INVESTIGATION OF ACTIVE DETUMBLING SOLUTIONS FOR DEBRIS REMOVAL

COMRADE

Clean Space Industry Days 24-10-2017

AGENDA

- **Project Overview**
- **Mission Scenarios**
- **Design and DDVV approach**

DETUMBLING

Project Overview

PROJECT OBJECTIVES

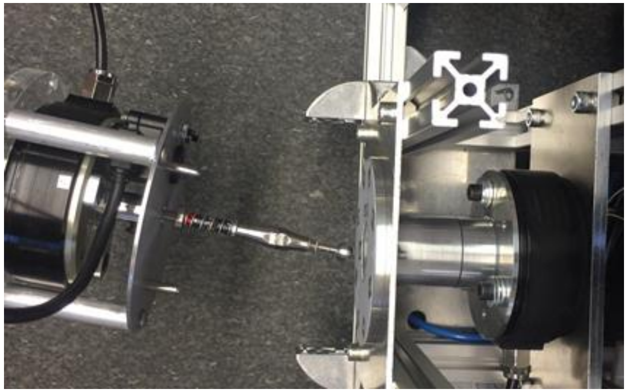
- Design, develop and test the **control system** of a robotic S/C (including manipulator and end-effector) for two missions:
  - Active Debris Removal (ADR). **eDeorbit** mission is the ADR reference mission with dedicated 7DOF robotic manipulator and LAR gripper end-effector.
  - Re-fueling mission. **ASSIST** is the reference mission with dedicated 6/7DOF robotic manipulator and ASSIST end-effector.
- Specific requirements on the chaser Control System:
  - Combined control and management of the whole chaser, in the operations of grasping, stabilisation and hold of the debris with the aim to perform controlled de-orbit.
  - 6DOF coupled (chaser position+attitude) for those phases where robotic manipulator/end-effector do not need to be operated
  - 13DOF coupled (chaser position + attitude + 7 manipulator joints) for those phases where robotic manipulator/end-effector are in operation.

PROJECT OBJECTIVES

- Chaser Control System intended to be developed within this activity up to **TRL 5** (Component and/or breadboard critical function verification in relevant environment).
- Incremental Design, Development, Verification and Validation (DDVV) approach based on the chain:

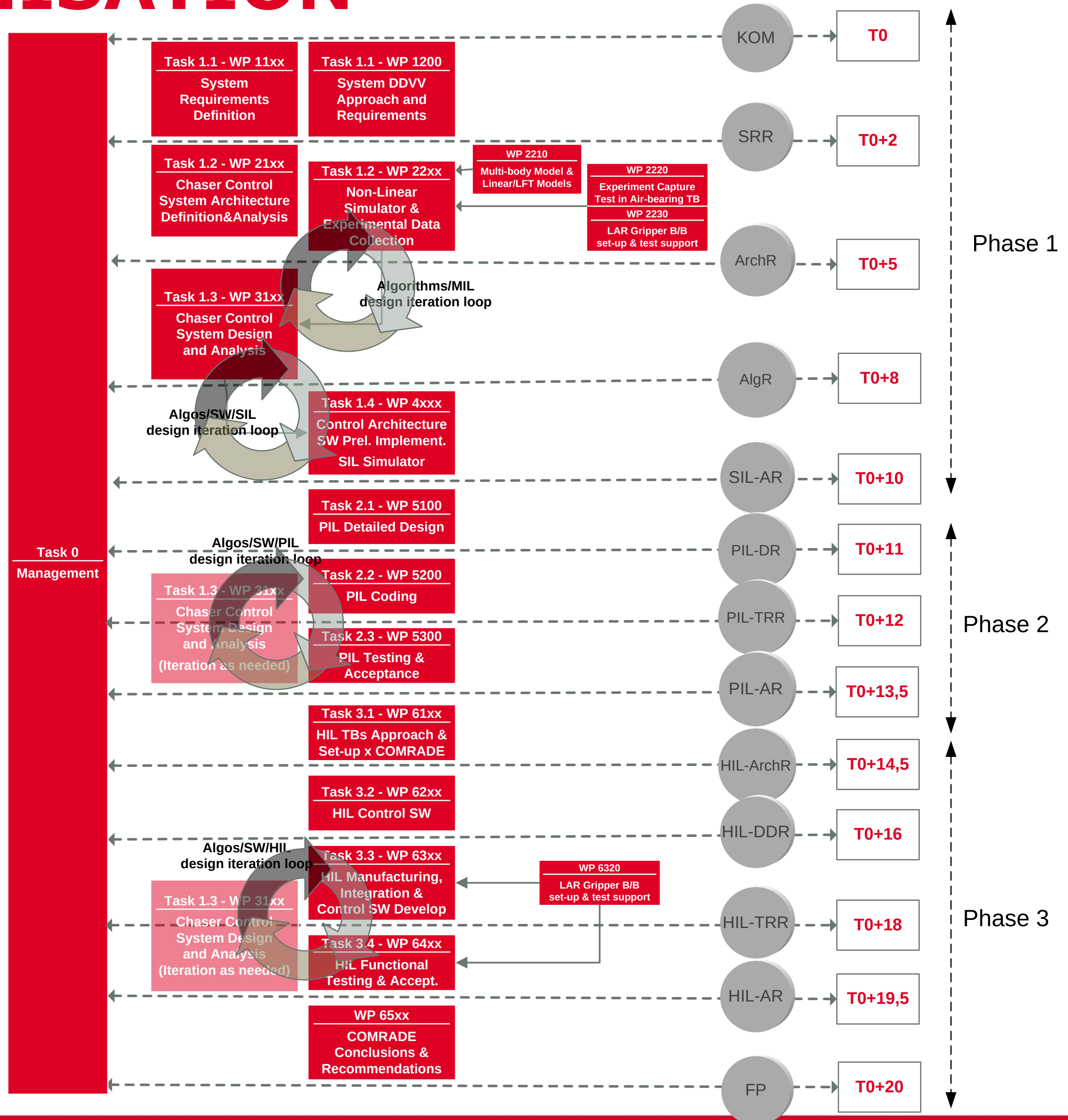
MIL → Autocoding → MIL-SIL → SIL TB → PIL TB → HIL TB

- The fidelity and space-representativeness of the test tools used at each level need to guarantee that TRL 5 is achieved.



PROJECT ORGANISATION

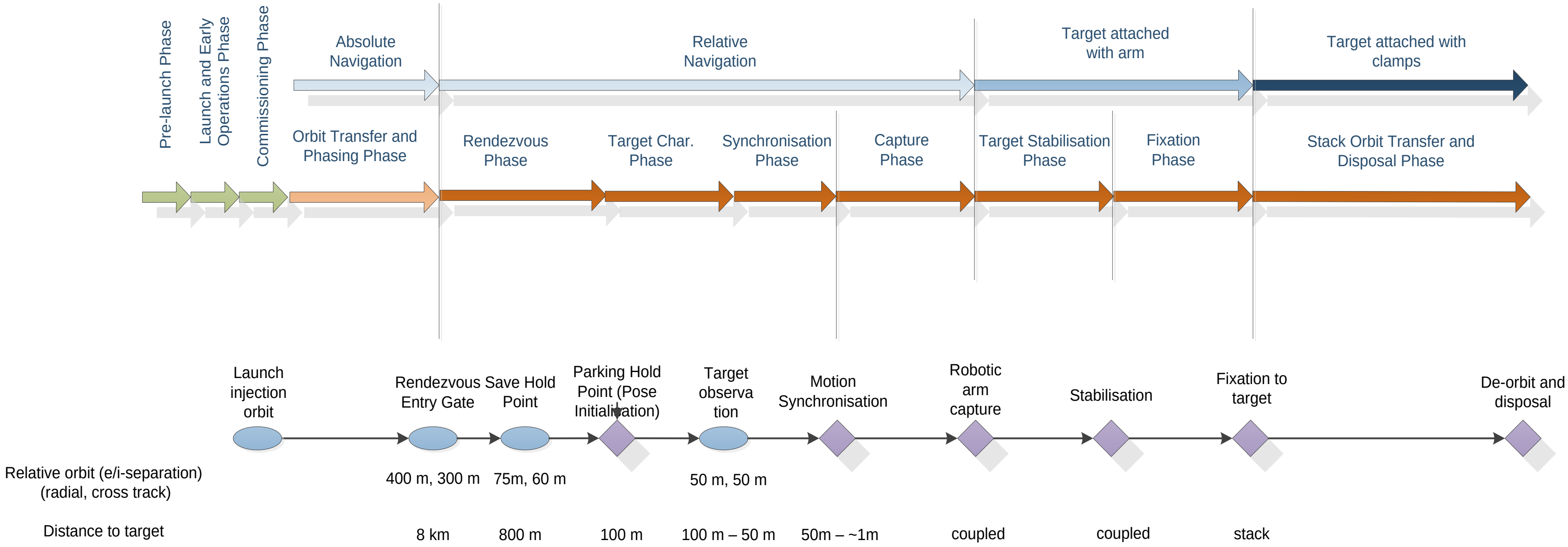
- GMV Spain
- GMV Portugal
- ADS (Germany)
- DLR (Germany)
- NTUA (Greece)
- IMS (France)
- PIAP (Poland)

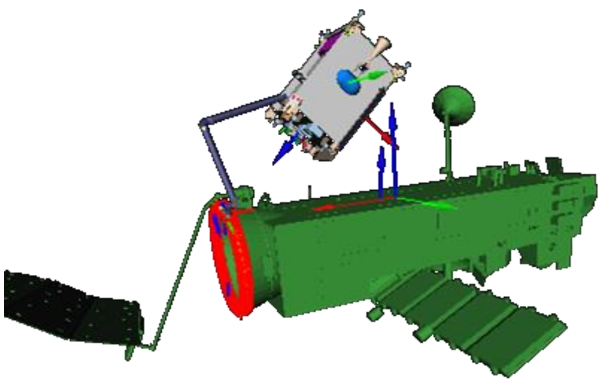


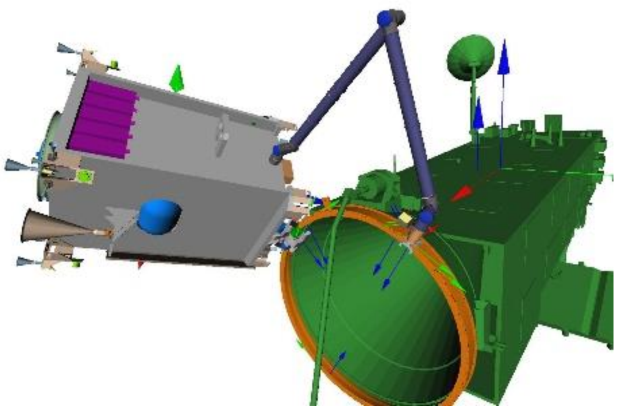
DETUMBLING

Mission scenarios

E-DEORBIT SCENARIO

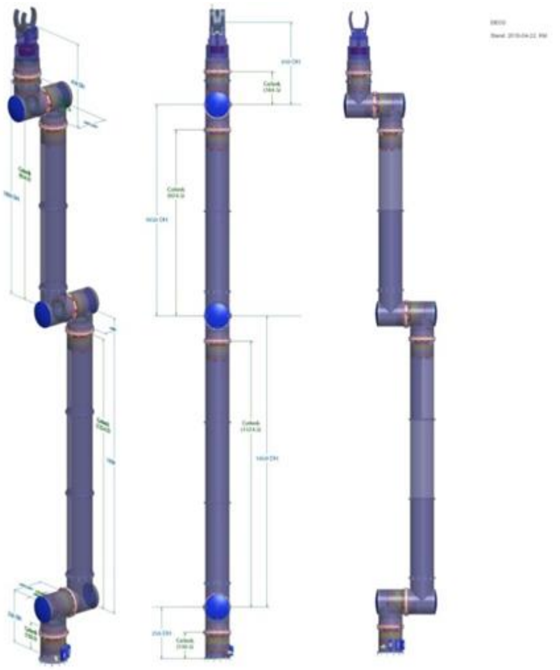




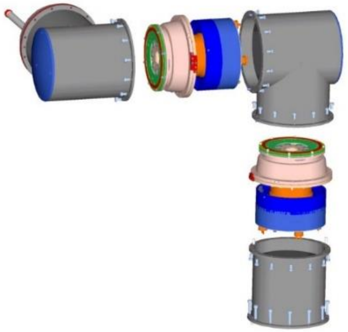


E-DEORBIT SCENARIO

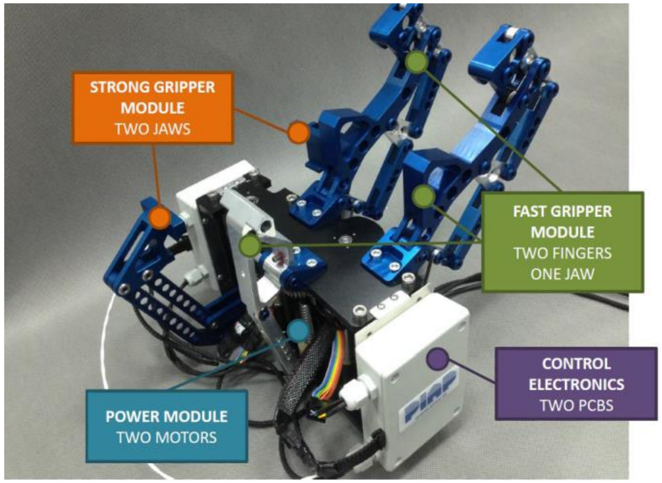
- The robot manipulator configuration was chosen to be the one defined in the DEOS project. The 7-DoF arm kinematics of DEOS was however adapted to allow the robot to grasp the Adapter Ring of ENVISAT and subsequently seat the Chaser above the Adapter Ring. For this, two of the robot links were extended in length appropriately



7-DoF arm



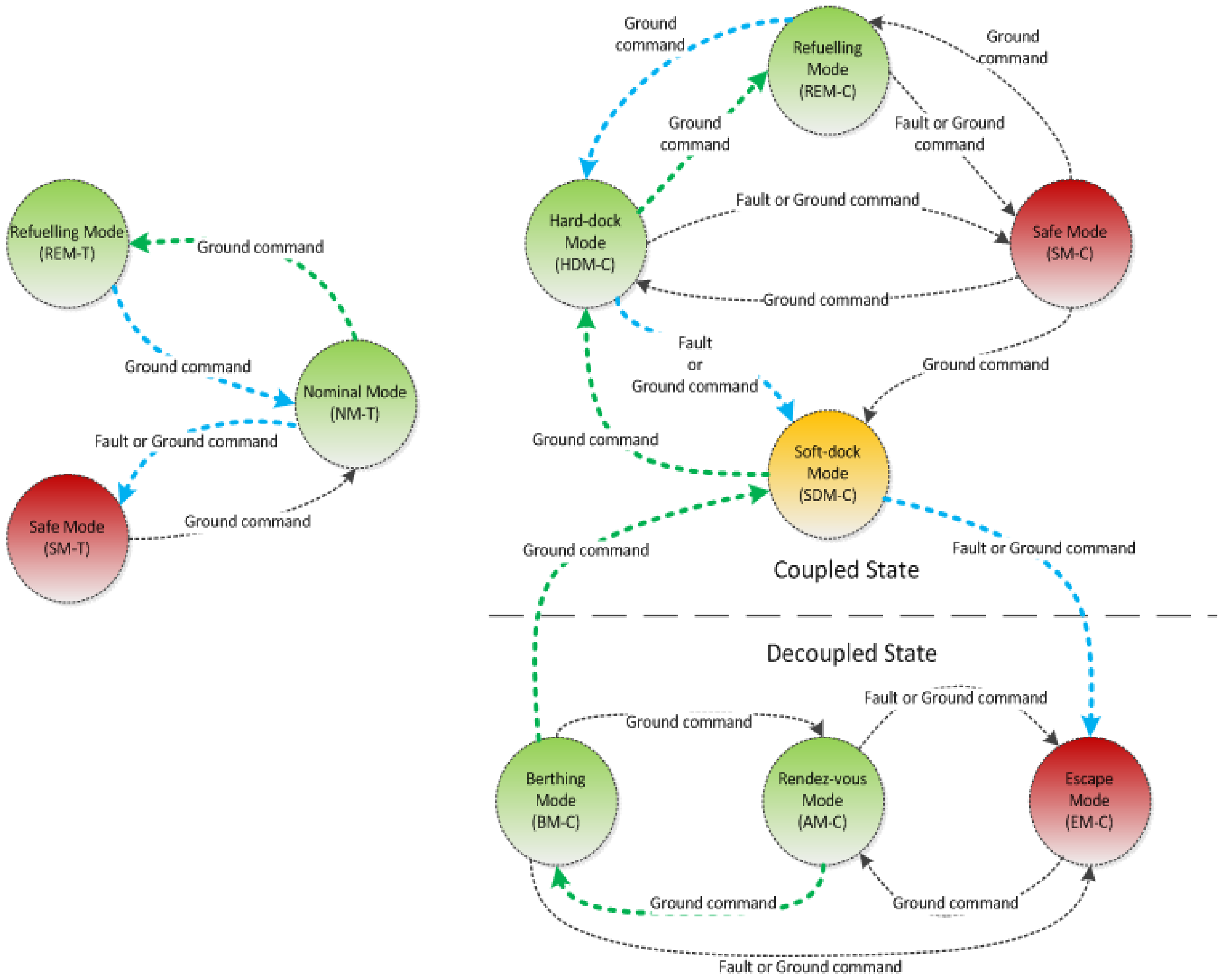
RokViss 2-joints



LAR gripper

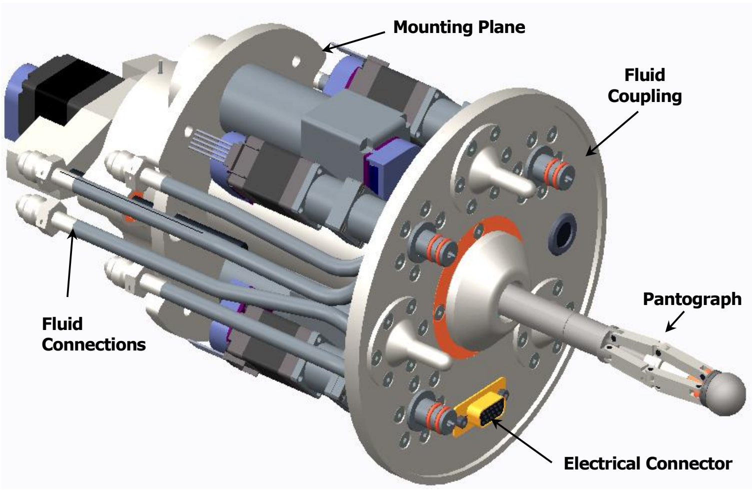
ASSIST SCENARIO

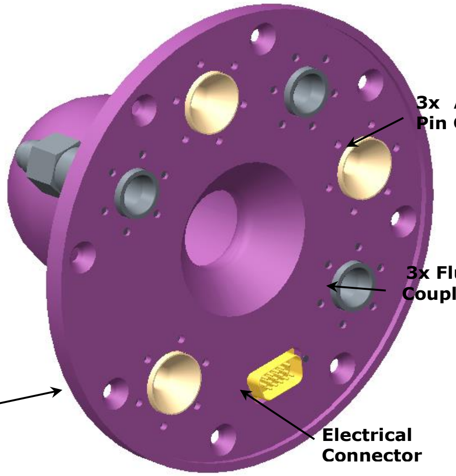
- Re-fueling modes



ASSIST SCENARIO

- ASSIST system is composed of an end-effector (hosted in the Servicing S/C) and a Berthing Fixture (hosted in the Serviced S/C).
- The end-effector is foreseen to be attached to a robotic arm on the servicing S/C (includes the fluid and electrical connections and a grasping mechanism which docks with the berthing fixture on the serviced S/C).
- A reduced scale model of the end-effector and berthing fixture have been developed in ASSIST activity for dynamic testing on the air bearing test facility with scaled mass and geometry.





DETUMBLING

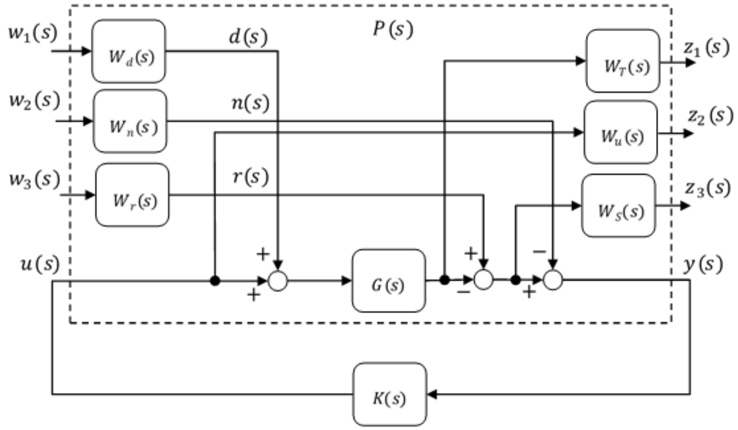
Design and DDVV approach

CONTROL MODES

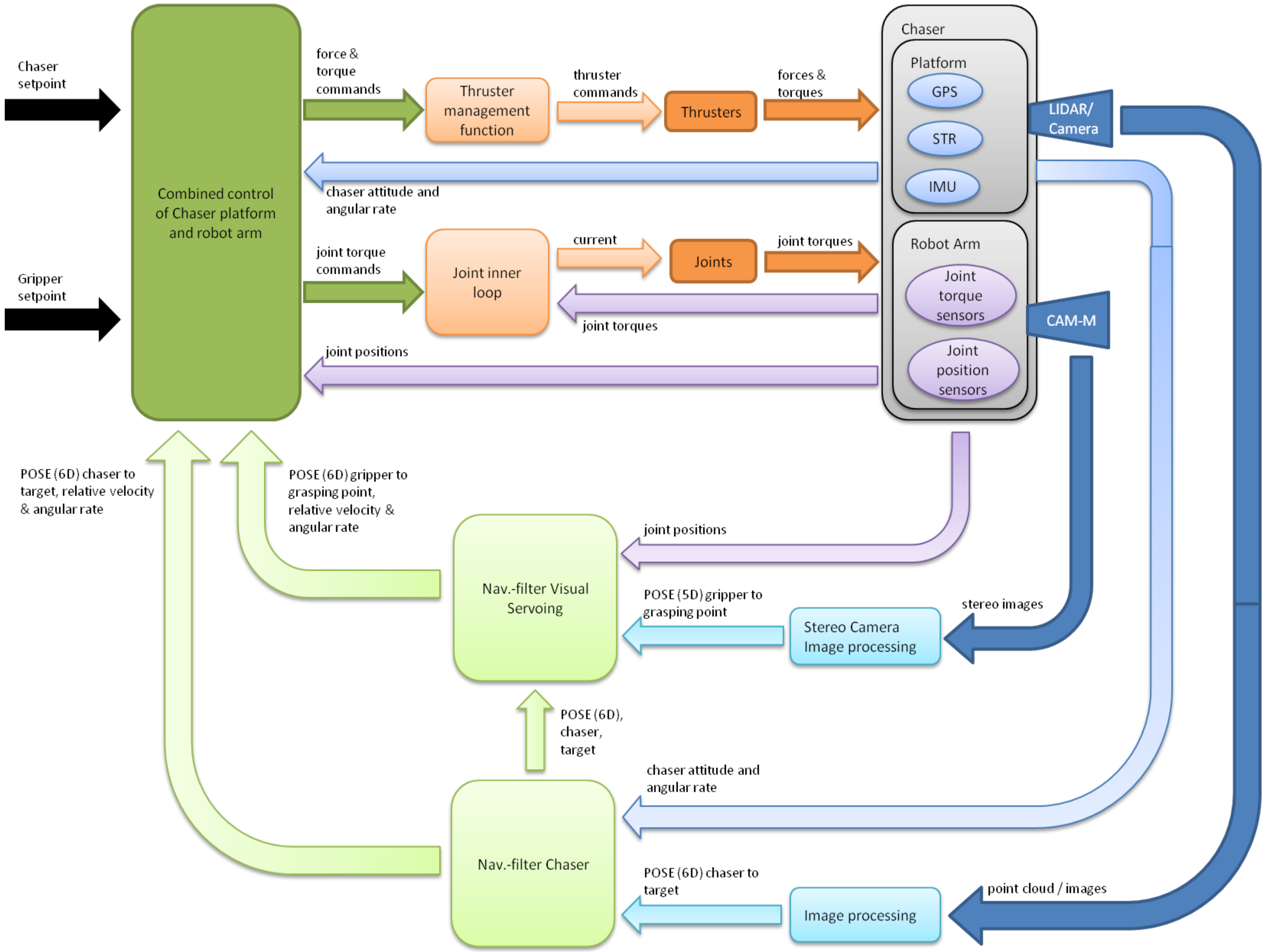
COMRADE Control Mode/Name	Main characteristics	ASSIST Modes best matching to COMRADE	Responsible / (Justification)
Synchronization	Folded manipulator, brakes on, no signficant flexible effects in the manipulator. Control type: coupled chaser pos/att 6 DOF	RVM-C	GMV-POR (eDeorbit Phase B1)
Reach	Manipulator unfolding, flexible effects, no contact phase Control type: combined Chaser+manipulator 13 DOF, compliant control is not applicable	BM-C HDM-S, HDM-C[Note1] (contact forces but not compliant control needed)	ADS (eDeorbit Phase B1)
Closure	Manipulator/gripper making contact/grasping and increasing stiffnes, flexible effects, contact effects Control type: combined&compliant Chaser+manipulator 13 DOF	-	DLR (previous ESA activities)
Rigidization	Manipulator applying mechanical joint brakes with incremental stiffness, flexible effects Control type: combined&compliant Chaser+manipulator 13 DOF	-	DLR (similarity with Closure)
Stabilization	Detumbling of combo (Chaser+Target joined by rigid manipulator[Note2]), flexible effects Control type: coupled combo pos/att 6 DOF (combo) with flexible combo links	REM-C SM-C	GMV-POR (DETUMBLING activity)
Escape with Frozen manipulator	Frozen (unfolded) manipulator configuration, gripper opening (if needed), flexible effects Control type: coupled chaser pos/att 6DOF with frozen (flexible) manipulator Alternative: consider an automatic manipulator "folding" sequence (perturbtion for the chaser control)	EM-C	GMV-POR (eDeorbit Phase B1)
Combined Escape	Operating manipulator, gripper opening (if needed), flexible effects, no contact Control type: combined Chaser+manipulator 13DOF, compliant control is not applicable Alternative: consider an automatic manipulator "folding" sequence (perturbtion for the chaser control)	-	DLR (Research topic)

ROBUST MULTIVARIABLE CONTROL

- Control Design guidelines:
  - **MIMO** controllers (6DOF and 13DOF (6+7)) in different configurations to cover all phases.
  - Synthesised/analysed by means of modern robust control techniques.
  - Linear plant models with uncertainty representation by means of **LFTs** for synthesis and robustness analyses.
  - **Compliant** control modes developed in parallel for contact phases and to be compared to MIMO controlled synthesised with robust control methods.



CONTROL ARCHITECTURE



COMPLIANT CONTROL

- Compliant control (special case of Impedance Control in which the task is to modify the dynamical behaviour of the robot with respect to external forces acting on the system)
- Impedance controlled arm is able to follow a given trajectory in free motion, and at the same time exhibits a desired disturbance response, i.e. impedance, when in contact with the environment (compliance control focuses on the simpler problem of shaping only the stiffness and damping, while keeping the inertial behaviour unchanged).

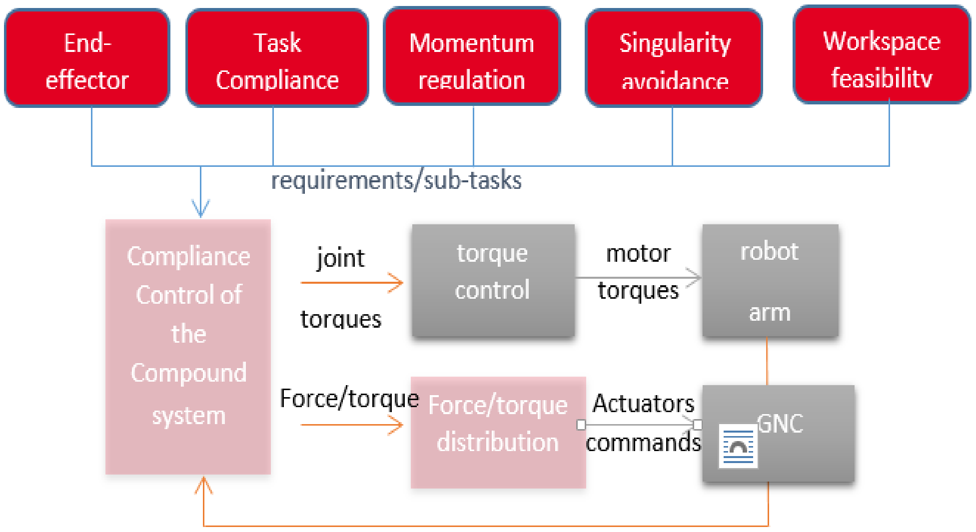
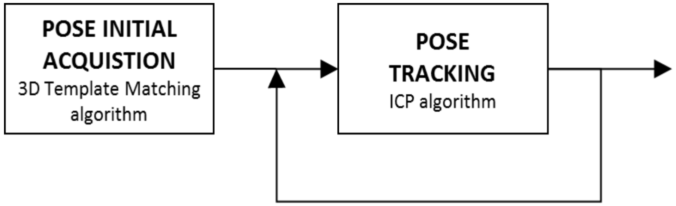
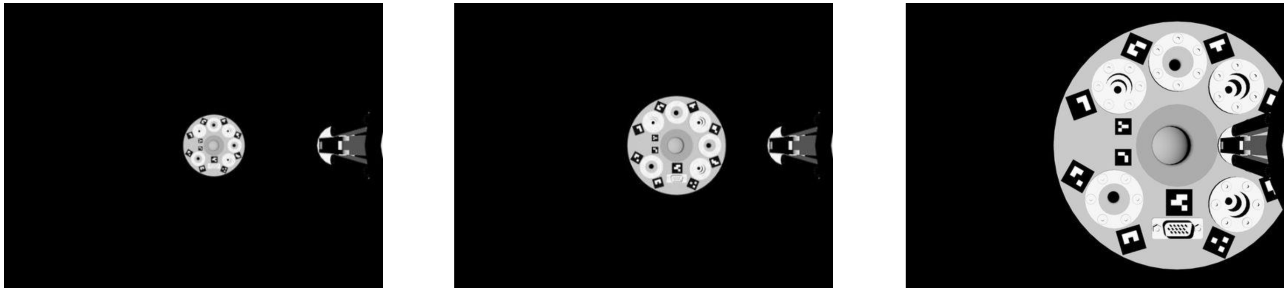


IMAGE PROCESSING

- Need for pose estimation (relative attitude and position of the chaser with respect to the target)
- Uncooperative targets (eDeorbit scenario):
  - Best way to deal with uncooperative targets is to adopt model-based techniques (able to compute the relative attitude and position parameters by comparing global or local target features, as extracted from the sensor measurements, to the corresponding ones in its 3D model)

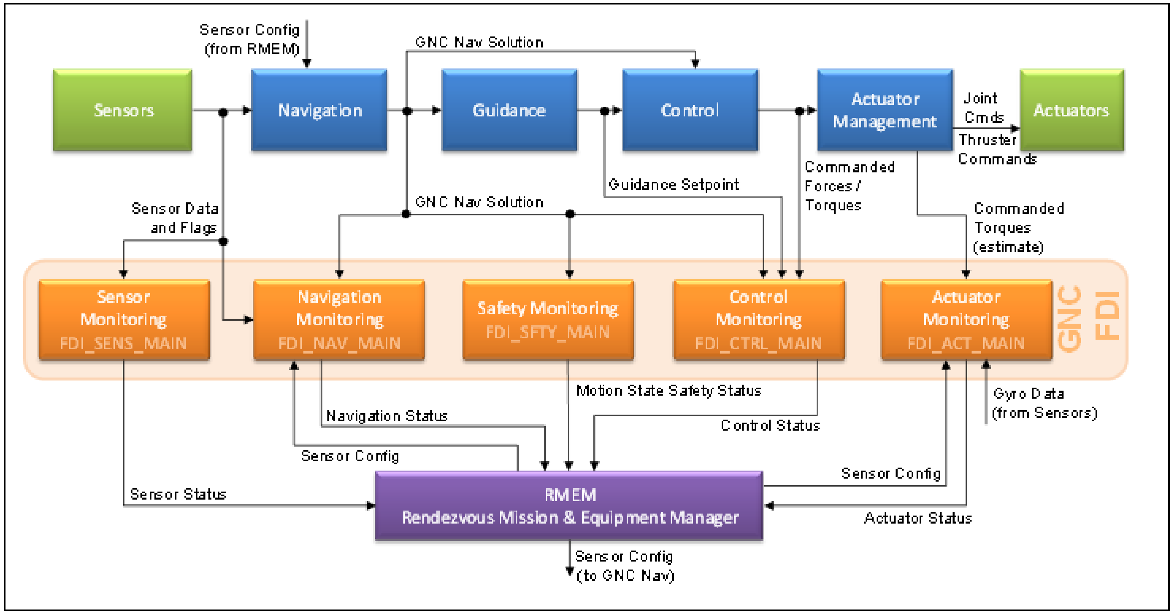


- ASSIST scenario: visual-based navigation assuming a cooperative target with a fiducial marker system (existing solution from ASSIST).

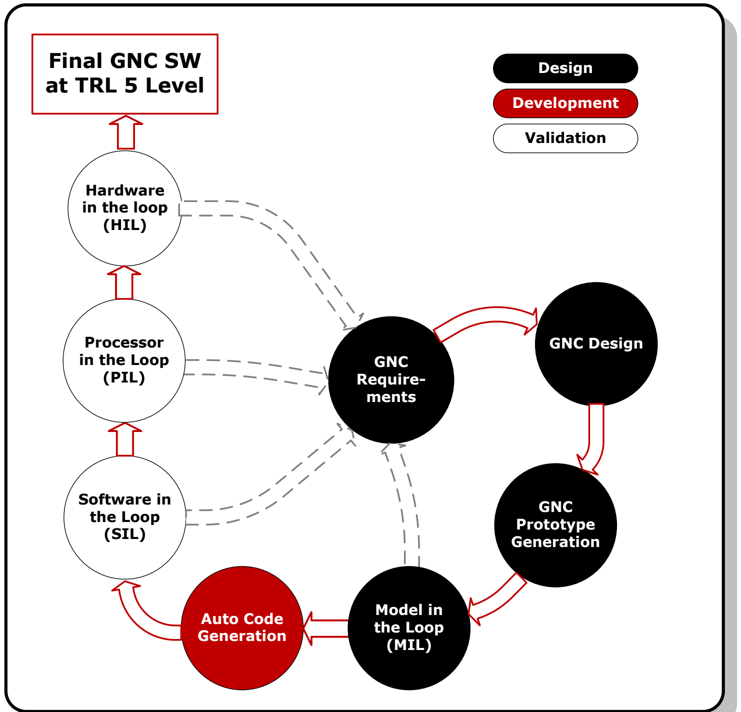


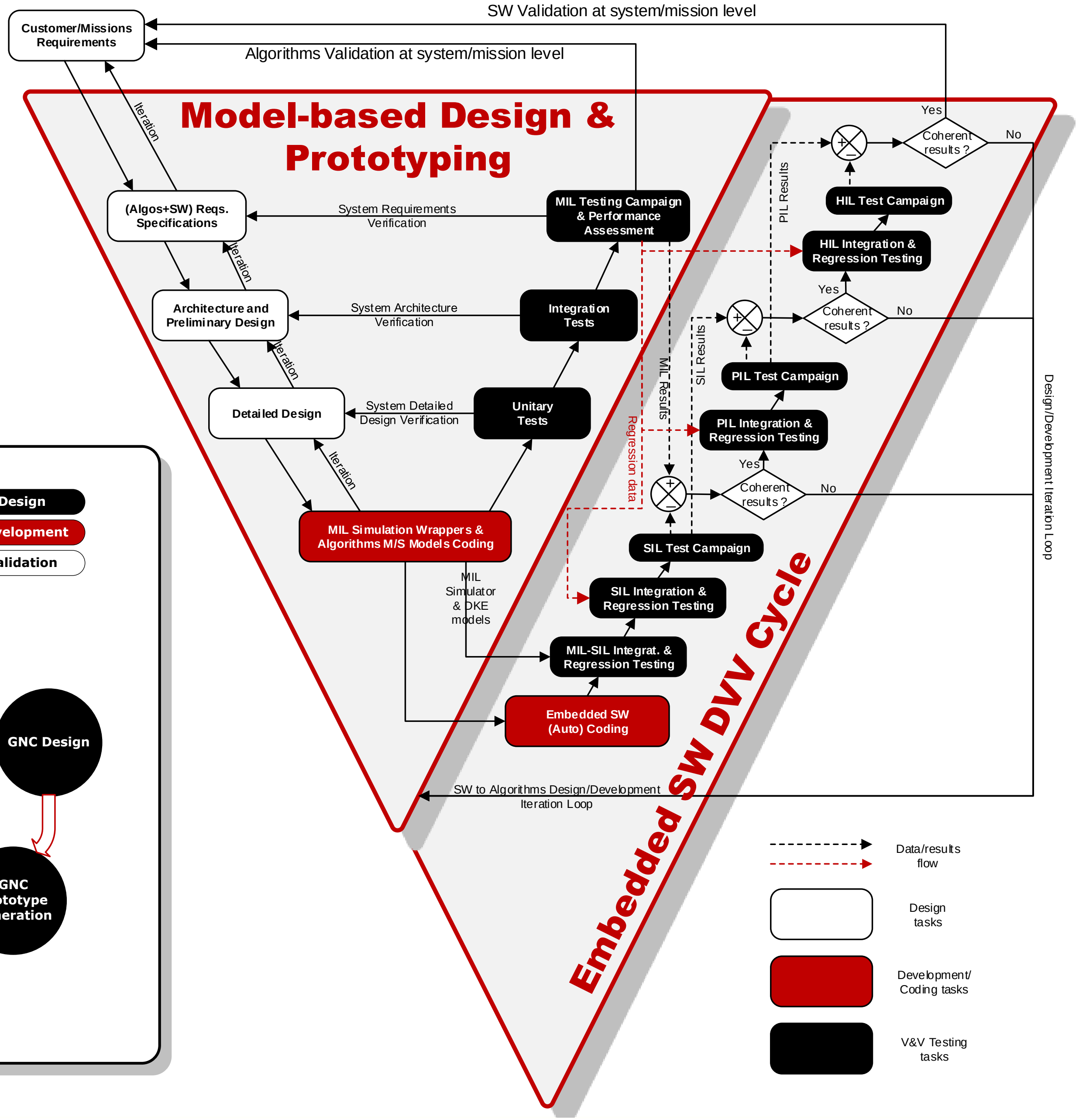
FDIR APPROACH

- FDIR supervises the rendezvous phase and relies on the following principles (the approach is the same for the platform navigation and the arm navigation):
  - Primary visual navigation sensor generating robust data.
  - Independent monitoring sensor to check the coherency of the navigation data computed with the primary visual navigation sensor.
  - On-board observer of the trajectories (pose, velocities and rates) for platform and robot arm, i.e. what is the deviation from the expected pose, velocity and rate and expected relative pose for detecting constraint violations.
  - On-board generation of escape trajectories for the platform (CAM) and the robot arm (retreat).
  - Independent processing core for primary navigation and monitoring.



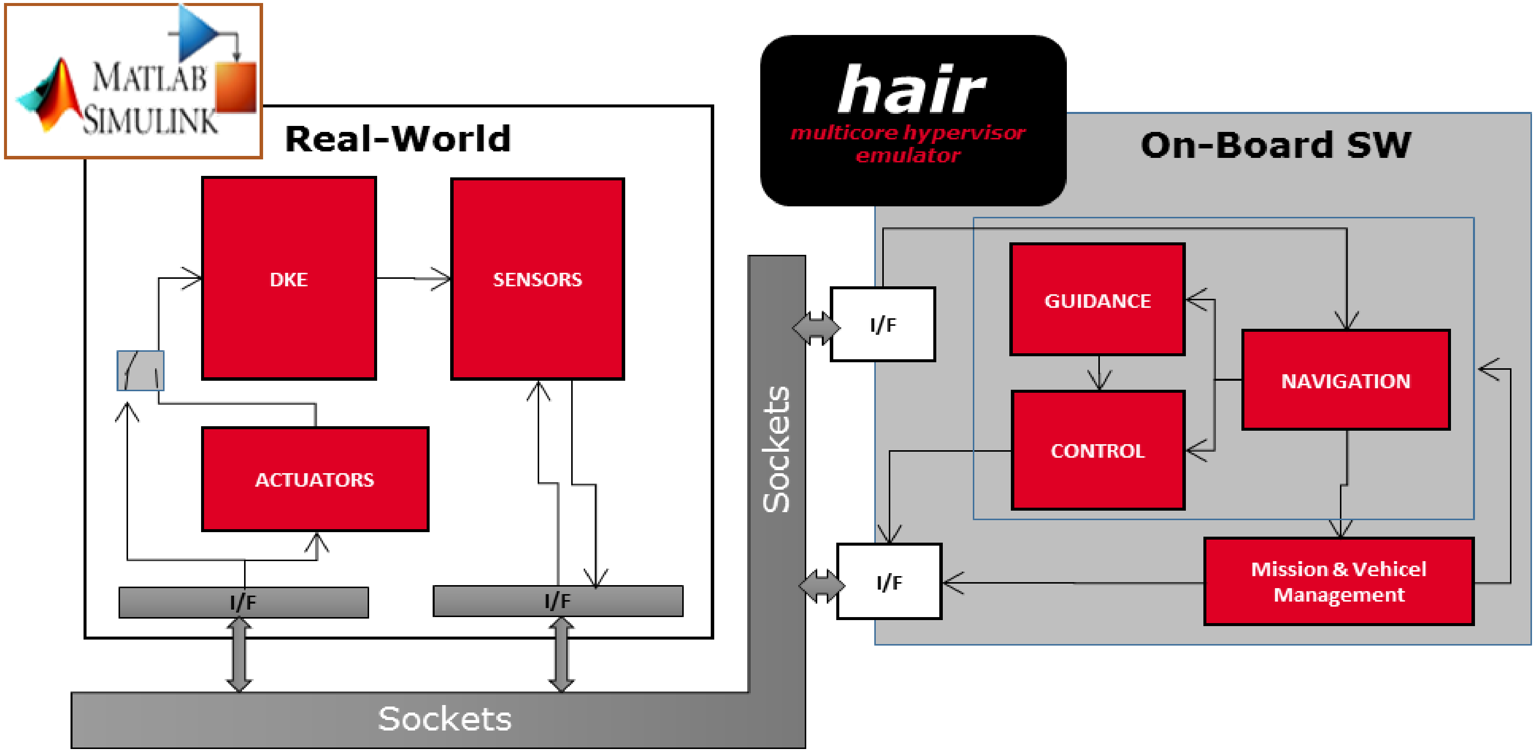
DDVV APPROACH





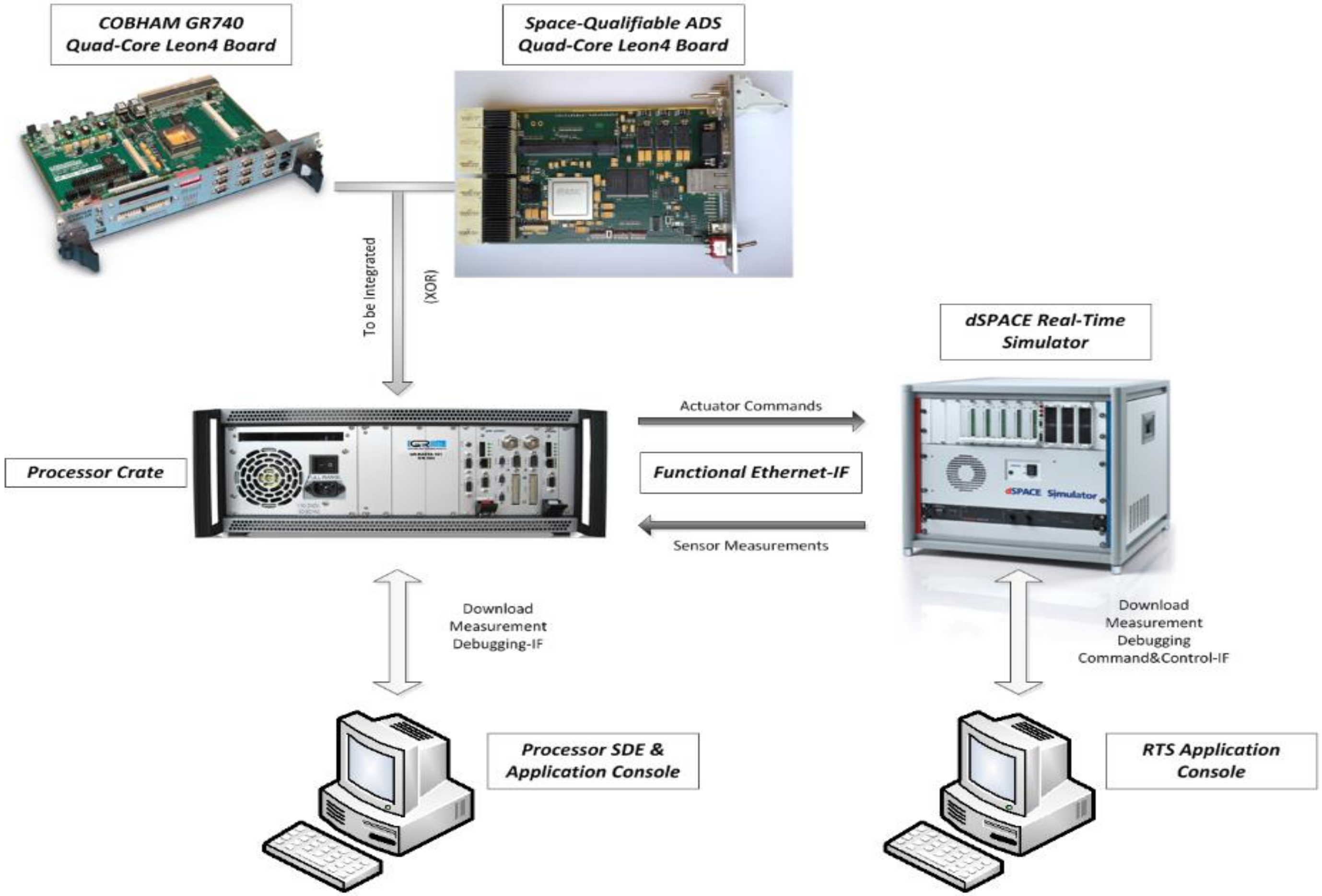
DDVV APPROACH

- SIL architecture



DDVV APPROACH

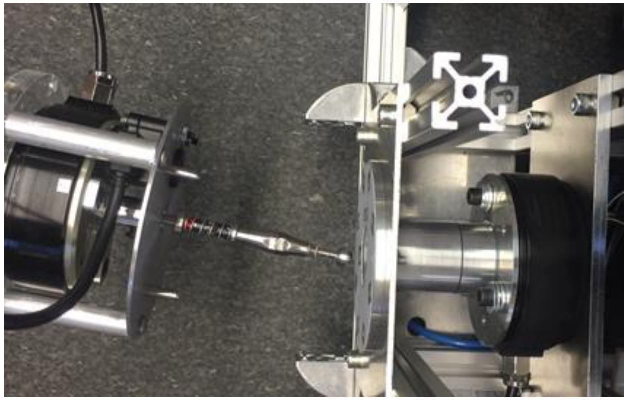
- PIL architecture



DDVV APPROACH

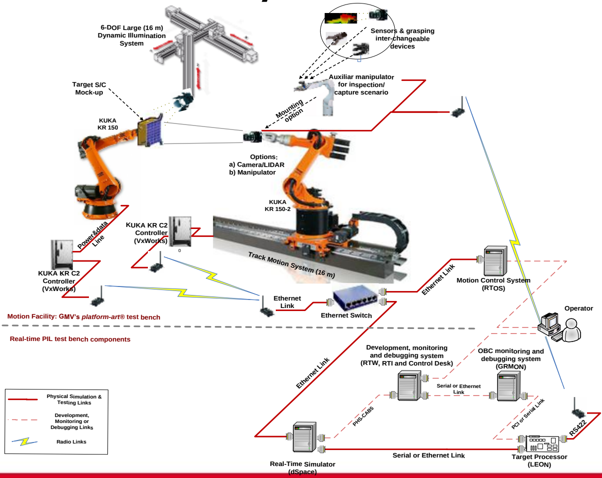
- Two HIL test scenarios are proposed:
  - 1) **eDeorbit** scenario: requires the use of a (COTS) 7DOF torque-controlled manipulator HW B/B suita-ble for implementing an active “compliant” control and a representative gripper HW B/B for proper compliant control testing and validation:
    - Use of air-bearing TB for high-fidelity experimental characterization of contact dynamics within eDeorbit scenario (2D version scenario, and using a space-representative gripper B/B).
    - Reproduction of same eDeorbit test cases (3DOF) in a robotics-based TB.
    - Perform a full HIL test campaign in the robotics-based TB covering all eDeorbit scenario phases (non-contact and contact)
  - 2) **ASSIST** scenario, using ASSIST B/B and a simple robotic manipulator with a low number of joints.+:
    - Use of air-bearing TB for high-fidelity experimental characterization of contact dynamics
    - Reproduction of same ASSIST test cases (3DOF) in a robotics-based TB

ASSIST at NTUA Space Emulator



OOS-SIM facility

***Platform-art* dynamic test bench**



Questions ?

Thank you

Fernando Gandía(GMV)