7th ESA Workshop on Avionics, Data, Control and Software Systems – ADCSS 2013

# Cost-effective Avionics Test Benches to support fast and iterative GNC Systems Design and Validation

V. Barrena (GMV)

© GMV, 2013 Property of GMV
All rights reserved

INNOVATING SOLUTIONS

# NEW TECHNOLOGIES: GNC CHALLENGES

- The big challenge of new technologies, particularly related to GNC systems, is to achieve a TRL (Technology Readiness Level) high enough before flying in order to minimize the failure risks.
  - Most of GNC related technologies need, in fact, to fly as experiment before being declared as validated for space use as mission baseline ➔ Expensive and low number of flight opportunities.

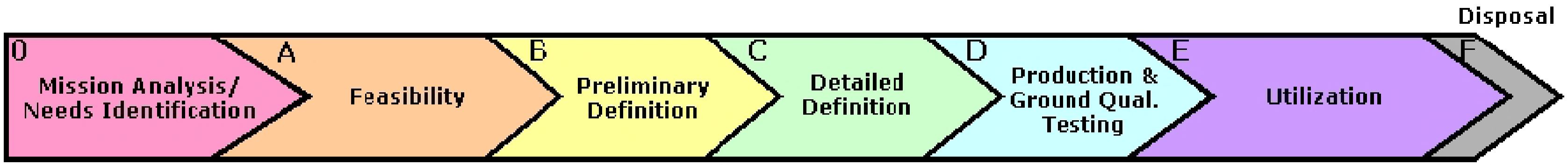
- In this context, it is fundamental to find different on-ground ways to increase the reliability/maturity level of the space technology/systems, and reduce the validation gap with respect to in-orbit validation/use.

- Dynamic HW-in-The-Loop test facilities allows to realistically reproduce on-ground the space dynamics (particularly true for low-dynamic scenarios, such as Formation Flying, RdD/RvC, In-Orbit Servicing and Active Debris Removal), include sensors with real air-to-air stimulation and validation till TRL 5/6 of GNC equipment and subsystems.


© GMV, 2013

# CLASSICAL DVV APPROACH

- Any space mission is composed by different phases ranging from the mission needs identification to the production of the different elements of the mission and its utilization during the mission lifetime

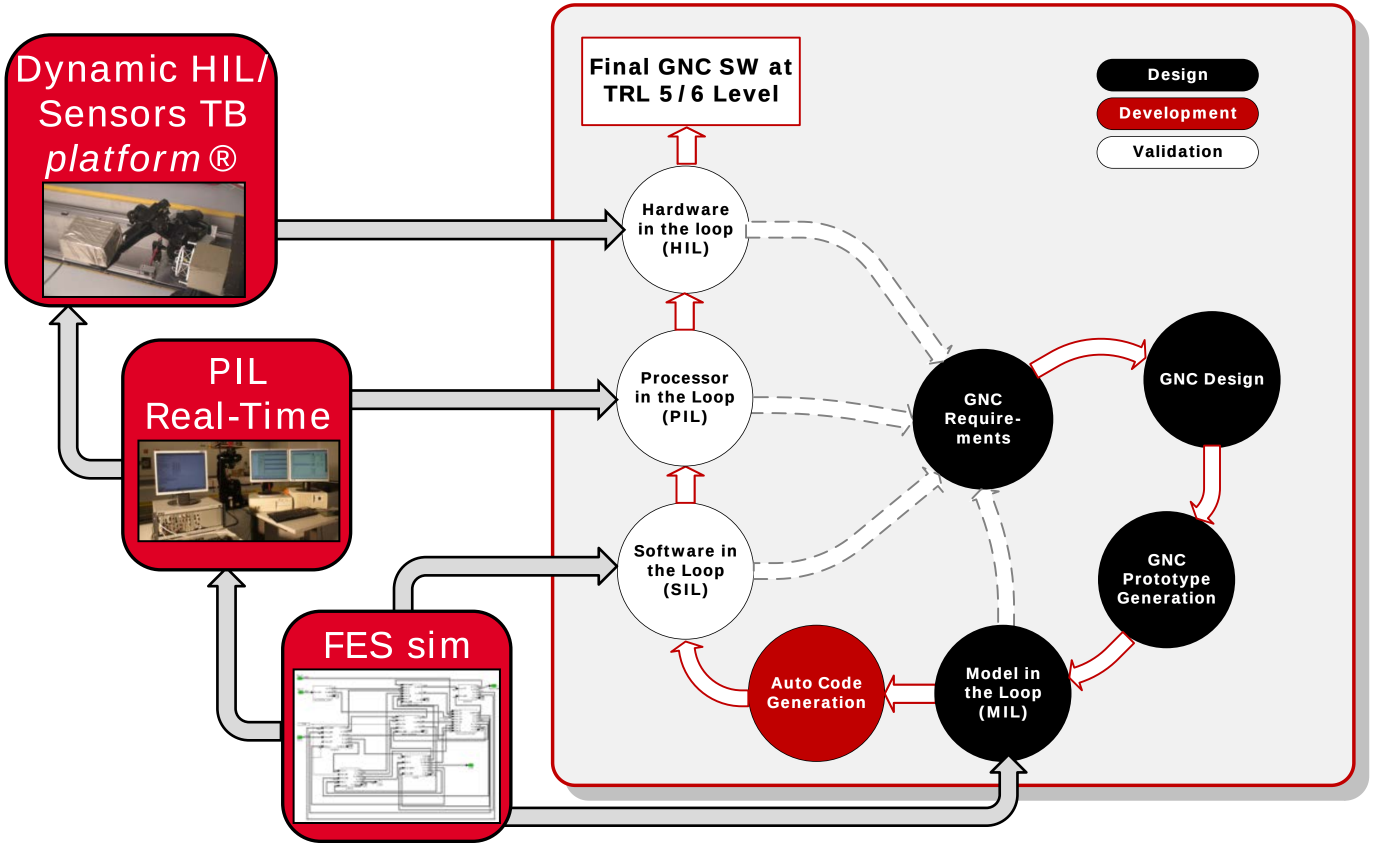



- Traditionally, each mission phase is performed by different types of engineer expert groups
  - The translation of the results from one phase to the next one is made through documentation and/or models specifications
  - Applicable to big projects with large development time scales and watertight development phases
  - But inappropriate in terms of cost-effectiveness related to technology development return (e.g. demonstration missions, precursor missions)
- Current challenges of the GNC systems demand compact, integrated and cost-efficient development cycles

 © GMV, 2013

# COST-EFFECTIVE GNC DDVV APPROACH

- GMV has defined and used in different ESA activities an incremental design and validation strategy for maximizing on-ground validation possibilities.



# COST-EFFECTIVE GNC DDVV APPROACH

- Starts by Model In the Loop (MIL, i.e.Matlab/Simulink) ➔ TRL=3
  - Functional Engineering Simulator (FES) as main conductive design supporting tool and verification at algorithm level. The FES simulator supports the full V-cycle for the GNC-ALG (Simulink algorithms).

- Continues through SW In the Loop (SIL, non real-time)
  - Intermediate step to verify the right coding of the algorithms.

- Arrives to Processor In the Loop (PIL, real-time) ➔ TRL=4
  - Allows testing the GNC SW in flight realistic conditions regarding the avionics (representative processor/s of the flight models)
  - Upgraded with sensor in the loop (stimulation based)

- Finalizes with Hardware in the Loop (HIL) ➔ TRL 5/6
  - With sensor in the loop in air-to-air stimulation conditions.
  - Space-representative relative motion generated by robotic devices synchronized with the GNC real-time host system and processor.

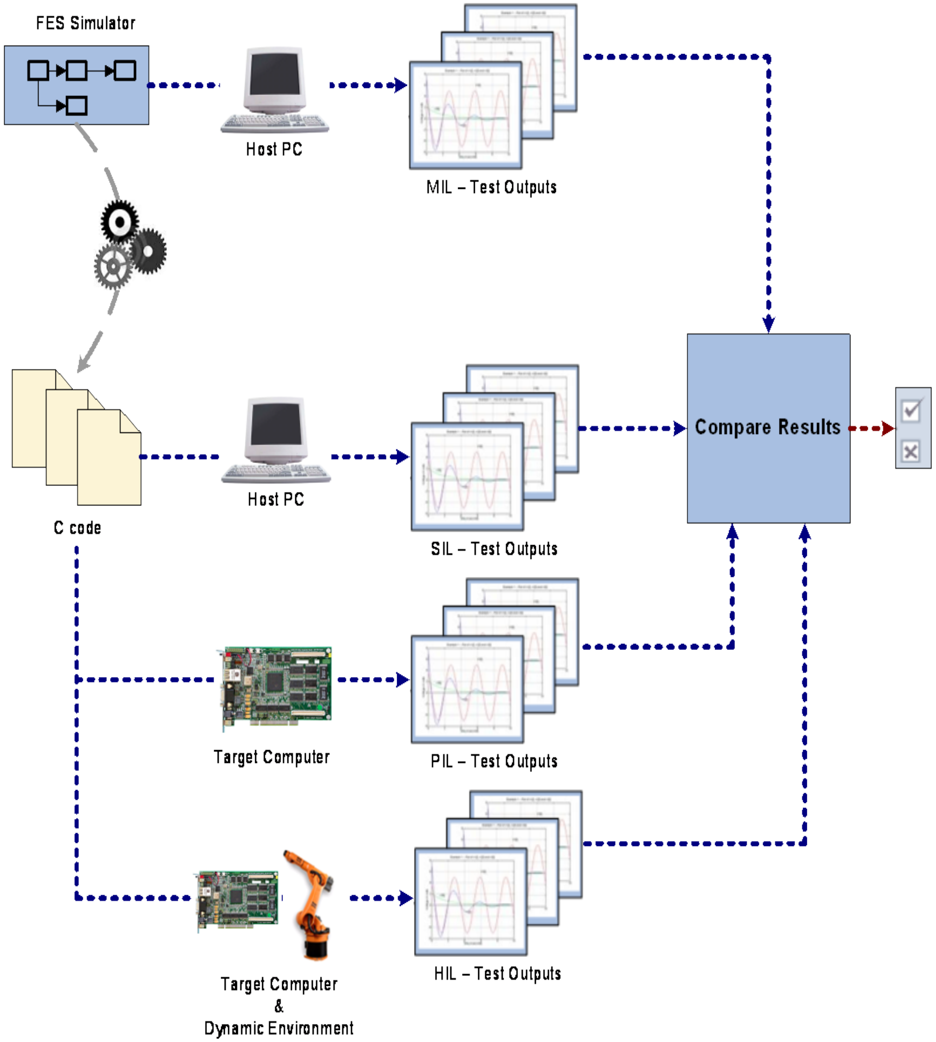
 © GMV, 2013

# DDVV APPROACH: AUTOMATIC VALIDATION

Automatic Validation :

- Automatic validation from FES to HIL:
  **FES➔SIL➔PIL TB➔HIL TB**

- Automatic Validation Process:
  1. Identify the performance metrics from the requirements.
  2. Formulate these identified performance metrics in terms of signal features which can be traced to the outputs.
  3. Obtain the features from the output of the simulations (output signal pre-processing).
  4. Evaluate these performance metrics obtained in MIL, SIL and/or PIL automatically.





© GMV, 2013

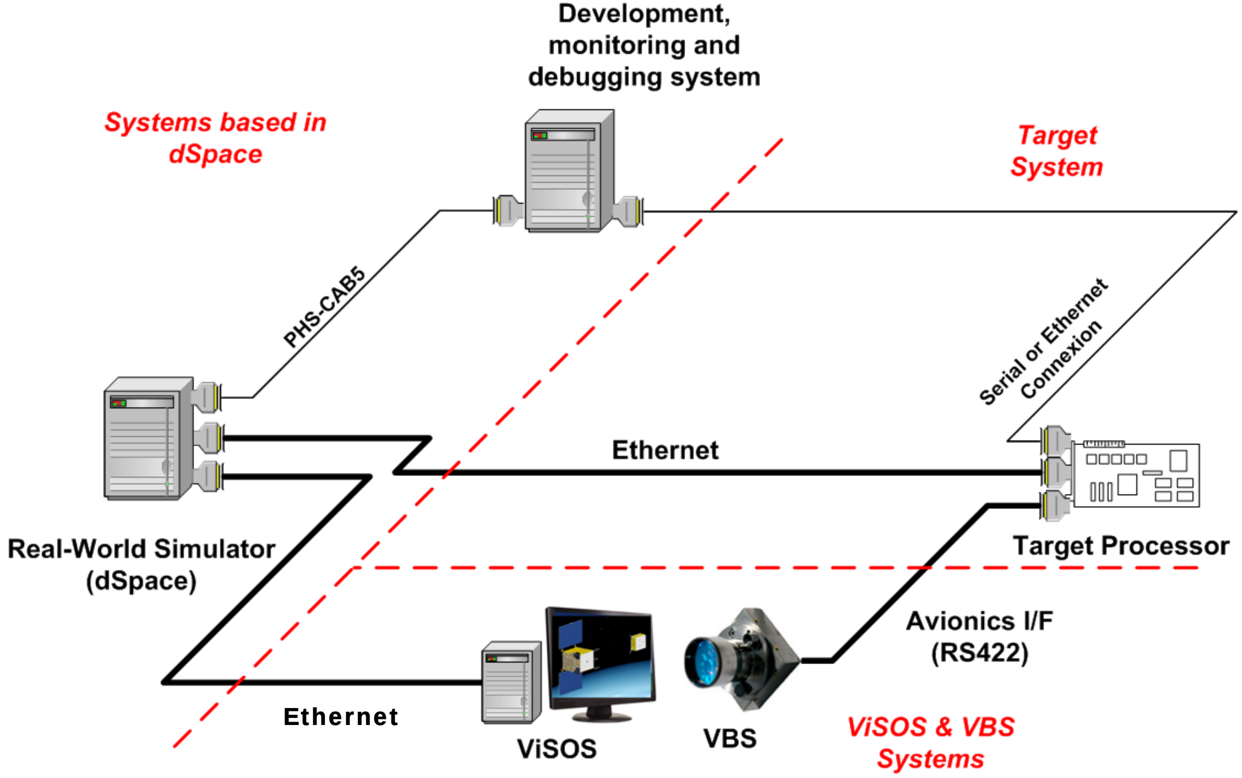
# DDVV APPROACH: VERIFICATION & VALIDATION

| Challenges to be tested | Type of Test/Test Bench | | | | |
|---|---|---|---|---|---|
| | FES (MIL) | FES (SIL) | Non-RT PIL | RT PIL | Dynamic HIL |
| GNC Functional Requirements | √ | √ | √ | √ | √ |
| GNC Performance Requirements | √ | √ | √ | √ | √ |
| GNC Design | √ | | | | |
| GNC Algorithms | √ | | | | |
| Autocoding Generation | | √ | | | |
| GNC Software Design | | √ | √ | √ | √ |
| Embedded code | | √ | √ | √ | √ |
| Algorithm robustness in the processor | | | √ | √ | √ |
| Compiler issues | | | √ | | |
| Code Performances (including timing) | | | √ | √ | |
| Algorithm robustness in real-time | | | | √ | √ |
| Real Metrology in the loop (functional) | | | | √ | √ |
| Real Metrology in the loop (performance) | | | | √ | √ |


© GMV, 2013

# PIL/HIL VALIDATION: STIMULATION BASED

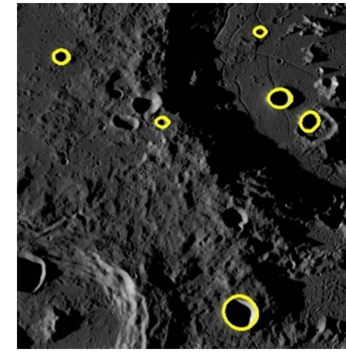
- Use of representative avionics (**RASTA system + FPGAs**)
- Real-World simulator (**dSpace system**)
- **Sensor Stimulator**
- **Sensor in the Loop**





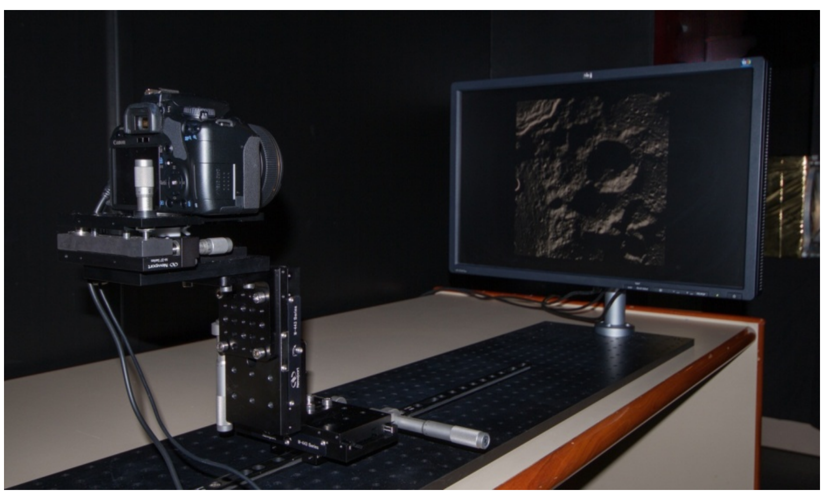
© GMV, 2013

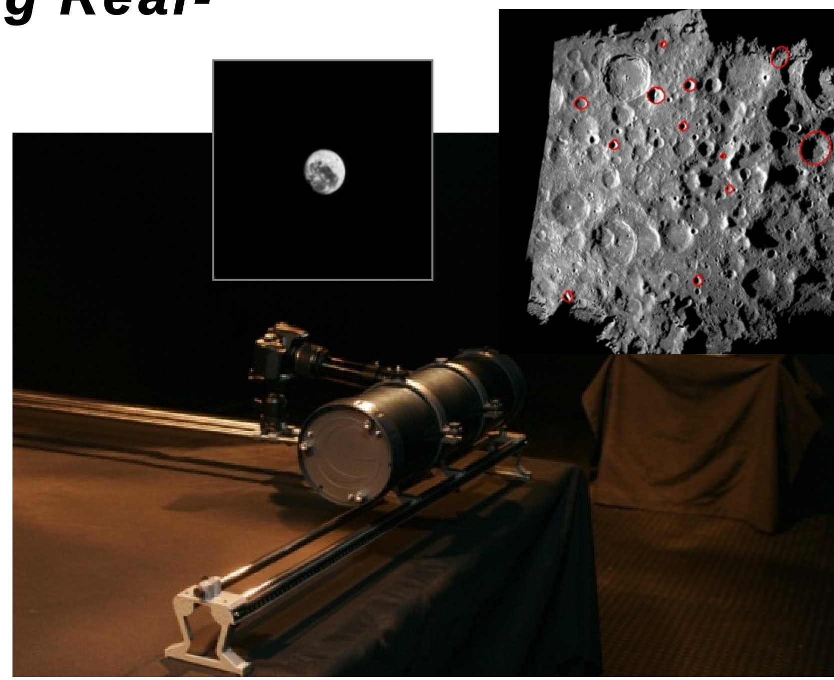
# GMV'S PIL/HIL TEST FACILITIES



- ***autolab*©: Autonomous Navigation Laboratory**
  - Suitable for autonomous optical based navigation on-ground tests

- ***RVD-RT: Rendez-Vous & Docking Real-Time Test Bench***
  - Rendez-Vous real time system
  - Upgraded with ViSOS from DTU

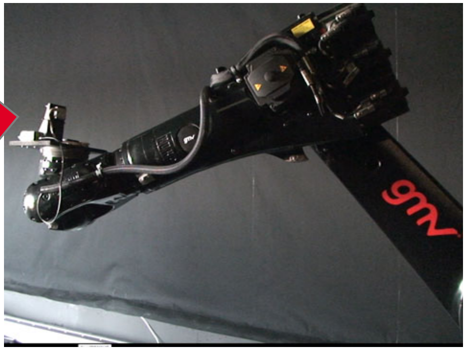





© GMV, 2013

# *platform-art®* DYNAMIC TEST FACILITY

- GMV's Dynamic Test Bench with real air-to-air metrology stimulation
- Allows use of sensors measurements in the loop through the recreation of relative trajectory and attitude profile by using robotic arms
- Sensors installed on-board the mock-ups experiment the same relative kinematics and produce the same measurements as in space environment



VBS by DTU

Chaser mock-up
Left:Lidar by Jena-optronik,
Right: COTS visual camera

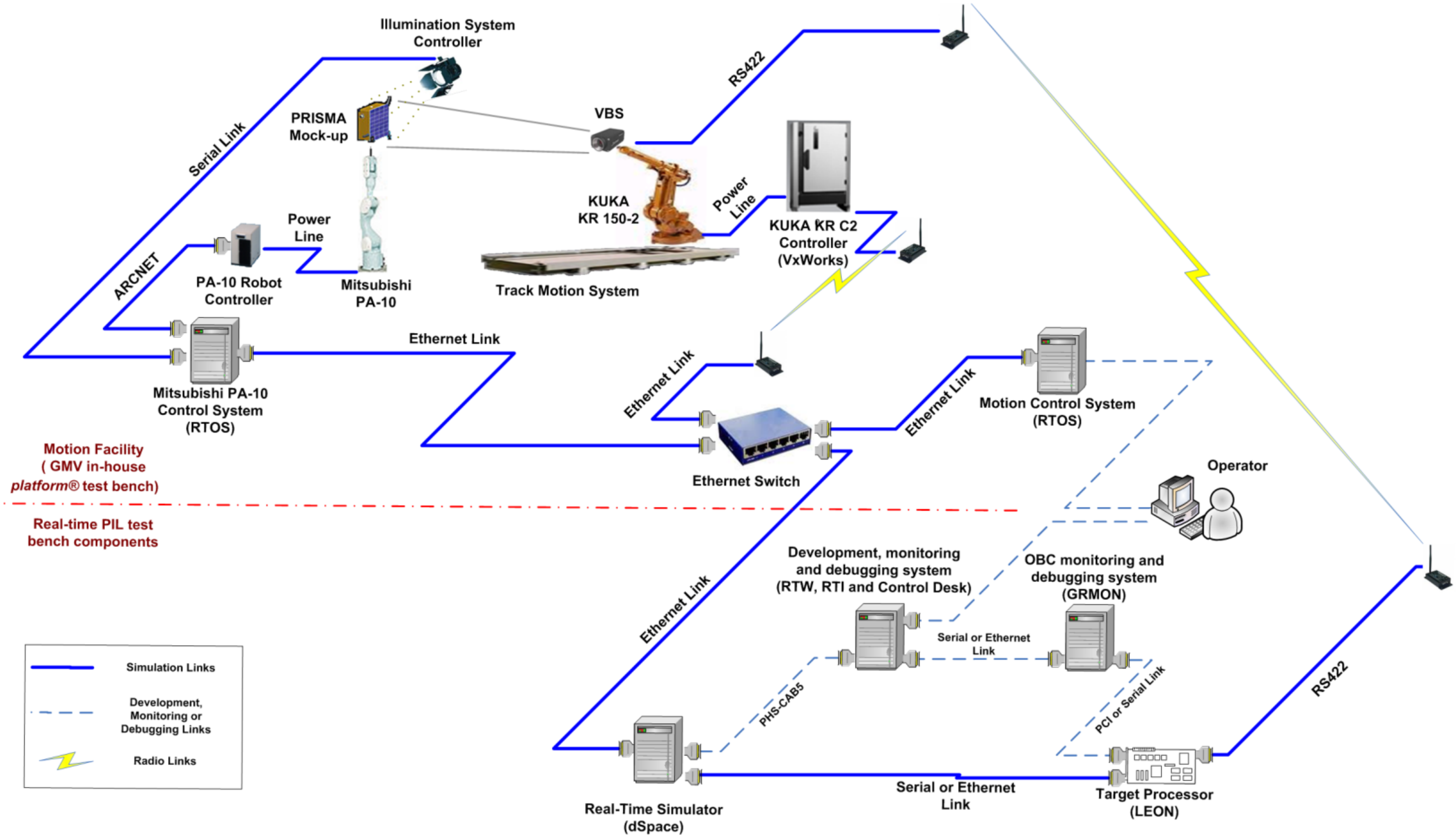

© GMV, 2013

# *platform-art®* DESCRIPTION

- Functional features:
  - Dynamic test bench with real air-to-air metrology stimulation
  - Compatible with GMV's Avionic Testbenches
  - Raises the GNC S/S (SW+sensors) validation till level TRL 5/6
  - Two numerically controlled robotic arms + 15 m length rail, allowing:
    - Short-range ADR, RdV and FF scenarios (up to 525 meters using scalability factor 1:35, reasonable for 1 m S/C size level; can be higher for bigger S/C), including GNC mode transition, scenario stop/resume, change of sensors, …
    - NEO or planetary landing (scaled scenarios)
- Performance features:
  - Dynamic range: 18 m
  - Accuracy: O(0.1 mm) (FARO laser tracker calibration)
  - Resolution: < 0.01 mm
  - Mock-ups (Inc. metrology): <150 kg, sensors remote control
  - Darkness: full darkness room (optical spectrum)
  - Illumination: space representative at optical spectrum

 © GMV, 2013

# *platform-art®* ARCHITECTURE

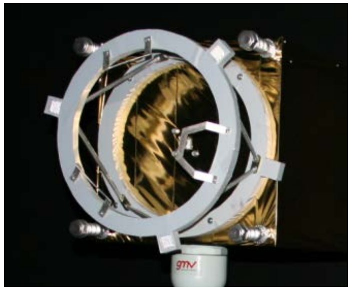




© GMV, 2013

# USE CASE 1: ESA HARVD GNC FOR RVD / RVC

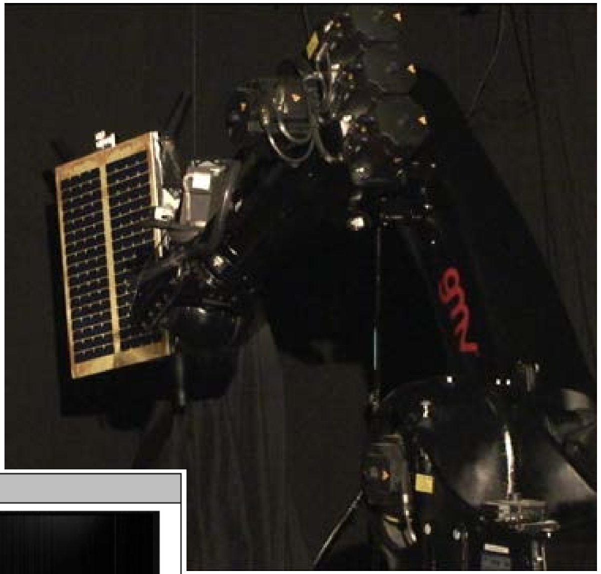
- HARVD GNC autonomous scenarios:
  - Mars Sample Return mission –capture phase
  - Earth in-orbit servicing
- The sensors electrical models mounted on board the mock-up are:
  - Imaging Lidar Technology (ILT) LIDAR breadboard from JenaOptronic/ESA, for fine range and lateral metrology.
  - Optical navigation camera (from GMV), for acquiring relative navigation observations with real IP function.

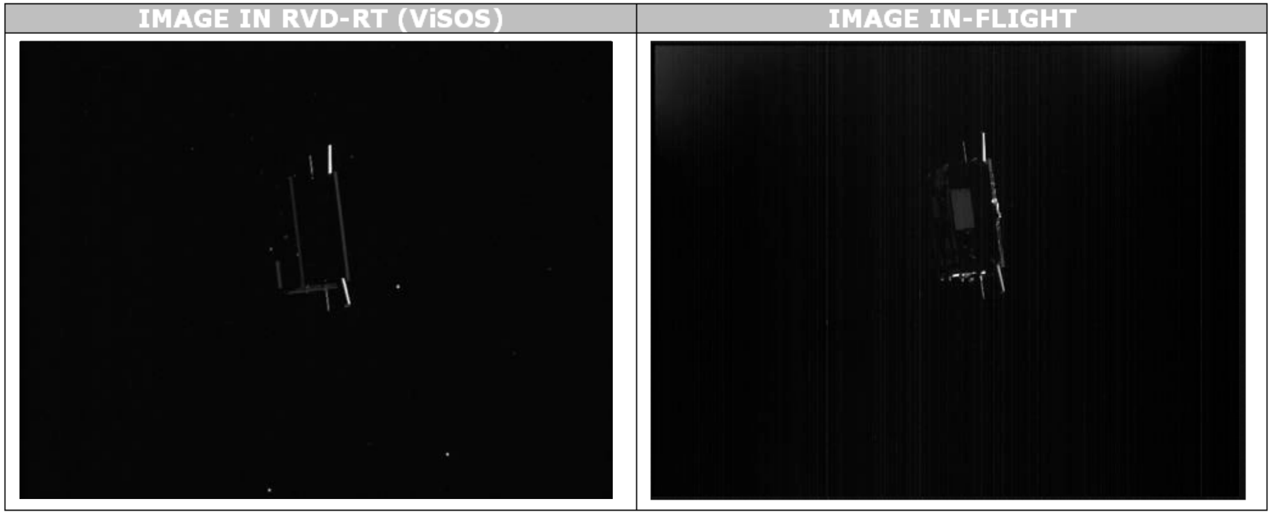


© GMV, 2013

# USE CASE 2: PRISMA-HARVD EXPERIMENT REPRODUCTION ON-GROUND

- MSR-like trajectory exercised on PRISMA mission:
  - Based on FFRF and VBS measurements
  - Validation of the GNC system
- VBS from DTU included in-the-loop:
  - ViSOS system + RVD-RT laboratory
  - *platform-art*® with scaled mockups at 1:1 and 1:35

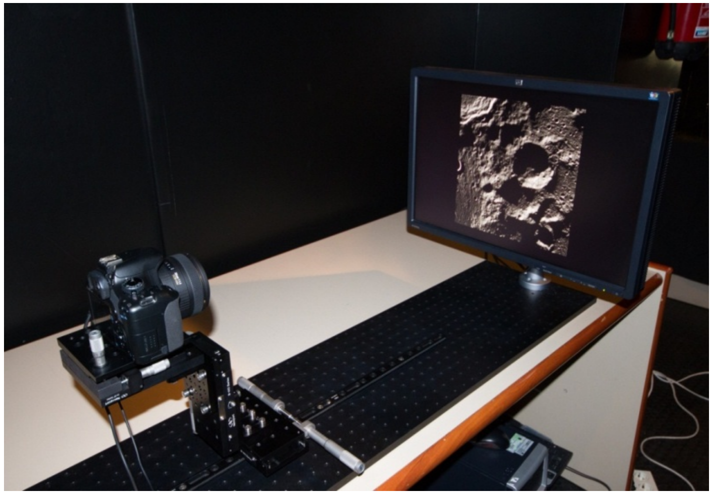





 © GMV, 2013

# USE CASE 3: VISONE AND ANTARES

- Absolute navigation system for the Lunar Lander
  - Image Processing algorithms implemented in HDL in a FPGA
- Validation with COTS camera in the loop:
  - Based on visual stimulation (COTS camera accurately positioned in front of high definition screen)
  - Based on physical stimulation (scaled 3D mockup of the Moon surface) in *platform-art*®



 © GMV, 2013

# CONCLUSIONS

- An **incremental nested design / validation loop** has been used and demonstrated in several ESA activity (and in on-going activities ADR, Autonomous RVD, NEO GNC).
  - The final use of dynamic test facility has allowed to realistically test **GNC systems** with space representative dynamics, **air-to-air sensors stimulation**, and with representative real-time Avionics platform.
  - GNC system has been **validated till TRL ~5** (wrt achieved TRL 3/4 level if not using a dynamic test facilities). TRL 6 would be also achievable by using more representative avionics.
- Dynamic test benches has demonstrated to be a **very cost-effective solution** towards **increasing the validation level** and maturity of GNC systems and GNC sensors.
- The described approach is fully **applicable to** similar scenarios, such as **Formation Flying**, **In-orbit Servicing**, **In-orbit Assembly** and **Active Debris Removal** (ADR) scenarios (e.g. capture/berthing/grasping mechanisms systems and proximity/synchronization GNC modes/systems).


© GMV, 2013

# Thank you

**COST-EFFECTIVE AVIONICS TEST BENCHES TO SUPPORT FAST AND ITERATIVE GNC SYSTEMS DESIGN AND VALIDATION**

Valentín Barrena (vbarrena@gmv.com)

gmv® INNOVATING SOLUTIONS