Space Case Study

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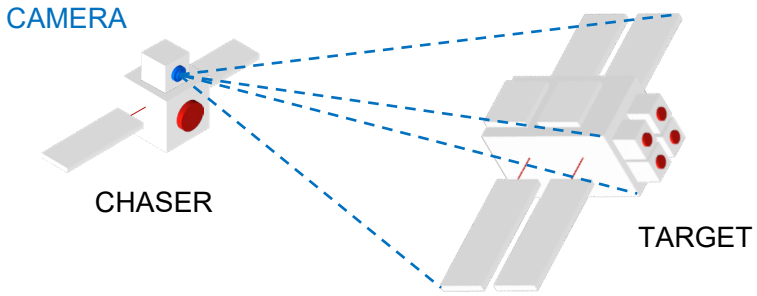
Introduction

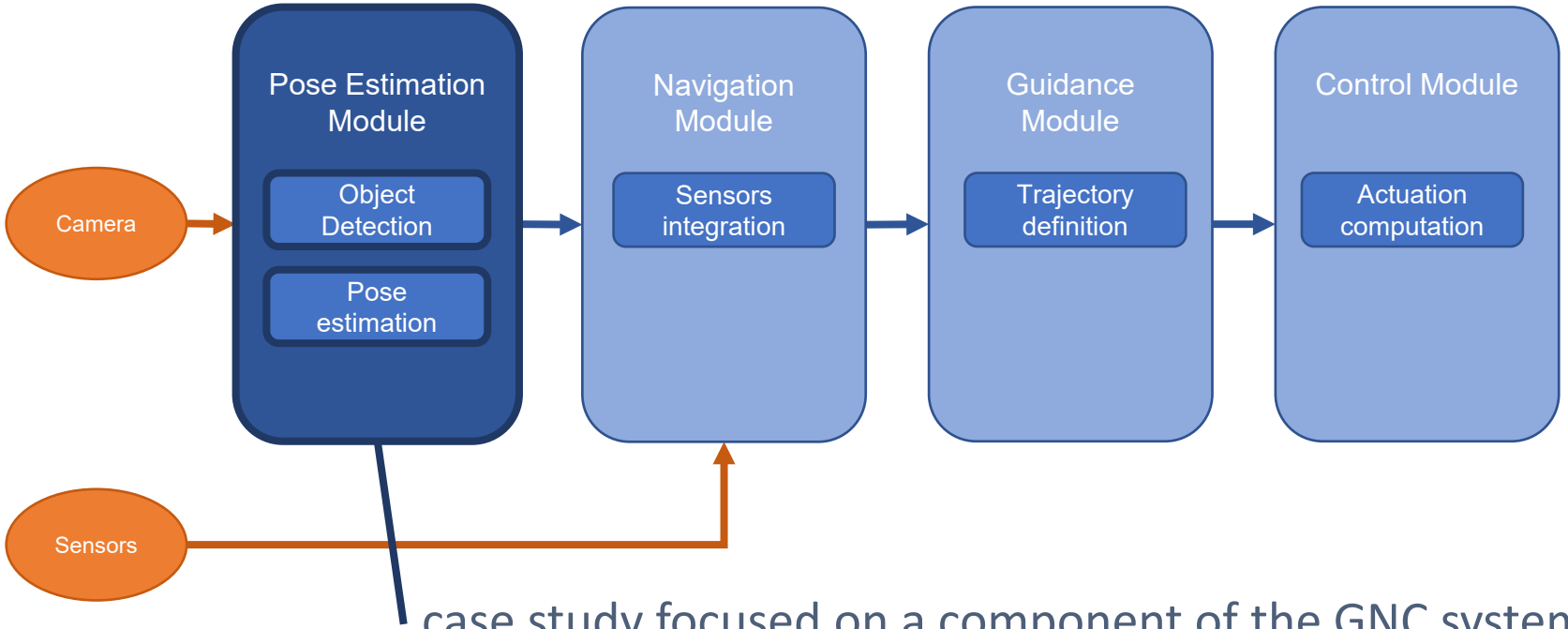
- Introduction to Case Studies
- Space Case Study
  - Scenario
  - Dataset
  - Algorithm
  - System integration
  - Testing
  - Demo

Scenario

- Scenario:
  - Chaser spacecraft approaching a target
  - Optical mono camera images
  - Autonomous navigation and docking
  - In-Orbit Servicing operations



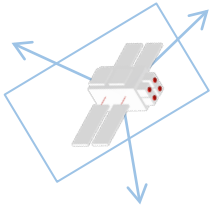
Scenario

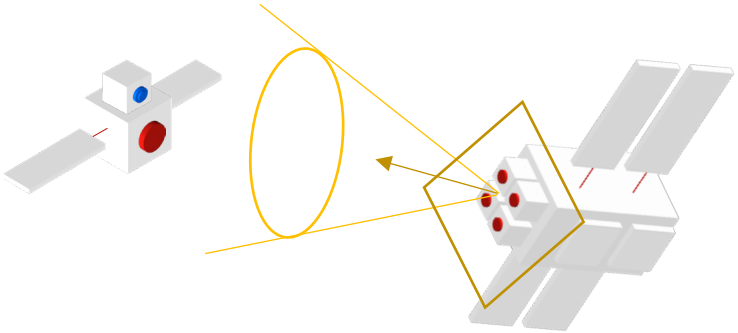


case study focused on a component of the GNC system

Scenario

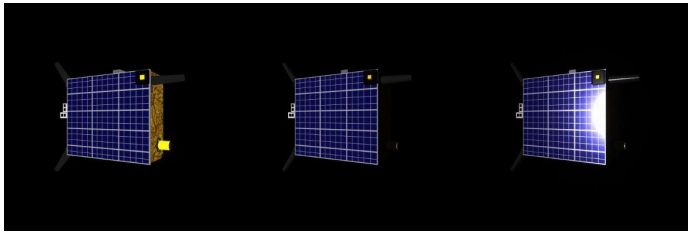
- 6D pose estimation: translation + rotation
- Functions under evaluation:
  - **Detection** of the docking target
  - Computation of the **relative position and attitude** between spacecraft and target
  - Computation of **orthogonality** to the docking site
- Safety requirements:
  - Computing the pose estimation within an adequate level of spatial accuracy
  - Computing the orthogonality within an adequate level of accuracy
  - Computing the previous outputs within an adequate computational time

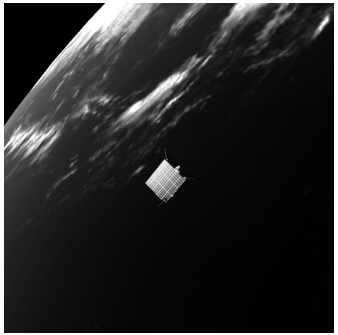
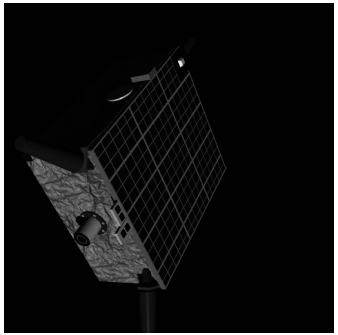
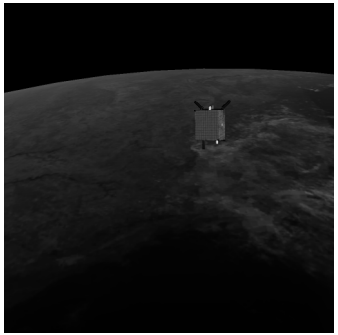
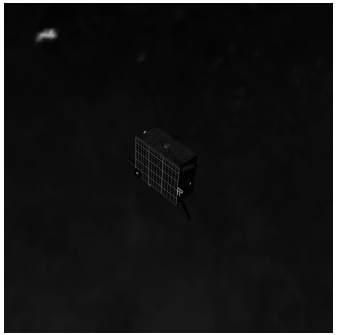




Dataset

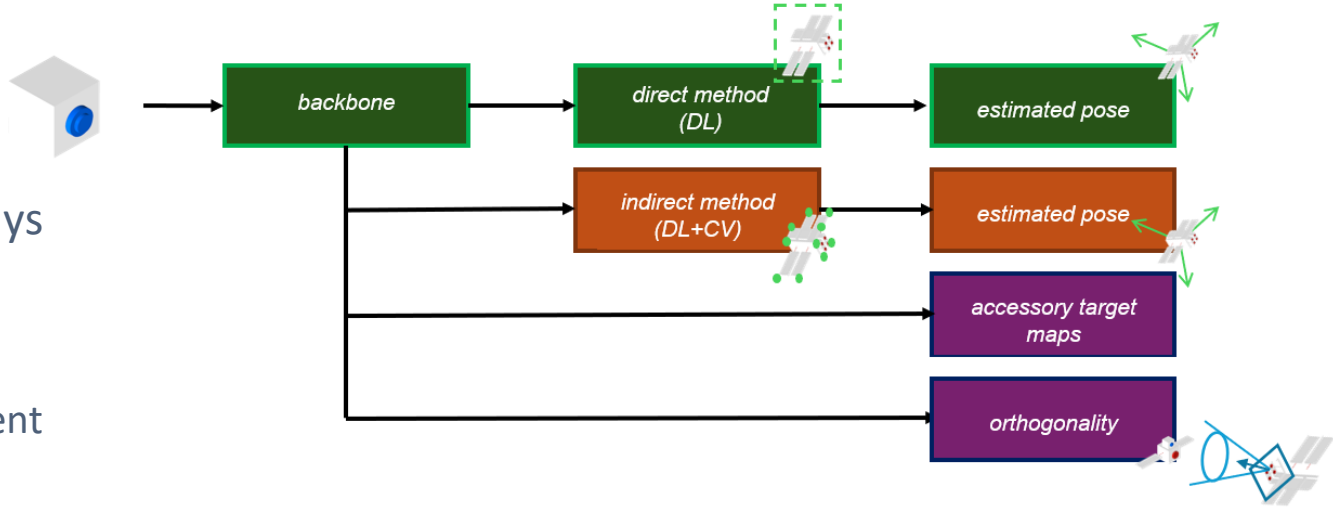
- Dataset generation pipeline, inspired by SPEED+ dataset
  - configurable (camera FOV, output size, target distance, background, light conditions…)
  - ground truths complete (pose, target info, bounding box, keypoints…)
  - random set or trajectory-based set



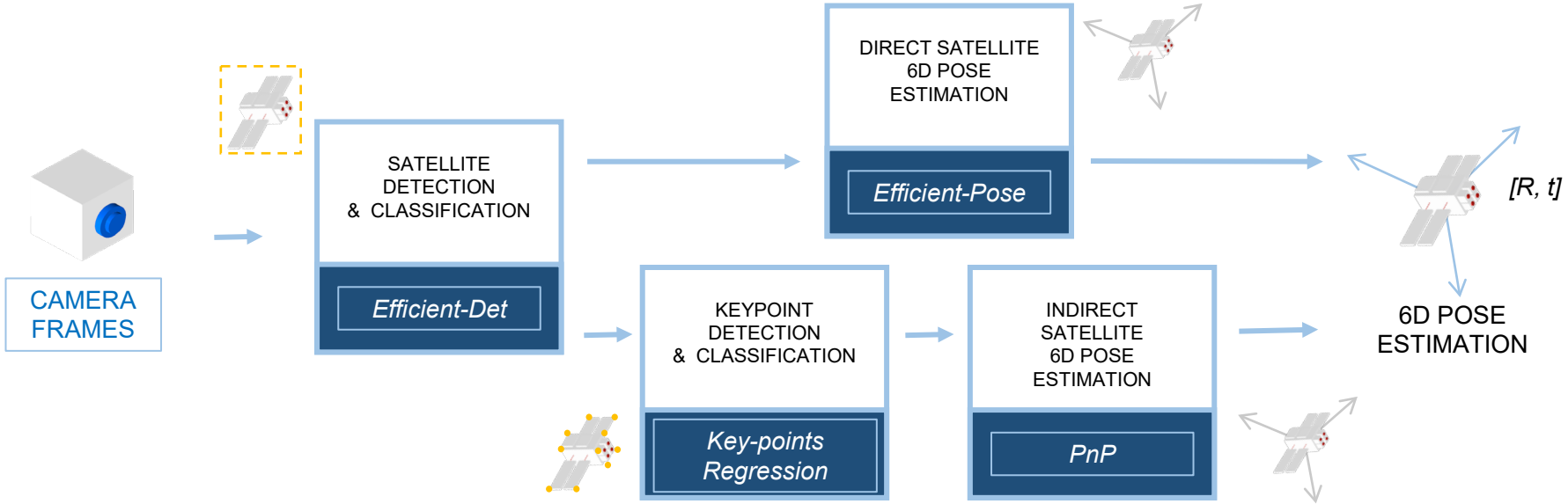

Algorithm

- PyTorch framework
- 60,000 images - data split of
  - 70% training
  - 20% validation
  - 10% testing
- Training time < 5 days
- Data augmentation
  - Noise addiction
  - Colour adjustment

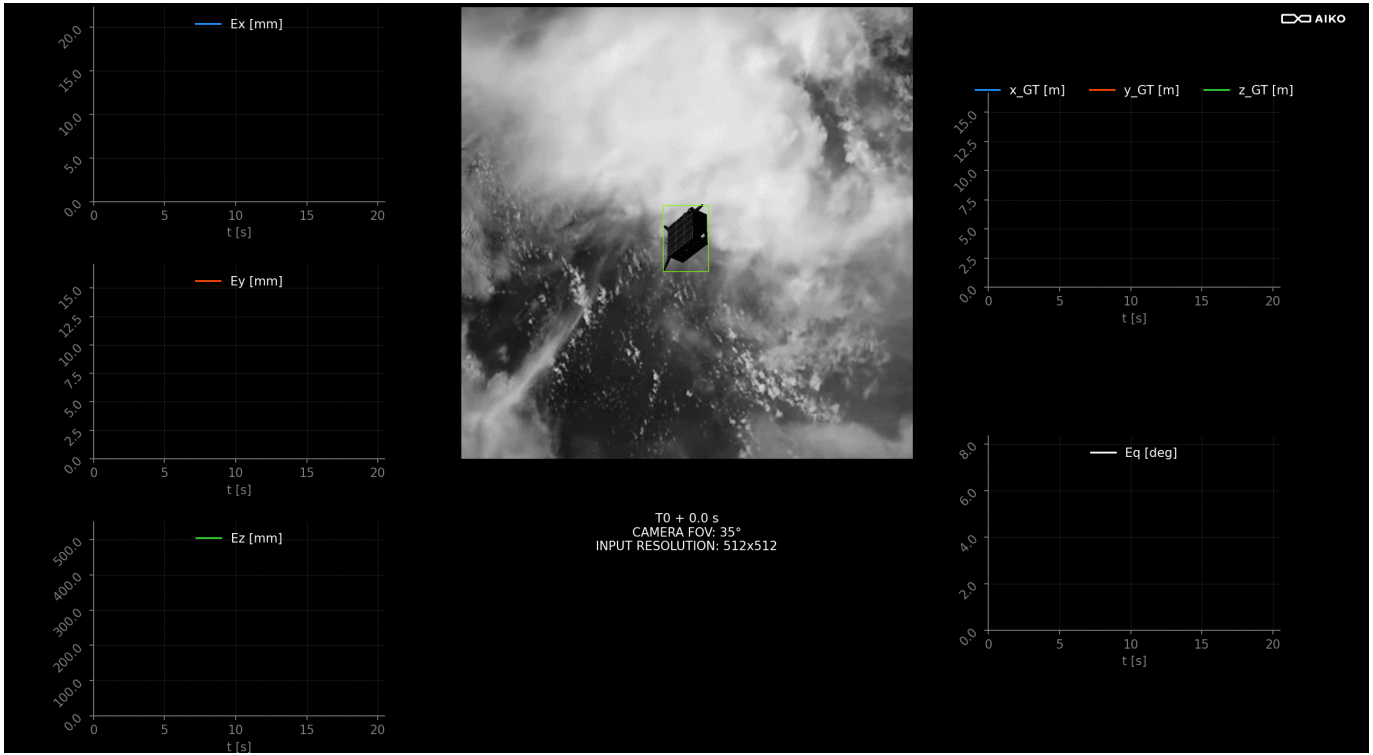


Algorithm

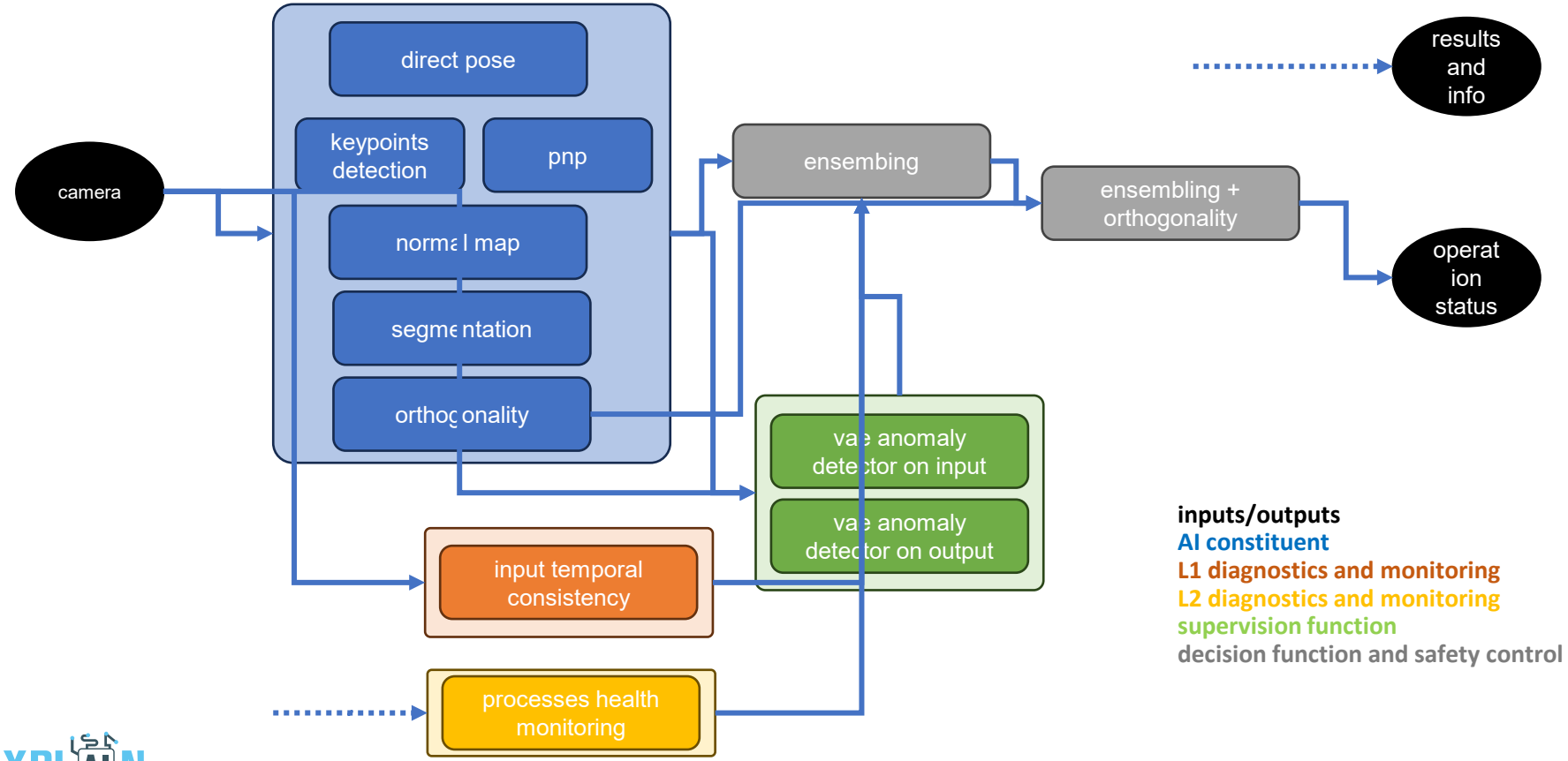
DEEP LEARNING ARCHITECTURE – MAIN SCHEMA



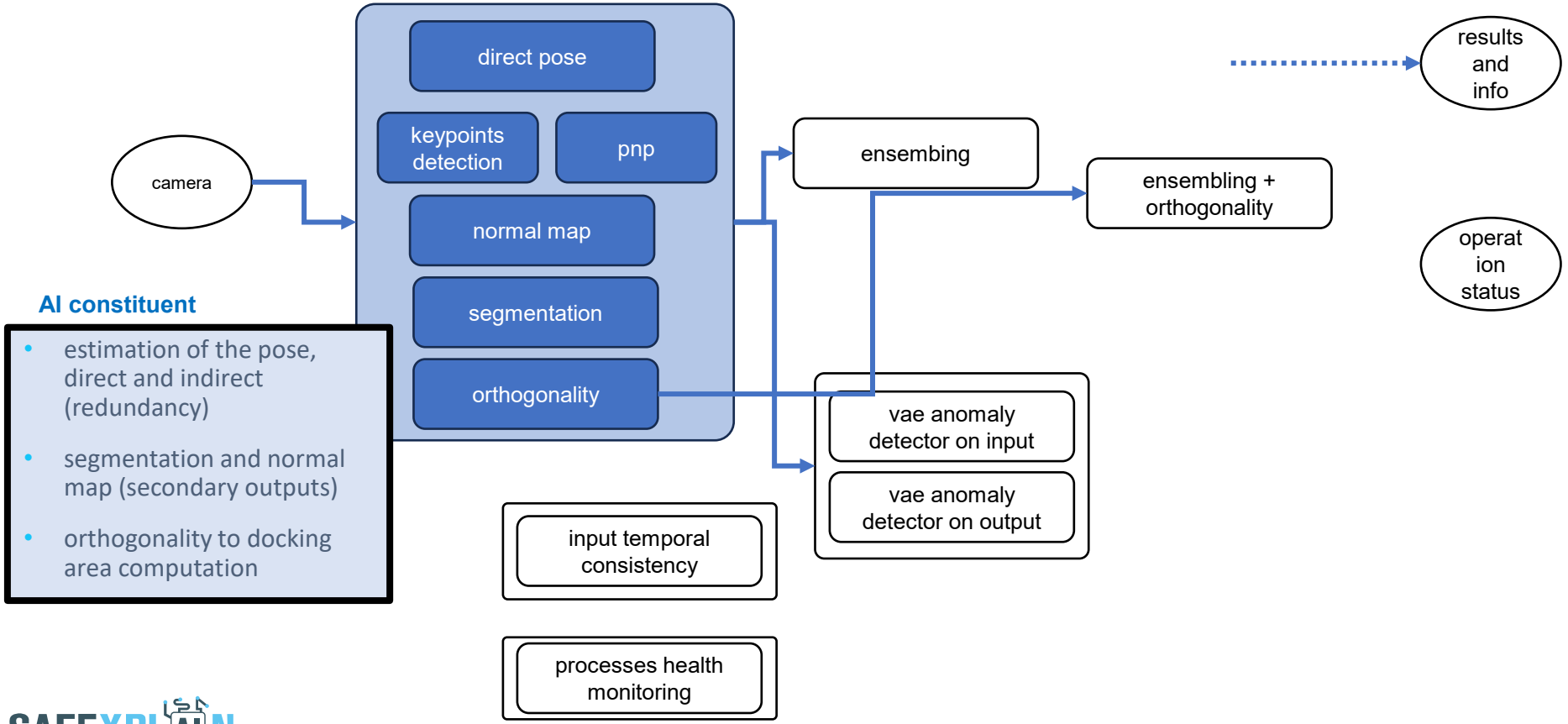
Algorithm


Ex [mm]
Ey [mm]
Ez [mm]
t [s]
T0 + 0.0 s
CAMERA FOV: 35°
INPUT RESOLUTION: 512x512
AIKO
x_GT [m]
y_GT [m]
z_GT [m]
Eq [deg]

System Integration



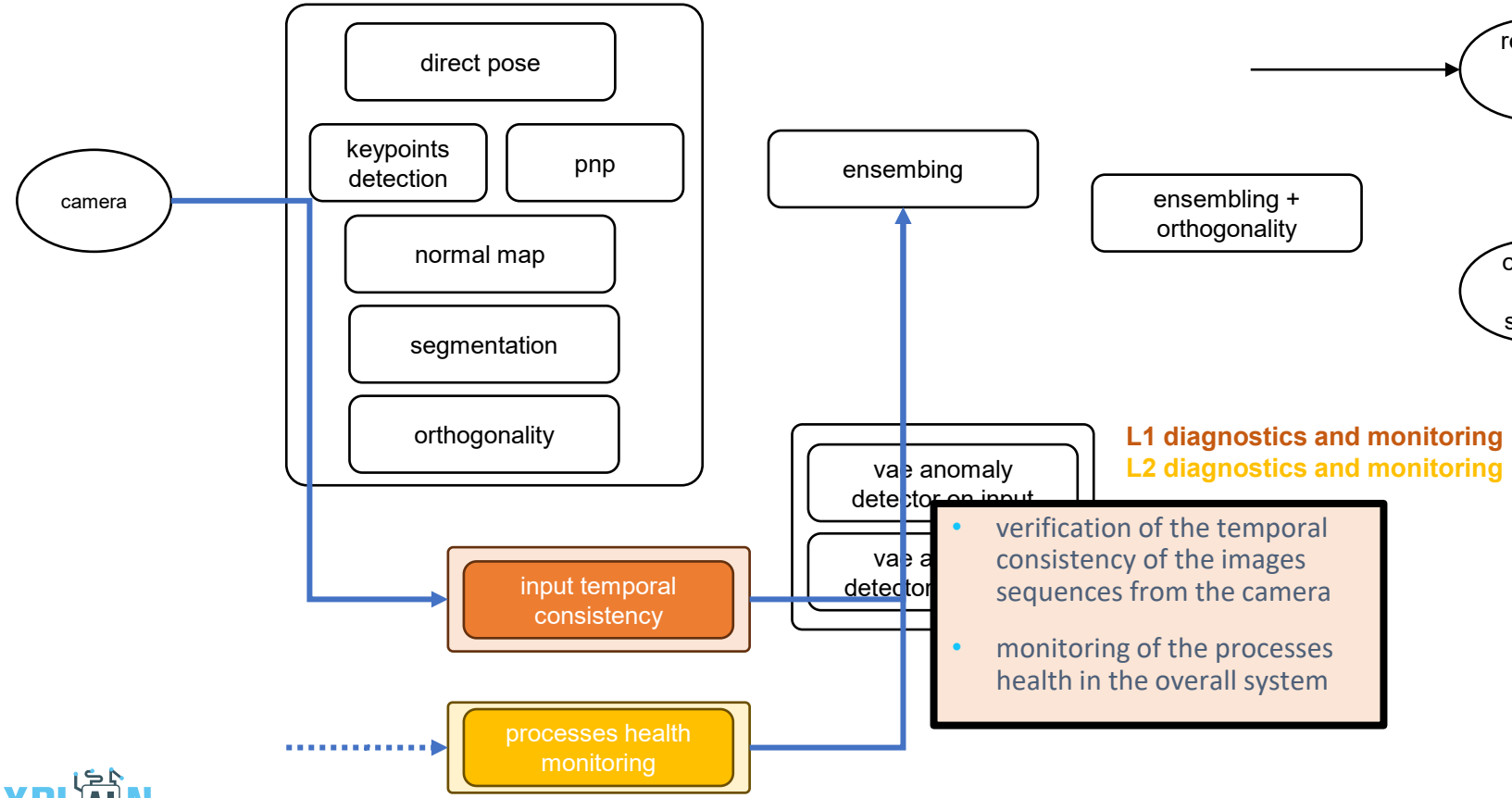
System Integration



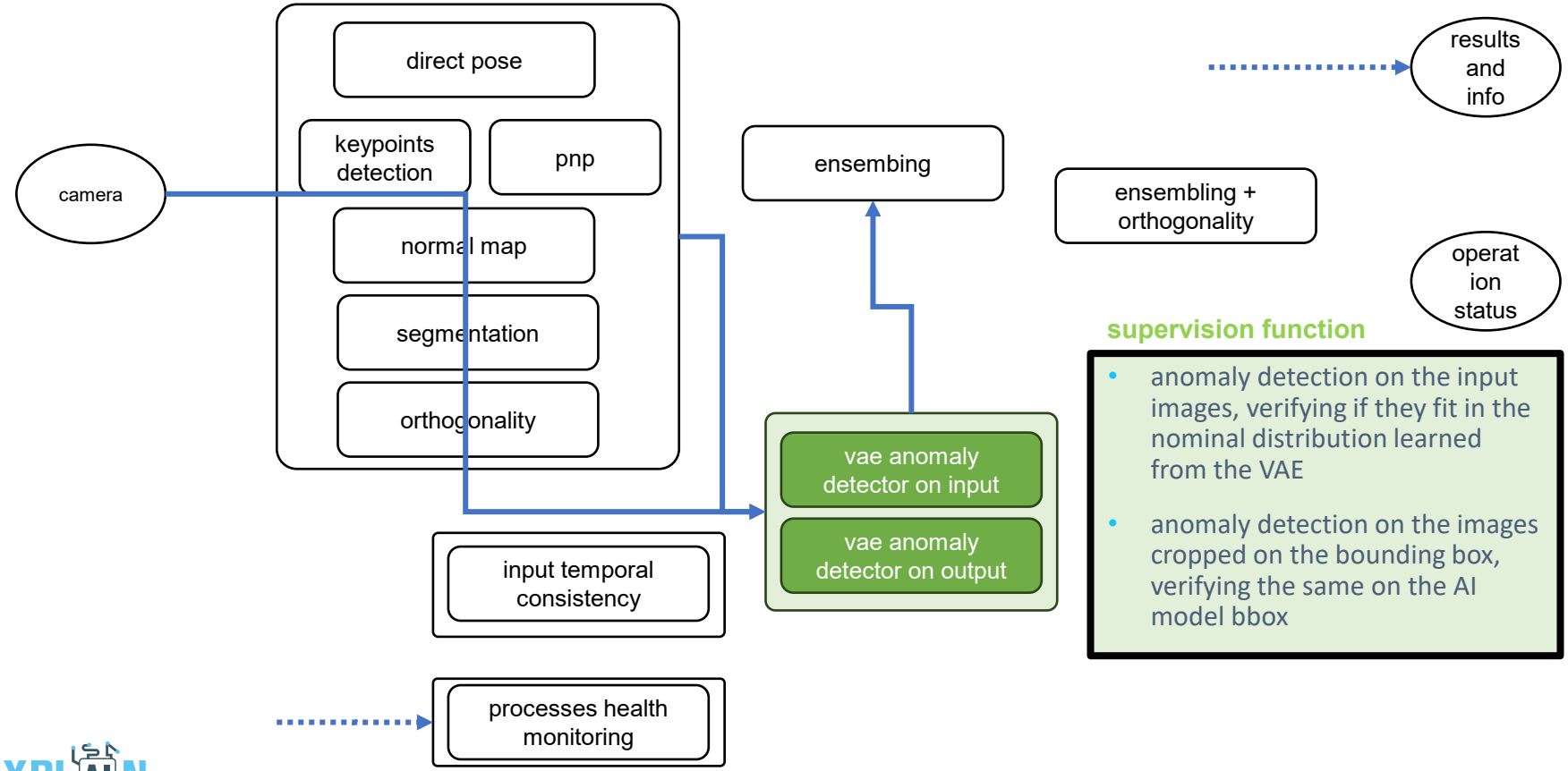
AI constituent

- estimation of the pose, direct and indirect (redundancy)
- segmentation and normal map (secondary outputs)
- orthogonality to docking area computation

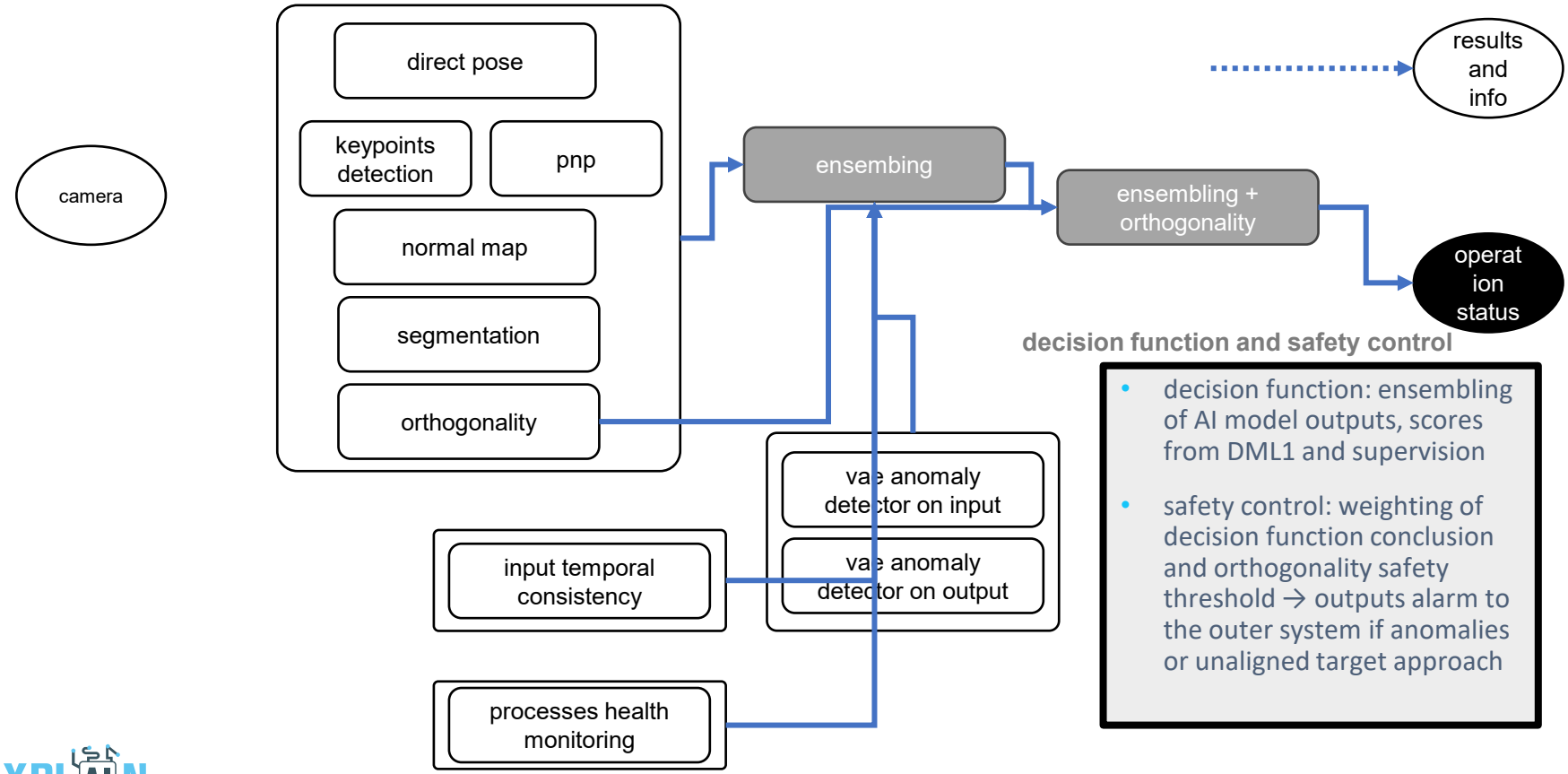
System Integration



System Integration



System Integration



Testing

- Simulation of trajectories to represent testing scenarios

ID	Target	Anomaly	Triggering condition	Expected behaviour
S1	The agent moves in the direction of an unrecognised target without a docking site			
	UFO	Target unrecognised	Unrecognised target in the input frames	- pose discarded - anomaly signalled
S2	The agent moves towards the target, when a camera failure occurs			
	Expected	Camera failure	Black input frames	- pose discarded - anomaly signalled
S3	The agent moves towards the target not centered in the image with some offset, aligning the trajectory through time			
	Expected	Nominal	N.A. dock warning: orthogonality to docking site > 8°	- pose provided - unsafe docking warning when unaligned
S4	The agent moves towards the target, when noise starts affecting the input images			
	Expected	Camera noise	Noisy input frames	- pose discarded - anomaly signalled
S5	The agent moves towards the target			
	Expected	Nominal	N.A. dock warning: orthogonality to docking site > 8°	- pose provided - unsafe docking warning when unaligned
S6	The agent moves towards the target, when an incorrect manoeuvre points the camera at the sun			
	Expected	Camera blinding	Blinded input frames	- pose discarded - anomaly signalled
S7	The agent moves towards the target unaligned to the docking site, through time aligning to it			
	Expected	Nominal, docking unsafe	N.A. dock warning: orthogonality to docking site > 8°	- pose provided - unsafe docking warning

Testing

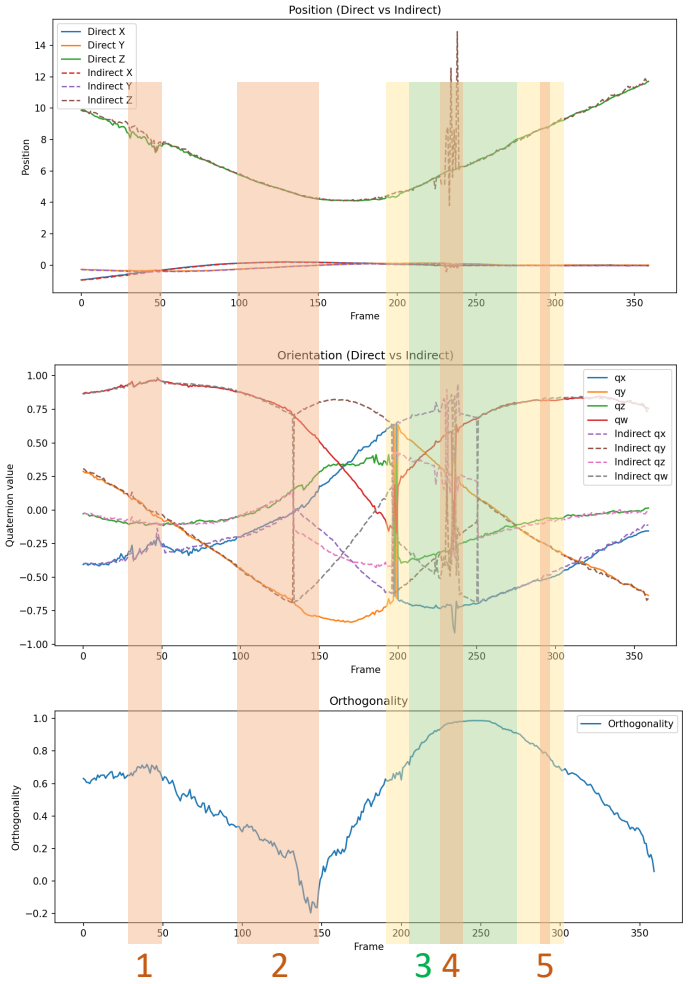
- For every scenario, varying conditions:
  - Light source direction:
    - Behind the camera (B)
    - In a randomised position (R)
  - Frame background:
    - Camera pointing to outer space: black background (S)
    - Camera pointing (partially or completely) to Earth: portion of the Earth in the background (E)

Demo

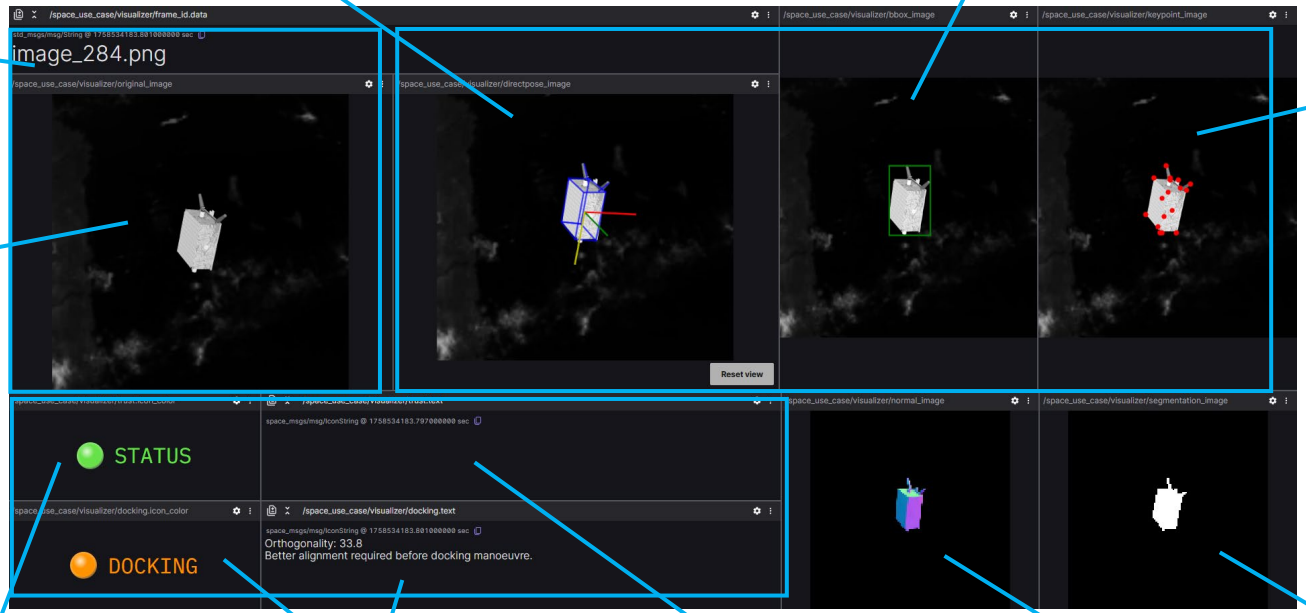
1. anomaly [32-53]: small perturbation of the redundant models consistency
2. injected anomaly [100-150]: noise in the input images
3. orthogonality to the docking site compatible with rendez-vous

   [195 – [218 – 280] – 312]
   warning ok warning
4. anomaly [231-236]: perturbation in the redundant models consistency
5. injected anomaly [290-293]: lag in the frames acquisition, represented by faster spinning target

notes:
- slowed camera rate for visualization
- frame ids/3 (image_002, image_005…)



Demo



estimated pose

estimated bounding box

frame id

estimated keypoints

input image

trustworthiness status

docking safety and orthogonality

detected anomalies

normal map

segmentation map

THANKS!

SAFEXPLAIN

Safe and Explainable
Critical Embedded Systems based on AI

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