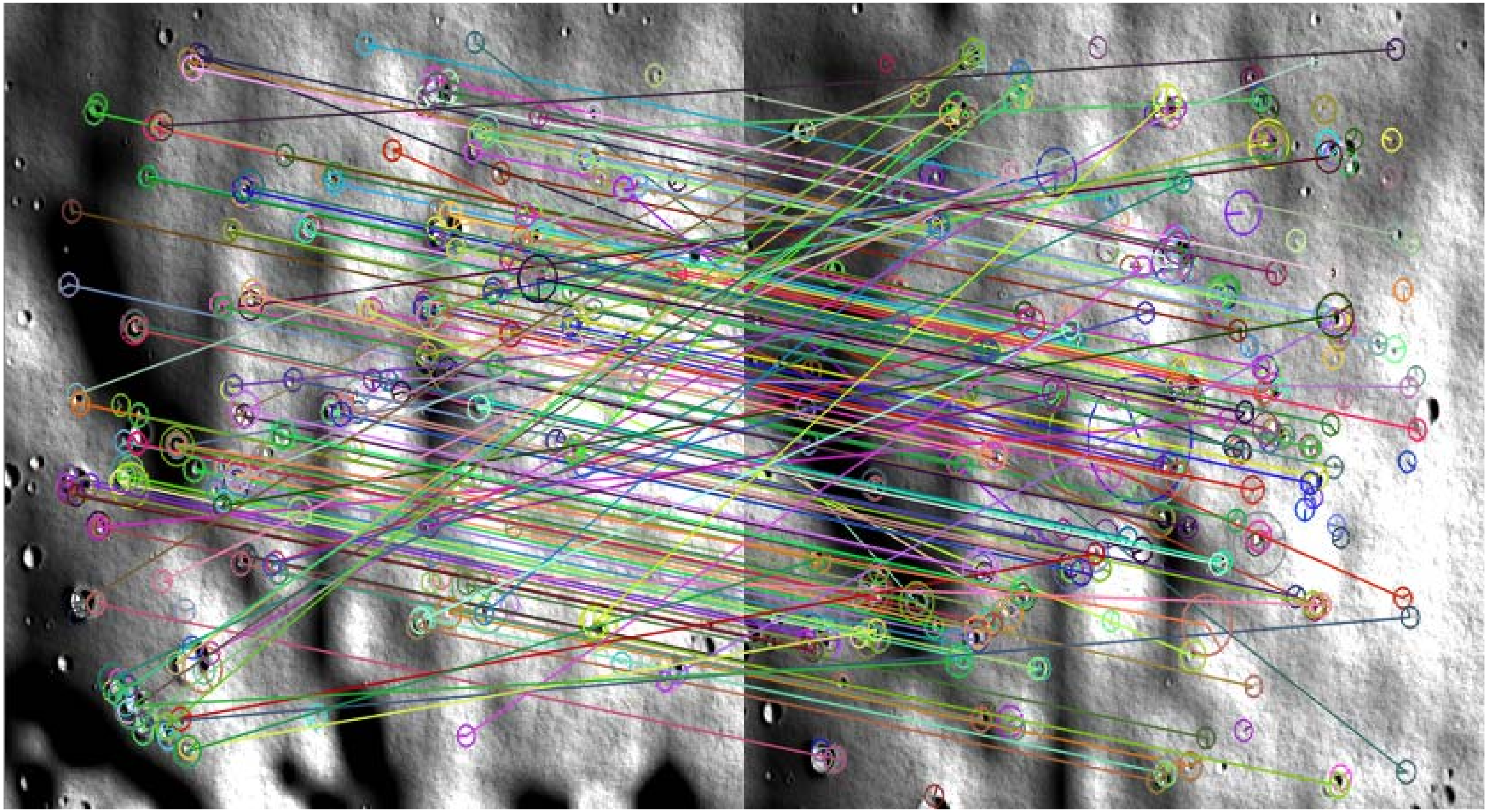


- Point extraction and matching
  - BRISK (fast extraction; binary descriptor = fast matching)
  - 30% inliers nominally in space images
    - Robustness is mandatory!

- Parallax-based outlier removal
  - propagate orientation (naive model; IMU; …)
  - reject pairs with large parallax

- Estimate $t = (t_x, t_y, t_z)$ the translation vector (up to scale), and $\Delta\Omega = (\Delta\omega, \Delta\phi, \Delta\kappa)$, the relative attitude between two images using the ‘coplanarity’ condition in a standard least-squares estimation approach.

Mixed inliers/outliers

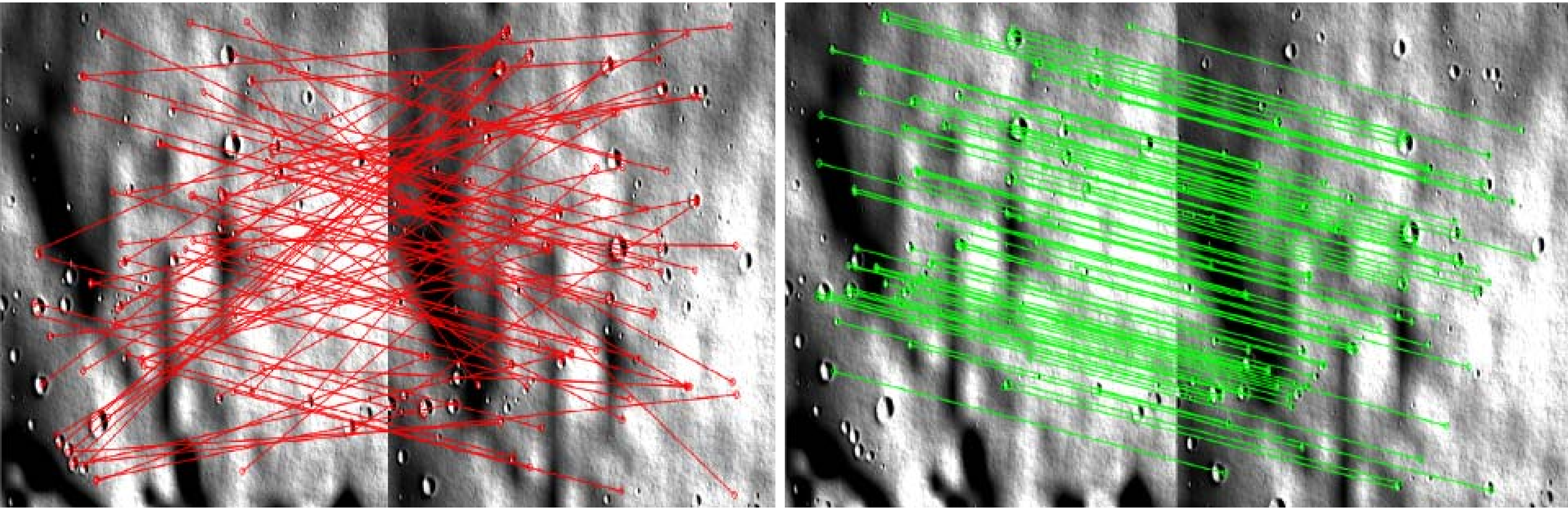


BRISK operator: 144 ‘correct’ matchings over 386 (37%) [correct = parallax < 0.5 m]

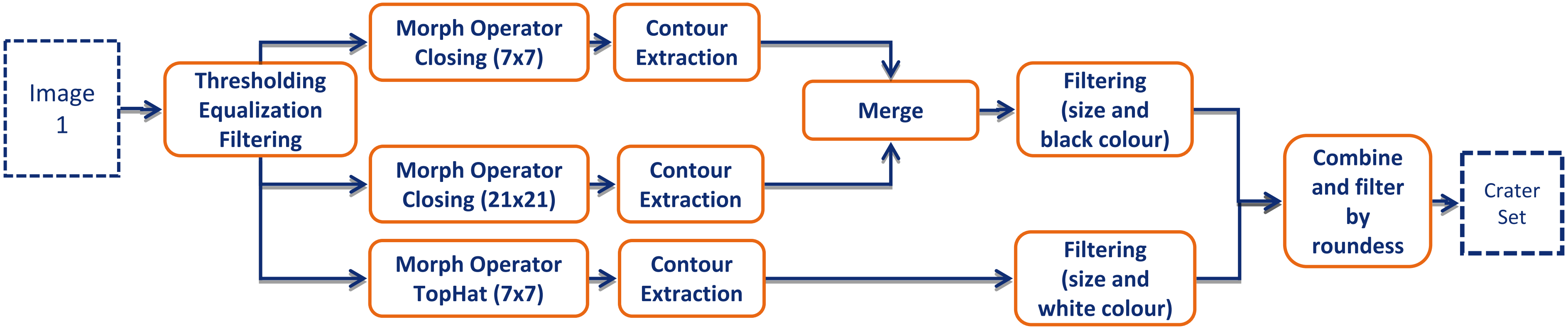
Inlier/outlier discrimination

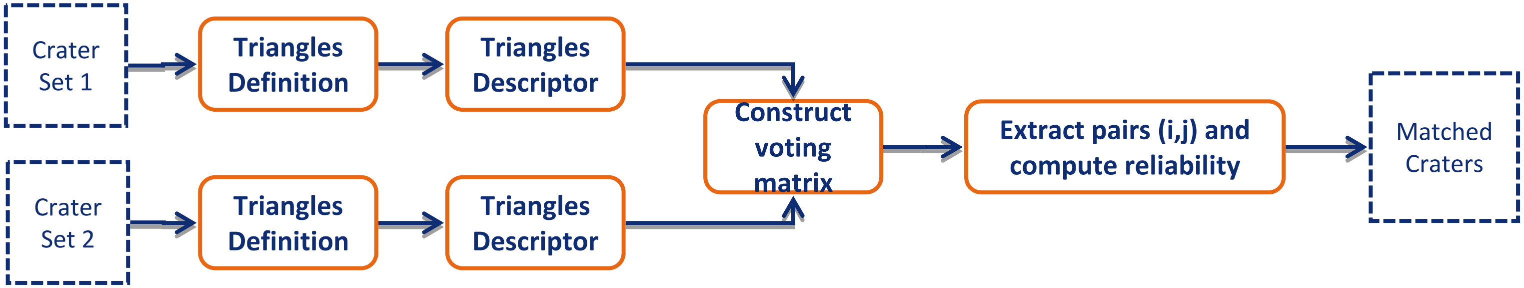
Using orientation prediction and parallax computation, we distinguish inliers and outliers.

Still some wrong matches escape → projecting rays intersect 'between camera and terrain'



Vision-based Absolute Navigation





- Crater extraction:
  - Image processing (morphological operators, thresholding)
    - → contour extraction

- Crater description and matching:
  - normalized distances and areas of crater groups
  - matching to geo-referenced imagery
    - 2D-3D crater centroid correspondences

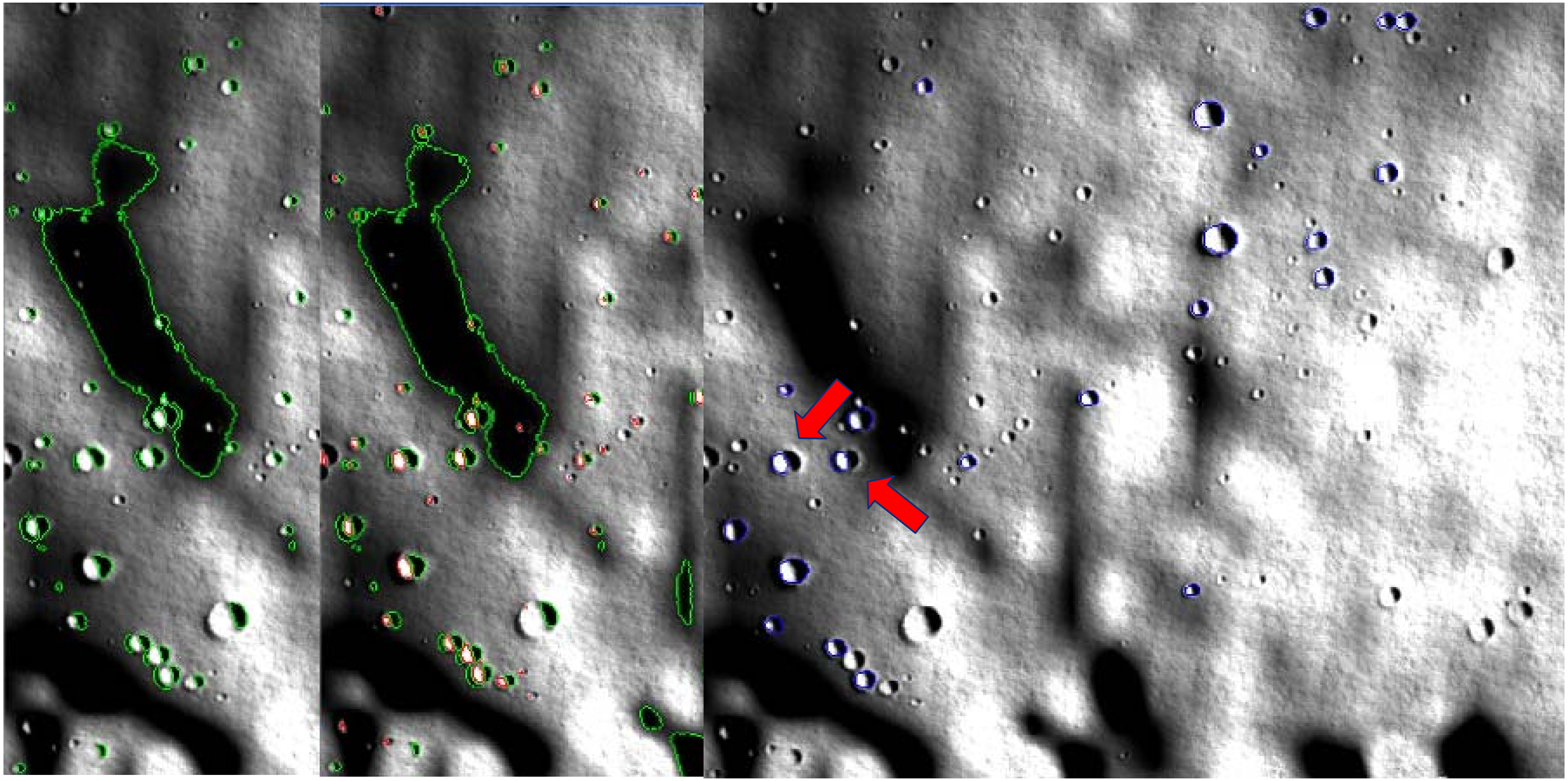
Estimate (p, Ω) the camera exterior orientation using the ‘colinearity’ condition.

Illumination-based incremental contour extraction (45º Sun elevation)

Results: **- 23 detections over more than 50 craters**

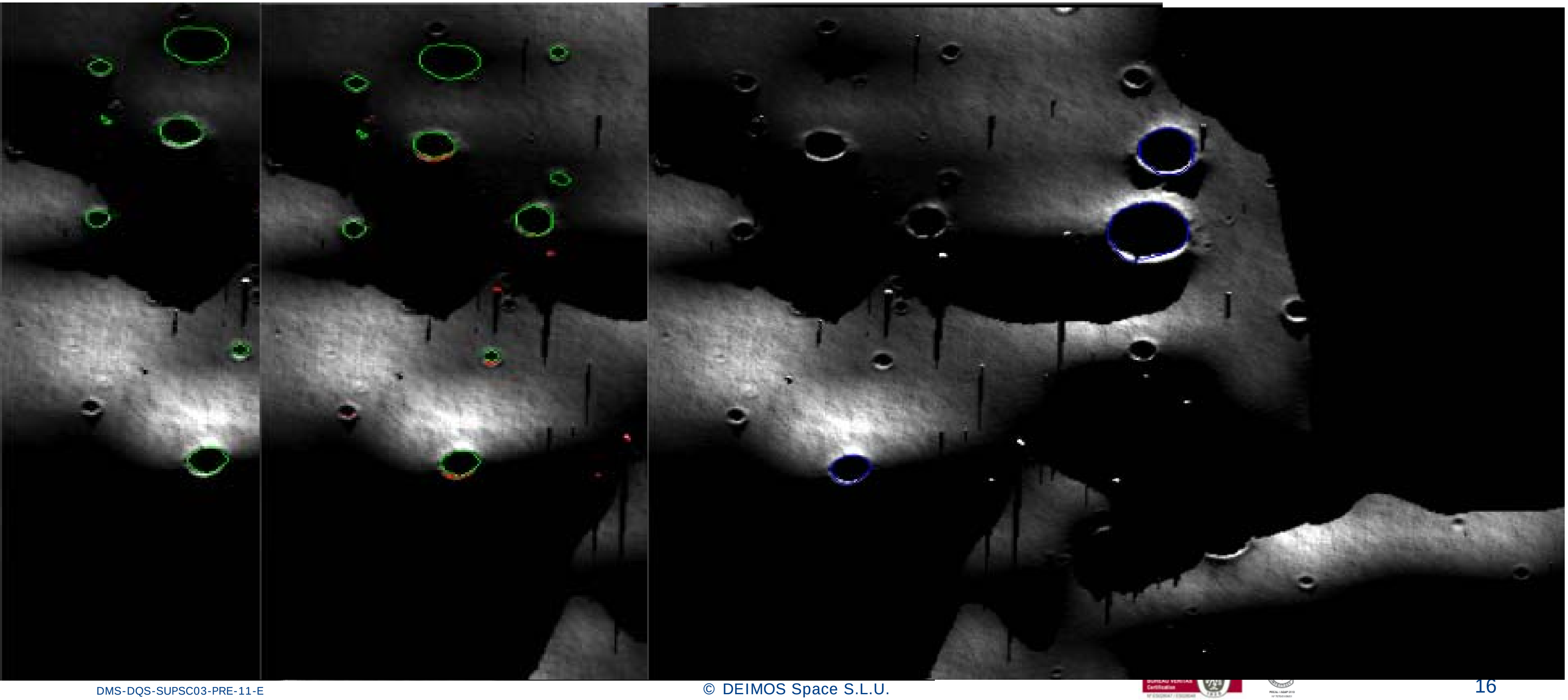
- 2 miss-associations (black/white areas switched)

- towards illumination independency (next slide)



Illumination-based incremental contour extraction (<1º Sun elevation)

Results: - 3 detections over around 15 craters
- Illuminated areas (white) areas are poor
  → algorithm tuning is key



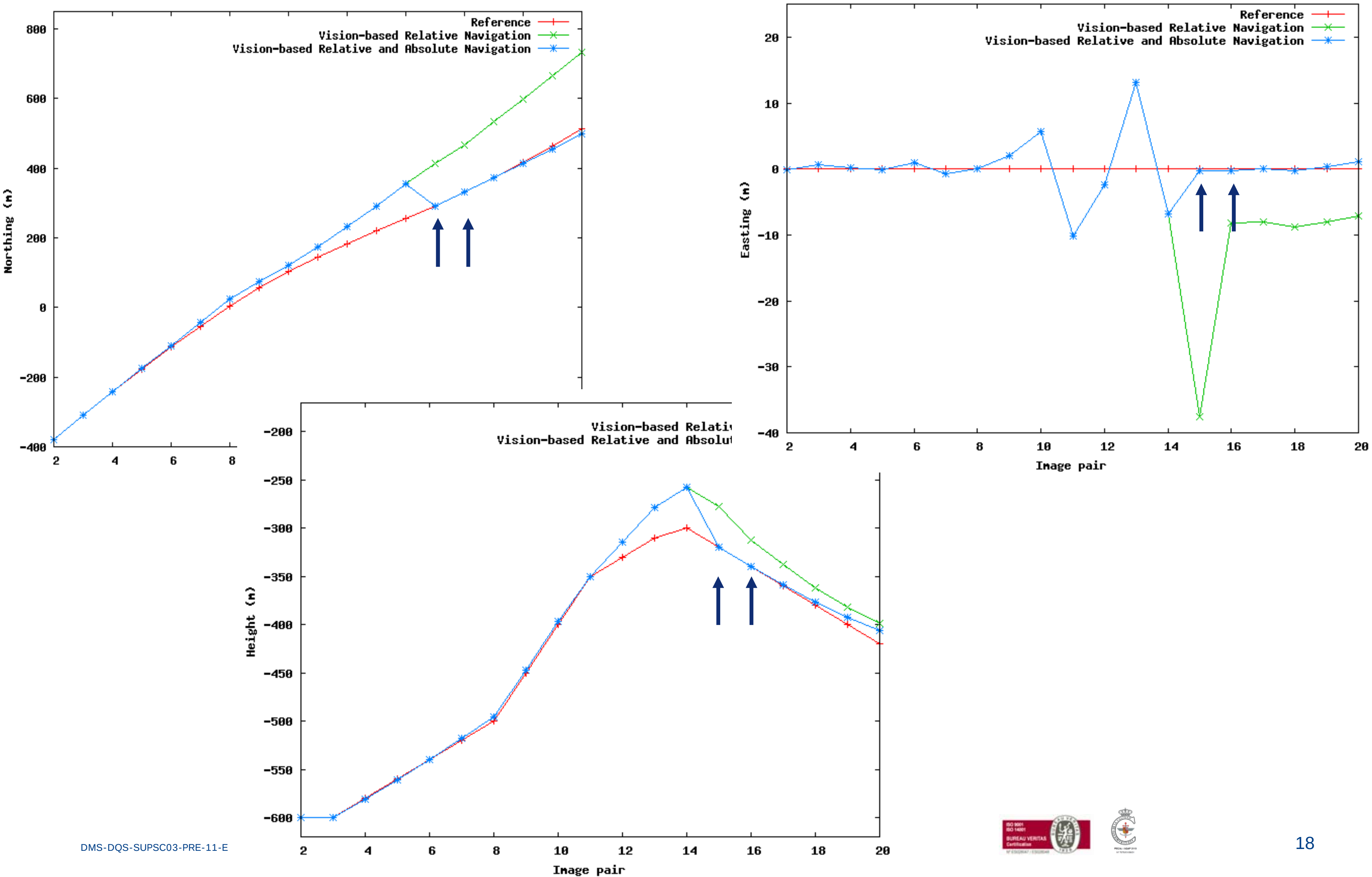
Preliminary results with Simulated Images

Synthetic trajectory
→forward motion towards North, ‘descend-ascend’, roll & heading turns (Titan’s case)
→45º Sun elevation
→PANGU simulator (simulation of camera and digital elevation models)
  → see .fig and pics

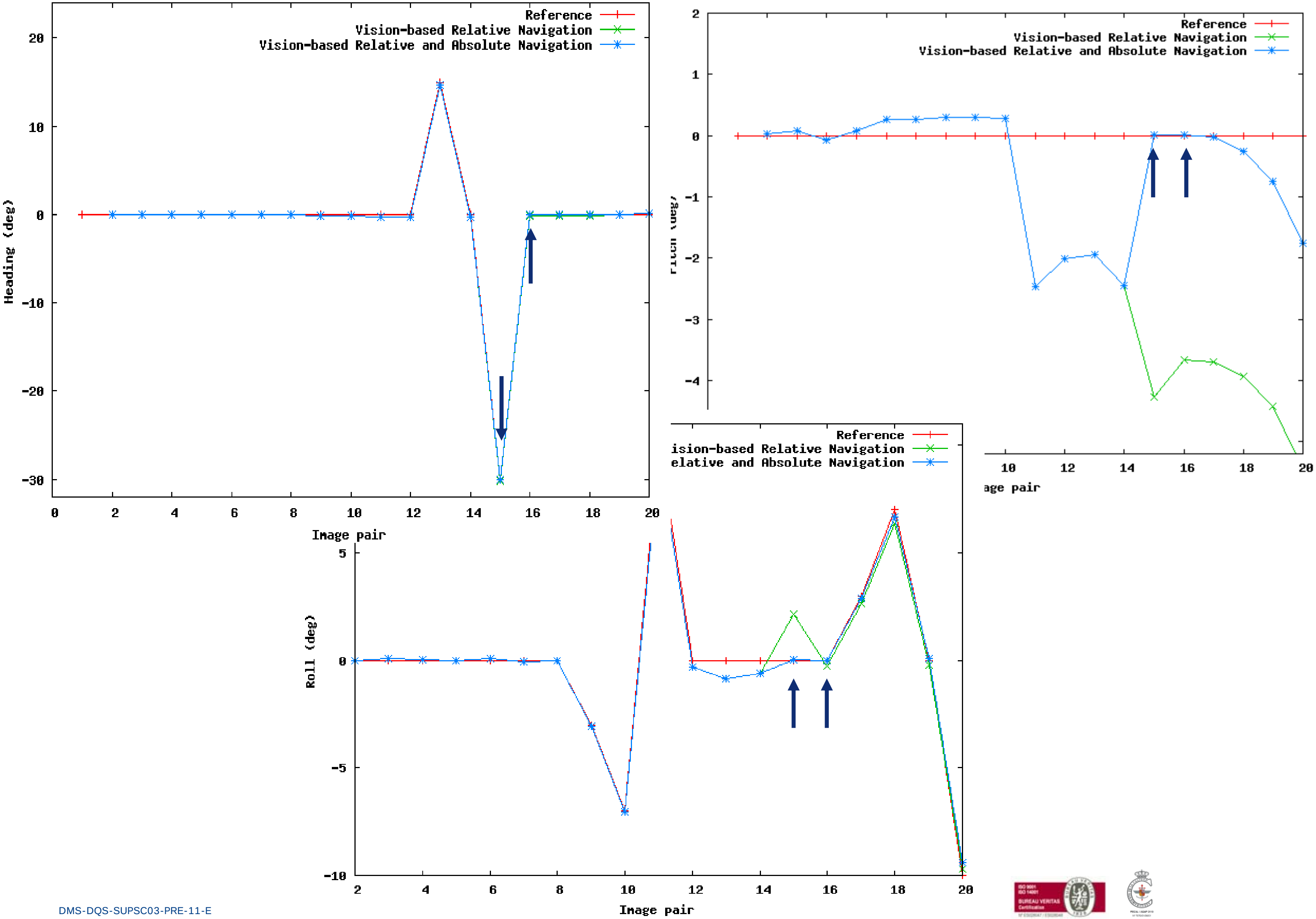
For the 19 image pairs,
→ Points extracted and matched using BRISK
→ All outliers removed (equivalent to using a perfect propagation model, e.g. perfect IMU)

→We compare camera-only {relative} vs {relative/absolute} navigation
  → In images 15 and 16, absolute navigation was performed by extracting 5 craters and matching those to geo-referenced imagery.

VISION-BASED RELATIVE NAVIGATION: POSITION ESTIMATION RESULTS

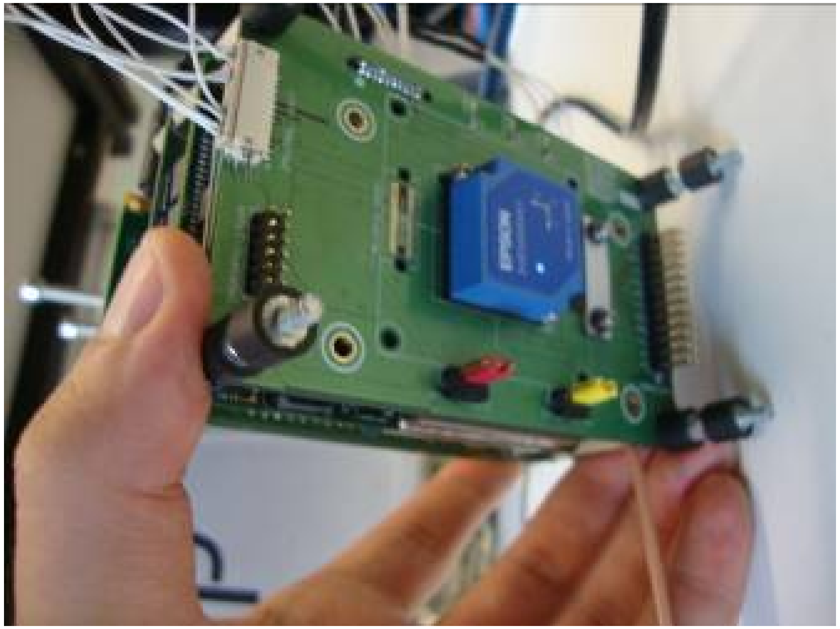


VISION-BASED RELATIVE NAVIGATION: ATTITUDE ESTIMATION RESULTS



REPRESENTATIVE ENVIRONMENT: FLYING ON THE UAV

Subsystem or sensors	Functionalities
GRIP	In-house multi-frequency GNSS receiver, featuring Galileo’s AltBOC signal reception
VISIONA	Camera- and LiDAR-based navigation system, and input provider for HDA tasks
CAPTURA	Miniaturized INS/GNSS acquisition system and time-reference server
Fault-tolerant Processing Architecture	LEON3-based processing architecture including INS/GNSS/image processing software
Prosilica GC2450C	Camera for online image processing tasks
Hokuyo UTM-30LX	LiDAR for online digital elevation model generation
Sony NEX-5N	Camera for high-resolution observation
EPSON M-G350-PD11	Low-cost miniaturized IMU
Javad TR-G3T	Geodetic-grade, multi-frequency GNSS receiver



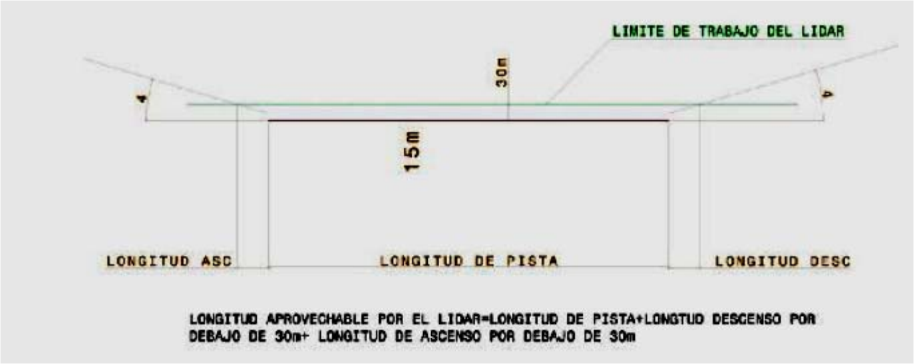
PREPARING THE REPRESENTATIVE ENVIRONMENT

Adaptation of the algorithms is needed (mainly, for crater detection)

- Trees as craters … ?

- Adaptation of environment is requirement for testing campaign

ELEMENTS IN THE REPRESENTATIVE ENVIRONMENT



LONGITUD APROVECHABLE POR EL LIDAR=LONGITUD DE PISTA+LONGTUD DESCENSO POR DEBAJO DE 30m+ LONGITUD DE ASCENSO POR DEBAJO DE 30m