EROSS PROJECT – EUROPEAN AUTONOMOUS ROBOTIC VEHICLE FOR ON-ORBIT SERVICING

i-SAIRAS Virtual Conference 19–23 October 2020

V. Dubanchet[1], J. Bejar Romero[2], K. Nyborg Gregertsen[3], H. Austad[3], J. Gancet[8], K. Natusiewicz[4], J. Viñals[6], G. Guerra[6], G. Rekleitis[5], I. Paraskevas[5], K. Nanos[5], E. Papadopoulos[5], L. Majewski[7], S. Ferraris[9], J. Purnell[10], D. Casu[1], J. D'Amico[1], S. Andiappane[1]

1- *Thales Alenia Space – 5 allée des Gabians, 06150 Cannes (France) -vincent.dubanchet@thalesaleniaspace.com*
2- *GMV – Isaac Newton, 11, P.T.M. Tres Cantos, E-28760 Madrid (Spain) - jabejar@gmv.com*
3- *SINTEF Digital – Strindvegen 4, Trondheim (Norway) - kristoffer.gregertsen@sintef.no*
4- *PIAP-Space – Al.Jerozolimskie 202, 02-486 Warsaw (Poland) - krzysztof.natusiewicz@piap-space.com*
5- *NTUA University – Heroon Polytechniou 9, 15780 Zografou, Athens (Greece) - georek@central.ntua.gr*
6- *SENER – Cervantes Kalea, 8, 48930 Getxo, Bizkaia (Spain) - javier.vinals@aeroespacial.sener*
7- *SODERN – 20 avenue Descartes, 94451 Limeil Brévrannes (France) - laurent.majewski@sodern.fr*
8- *SAS – Leuvensesteenweg 325, 1932 Brussel (Belgium) - jeremi.gancet@spaceapplications.com*
9- *Thales Alenia Space – Str. Antica di Collegno, 253, 10146 Torino TO (Italy) - simona.ferraris@thalesaleniaspace.com*
10- *Thales Alenia Space – Business Park, Coldharbour Ln, Stoke Gifford, Bristol (UK) - joseph.purnell @thalesaleniaspace.com*

ABSTRACT

Current robotic developments for space application are making on-orbit servicing missions closer to reality, while also paving the way for future challenges like autonomous rendezvous with celestial bodies or active debris removal. Such technologies are being developed and integrated towards an experimental ground demonstration under the H2020 "European Robotic Orbital Support Services" (EROSS) project. It aims at developing, integrating and demonstrating the key European robotic building blocks within an autonomous solution for servicing tasks in orbit.

EROSS assesses and demonstrates the capability of a servicing spacecraft to perform medium and close-range rendezvous, and then to capture and manipulate a client satellite with a highest degree of autonomy. The client satellite is considered collaborative and prepared as it is designed with specific features to ease the rendezvous and capture. More importantly, it is assumed to be designed for servicing operations such as refuelling and payload replacement.

This project is led by Thales Alenia Space with support from GMV, National Technical University of Athens, PIAP Space, SENER, SINTEF AS, SODERN, Space Application Services, with additional collaboration with MDA and QinetiQ.

EROSS project is co-funded by European Union's Horizon 2020 research and innovation program under grant agreement N°821904 and part of the Strategic Research Cluster on Space Robotics Technologies as Operational Grant n°7.

1. INTRODUCTION

This paper presents the EROSS architecture for the autonomous performance of the final rendezvous, capture, refuelling and servicing of a Client spacecraft by a Servicer robotic vehicle. The EROSS Guidance, Navigation and Control (GNC) and autonomy layers are built upon the past Operational Grants (OG) led in the scope of the Strategic Research Cluster (SRC) on Space Robotics.

It reuses and integrates the ESROCOS software layer from OG1 [1], the ERGO autonomy framework of OG2 [2], the INFUSE data processing of OG3 [3], the I3DS sensors integrated through an ICU processing board within OG4 [4], the SIROM standard interface from OG5 [5], and the validation facilities from OG6. In parallel, EROSS project also integrates customized elements as a robotic arm, the ARAMIS rendezvous sensor, the ASSIST docking and refuelling interface, and a capture gripper.

The system design and the coordination of these Hardware (HW) and Software (SW) building blocks are presented in the sequel. For more details, see [6].

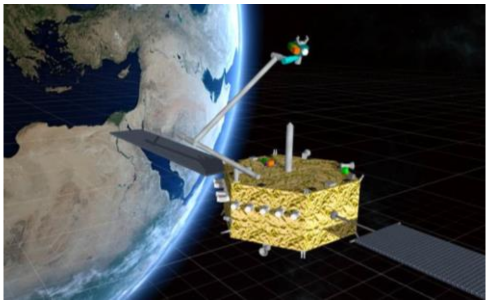


Figure 1: EROSS servicer overview

2. HERITAGE FROM PAST OGS

The heritage from the five past OG from 1 to 5 is presented below, before detailing the system design.

2.1. OG1 - ESROCOS

ESROCOS [1], European Space Robotics Control and Operating Software, is a framework that combines development tools and runtime components to build space robotics software. ESROCOS is based on the TASTE framework, developed by ESA. TASTE provides the capabilities to model critical real-time software and generate code from the models. The modeling capabilities of ESROCOS are completed with a new paradigm of robot modeling based on composability.

In EROSS, ESROCOS framework is used to model the EROSS Demonstrator HW and SW components, to implement the interface between Mission and Vehicle Management (ERGO agent) and functional layer (GNC functions); and the interface of the GNC functions with the sensors and actuators.

2.2. OG2 - ERGO

ERGO [2], European Robotic Goal-Oriented Autonomous Controller, is a framework provides packages and components for controlling a robotic platform that requires a high level of autonomy. ERGO is composed of a Core Framework providing the tools to build a set of Reactors (functional blocks, responsible of a single control loop) that are connected via a generic robotic controller and embedded into an Agent. It also includes the Ground Control Interface that handles the TM&TC function, providing autonomy services defined in the ECSS standards. It integrates the Stellar Mission Planner, designed specifically for space robotics applications. Finally, a set of tools allows for the formal verification of the system and FDIR modeling.

In EROSS ERGO framework will be in charge of handling full spacecraft mock-up resources, different types of robotics operations in the frame of on-orbit servicing operations with the goal of maximizing the operations in autonomy level E3.

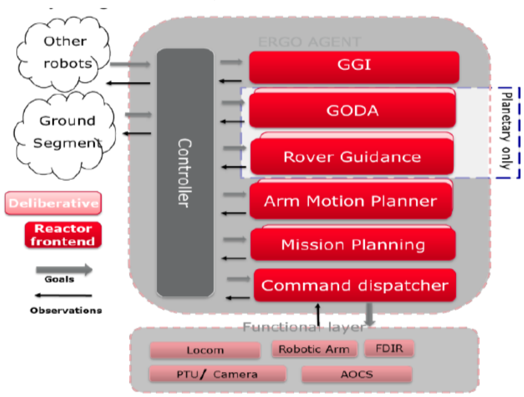


Figure 2: Generic ERGO architecture

2.3. OG3 - INFUSE

InFuse [3], Infusing Data Fusion in Space Robotics, provides a framework for the development, evaluation and deployment of space robotics data fusion technologies. Any data fusion process developed using InFuse will be portable to target architectures with limited efforts due to standardized software interfaces. InFuse has mechanisms to select and parametrize its processes on the basis of requirements expressed by ERGO and provides it with data products resulting from sensors data fusion. InFuse controls the set of operational modes available in I3DS and a limited set of internal parameters of the sensors. Data fusion capabilities in the InFuse framework are stereo vision based target detection, image based target tracking, point cloud based tracking, 3D reconstruction, 3D tracking and visual servoing.

In EROSS, InFuse is used to design the image processing solution feeding the navigation filter describe in the following. The Client spacecraft is detected and tracked thanks to model-based and marker-based methods for the approach and robotic capture.

2.4. OG4 - I3DS

The I3DS project [4], Integrated 3D Sensors, provides a modular sensor suite interfaced through a unique processing interface with the system platform. It relies on standardized interfaces for the different classes of sensors such as cameras, LIDAR's, star trackers, IMU's etc., independent of the actual sensor hardware implementation. This allows for greater flexibility and modularity when the sensor suite for a space mission is composed and updated. The sensor interfaces are based on the ASN.1 message format as specified by the ESROCOS middleware. This work followed the design patterns of ESROCOS and is state-of-the-art within its domain.

The OG4 Zynq ICU is based on the Xilinx UltraScale+ and represents state of the art in terrestrial MPSoC FPGA technology. The targeted networking architecture for I3DS is SpaceFibre which represents state of the art in the Space industry with the standard released on 2018.

2.5. OG5 - SIROM

SIROM project [5, 7, 8], Standard Interface for Robotic Manipulation, focused on the design, prototyping and testing of a robotic interface blocks for operation in space environments (orbital and planetary). SIROM is a multi-functional (4-in-1 functionalities) intelligent interface combining the following in a single and integrated form: mechanical, electrical, fluid and data interface.

3. MISSION DESCRIPTION

The EROSS project focuses on the demonstration of:

- **Mating**: final approach, berthing position keeping, coordinated and compliant robotic capture;
- **Servicing**: docking and refuelling through, robotic exchange of an orbital replaceable unit.

3.1. MISSION

The complete phases of the mission are:

- **Final Rendezvous** : it includes the Client search, its detection, acquisition and tracking, along with the final forced motion manoeuver to reach the berthing position
- **Berthing**: once the berthing box on the side of the Client is reached, the Servicer grasps it by its robotic arm, and dampen the impact vibration to stabilize the composite system.
- **Servicing**: the two spacecraft linked by the Servicer robotic arm are mated through the ASSIST refuelling interface, allowing to release then the robotic arm for an exchange of Orbital Replacement Unit (ORU) between the Servicer and the Client using the robotic arm.
- **Separation**: following the same steps in the opposite order, the two spacecraft are eventually released after a separation by the robotic arm for safety.

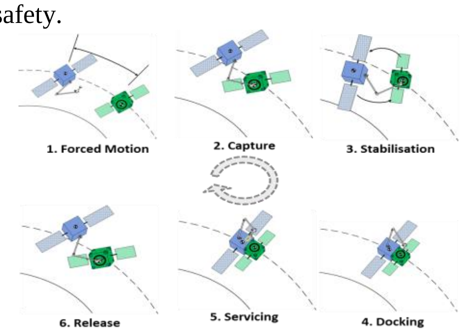


Figure 3: EROSS mission steps

3.2. MAIN REQUIREMENT

Among the system requirements driving the design of such a mission, the main one is the **need for autonomy** all along the final rendezvous phase. According to the ECSS Space Segment Operability document [10], four main autonomy levels can be identified:

- **E1**: execution under real-time ground control,
- **E2**: execution of pre-planned mission operations on-board through an embedded scheduler;
- **E3**: execution of event-based autonomous operations with embedded control procedures;
- **E4**: execution of goal-oriented mission operations on-board with re-planning capabilities.

In that respect, the EROSS mission targets to **reach the E3 level of autonomy** from the last forced motion, until the capture and start of the servicing tasks.

4. SYSTEM DESIGN

The whole system is built upon a ground link between the two operators of the Servicer and Client spacecraft. This link allows to synchronize the different spacecraft modes of operations to initiate the servicing mission.

In the next paragraphs, the Servicer architecture is detailed to highlight the reuse of the past OGs and the integration of new building blocks within an integrated design not only suited for on-orbit servicing missions but also for future rendezvous scientific missions like celestial bodies inspection or sample capture and return.

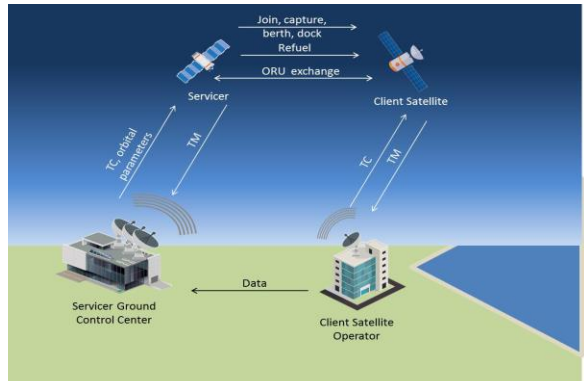


Figure 4: EROSS system overview

4.1. SERVICER ARCHITECTURE

The Servicer design is illustrated in Figure 1 through a general overview. The product tree of the system is detailed hereunder and is articulated along two main domains: the platform and the robotic subsystems, considering that the platform is dedicated to rendezvous and inspection while the robotic arm is seen as a sort of payload for the capture and servicing tasks. The following simplified product tree focuses on the main Guidance, Navigation and Control (GNC) elements at both HW and SW levels.

PLATFORM subsystems

The traditional platform elements cover :

- **[HW] OBC board**: a standard On-Board Computer (OBC) is considered to run the required layers of communication, Failure Detection, Identification and Recovery (FDIR), Attitude and Orbit Control System (AOCS), thermal management, etc. This OBC is interfaced with the RCUs dedicated to the relative motion control.
- **[HW] Inertial sensors**: a traditional suite of inertial sensors is used to perform the spacecraft AOCS with start trackers, GNSS, Inertial Measurement Unit (IMU).
- **[HW] Inertial actuators:** traditional Thrusters (THR) and Reaction Wheels (RW) actuators are used to control the orbit and relative motion.
- **[SW/OBC] OBSW**: the On-Board Software allows to handle the functions mentioned above, and is interfaced with the GNC application focused on the relative motion. In that respect, AOCS functions provide the inertial measurements to the GNC algorithms for rendezvous.

In parallel, the approach and inspection of the target for the rendezvous phase requires the additions of:

- **[HW] RCU board**: this processing board is dedicated to the management of the relative sensors in terms of command and acquisition, as well as data processing and fusion. It hosts I3DS and InFuse algorithms to feed the navigation filter in GNC.
- **[HW] Relative sensors**: the platform embeds a subset of the previous I3DS sensors on its upper panel with a Narrow and a Wide angle camera (N/W-AC), a pattern projector for 3D measurements, and the ARAMIS sensor featuring the visible and thermal line for rendezvous in eclipse.
- **[HW] Relative actuators**: two main actuators are used for the servicing tasks mainly with the ASSIST refuelling interface also used as a latching system, and SIROM interfaces used to (un)latch and exchange the ORUs with the Client, and located on the side of the Servicer platform.
- **[SW/OBC] GNC application**: the sensors and actuators are commanded through the RCU and OBC using the algorithms running within the GNC application, in close correlation with the AOCS applications for inertial functions, as presented in the following GNC section.
- **[SW/OBC] ERGO autonomy layer**: the ERGO framework is considered as an application running on the OBC to orchestrate the GNC functions and ensure the proper E3 level of autonomy by translating high-level ground command into on-board commands and required modes triggers.
- **[SW/RCU] InFuse navigation algorithms**: the data processing of the relative sensors is performed by a dedicated avionics board called Robotic Control Unit (RCU) en described hereunder. This element allows the demanding processing of large data sets in a timeframe compatible with agility and autonomy requirements.

ROBOTIC subsystems

The robotic arm is considered as a payload mounted on the Servicer platform, as the ORU equipments to be exchanged with the Client. It is made up of :

- **[HW] Robotic arm:** it is made up of the structure of the robotic arm segments and of the joint motors and electronics, as described in the following.
- **[HW] RCU board**: another processing board is dedicated to the robotic sensor data processing and fusion. It hosts still I3DS pre-processing and other type of InFuse algorithms to feed the robotic navigation layer in the GNC application.
- **[HW] Robotic sensors**: the robotic end-effector embeds another wide angle camera coupled with a pattern projector as well to allow the 2D vision and the 3D measurement of the scene being face to perform the Client capture, and the ORU manipulation for servicing tasks or any assembly. In addition, the end-effector is equipped with a Force/Torque sensor to perform the compliance control of the gripper during the capture phase.
- **[HW] Robotic actuators**: apart from the robotic joints themselves, another set of robotic actuators is used with a capture gripper designed to grasp the Client spacecraft on its Launch Adaptor Ring (LAR), while a SIROM interface is also embedded on the end-effector design to grasp the ORU.
- **[HW] ORU Unit**: the arm is used to perform the ORU exchange during the servicing phase. These units consists in a payload (e.g., a camera or a sensor) with SIROM connectors on both side to latch it on the hosting platform, and for being manipulated by the robotic arm.

Among the previous equipments, some of them are reused and improved from the past OGs presented above, while others are new subsystems being integrated in the EROSS project to complete the solution of the H2020 SRC in Space Robotics.

4.2. PREVIOUS SUBSYSTEMS EVOLUTION

RCU processing unit

The Robotics Control Unit (RCU) is an evolution of the Instrument Control Unit (ICU) from the I3DS programme, offering more interfaces and greater processing power. The RCU is based on a Xilinx Zynq UltraScale+ architecture, offering a powerful processing system with both hard ARM processor cores and FPGA fabric in a single piece of silicon. This enables the RCU to interface with the large suite of sensors used in EROSS, implementing both standard interfaces (e.g. SpaceWire, SpaceFibre, CAN, 1553) and bespoke interfaces through the use of the FPGA fabric. System software can access these hardware interfaces directly via an on-chip bus and provide data processing and control functions. The large FPGA logic resources can further be utilised to provide hardware-accelerated functions such as image processing routines, and the high-speed SERDES support next-generation SpaceFibre data links. The RCU provides an excellent development platform for EROSS while remaining aligned with the route-to-flight hardware: the upcoming “NG-Ultra“ European FPGA from NanoXplore.

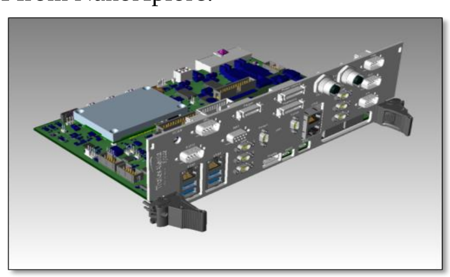
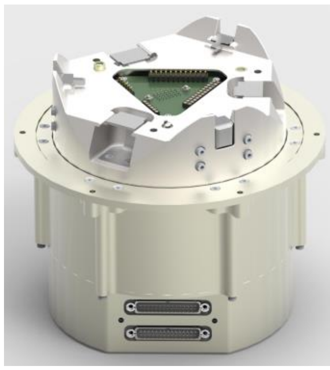


Figure 5: RCU CAD rendering

SIROM interface evolution

The first SIROM product from OG5 project achieved a Technology Readiness Level (TRL) 4 but did not integrate the electronics in a single envelope. Also, these electronics consisted of commercial off-the-shelf (COTS) components not flight proof.



To continue with SIROM development, SENER has developed an integrated product for EROSS combining the mechanics and flight proof electronics, resulting in a simple and compact mechanism [9]. This new version features spring-loaded pins allowing the implementation of more transmission lines; besides the latching time has been decreased based on OG5 heritage (down to 15s), smoother guiding petals geometry have been used, latch backlash has been removed, the number of moving parts has been reduced, and the assembly procedure has been optimized, etc.

Internally, SENER has foreseen a specific test campaign to reach qualification level (TRL5-6) by early 2021 for this new SIROM version.

Structured Light with Camera/Pattern projector

Robot vision – 2D and 3D – is of essence in robotics and autonomy on the ground, as well as in Space. The pattern illumination projects pattern sequences onto the scene to derive 3D measurements over it. This solution is developed by SINTEF A/S since I3DS project, and being actively improved on EROSS at TRL and performances levels.

Technically, the projector is combined with a 2D camera for triangulation and point cloud derivation. The benefit of pattern projection versus stereo imaging is that it is not required to simultaneously see features in the two stereo images, and it is possible to do measurements in all the camera's pixel points in parallel. In addition, using the proper filters, 3D image using pattern projection enables measurements simultaneously in sunlit and shadow regions thanks to its local illumination.

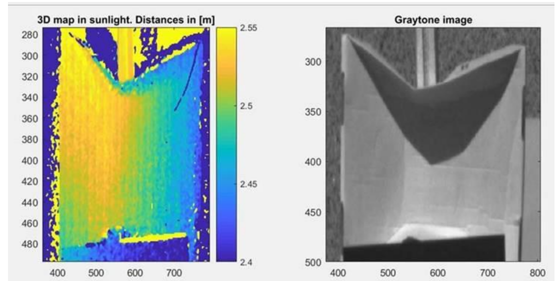


Figure 6: Example of Structured Light 3D map

4.3. NEW SUBSYSTEMS INTEGRATED

ARAMIS sensor

SODERN is currently developing a passive rendezvous sensor for upcoming on-orbit servicing missions and active debris removal. Based on passive sensing in the infrared and visible bands, ARAMIS which stands for Approach and Rendezvous Autonomous Multi-mission Integrated Sensor, is being designed to support all phases of a rendezvous with cooperative and uncooperative targets, from far range to close range and proximity operations.

The basic architecture of the smart sensor is that the optical heads connect to a high performance electronic unit running advanced algorithms allowing the delivery of a target's LOS in far range and of the relative range and relative attitude (6 DoF pose) in close range using the 3D model of the target.

ARAMIS-eXGS (for embedded eXperimental Ground Sensor) is a demonstrator of a distributed version of ARAMIS focusing on close range rendezvous that is being implemented in the frame of EROSS using COTS cameras and one of the RCU processing board to run the 6 DoF pose estimator.

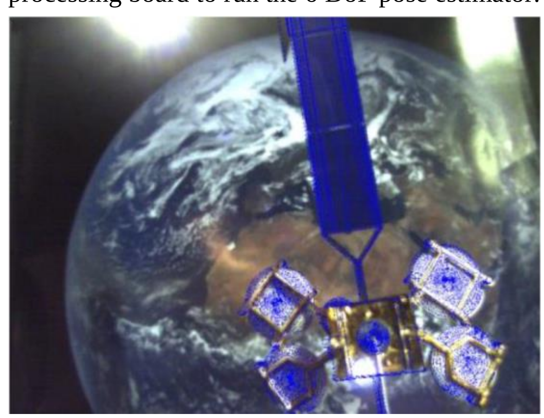


Figure 7: Example of ARAMIS 3D pose estimation

ASSIST refuelling

ASSIST, known as “hArmonised System Study on Interfaces and Standardisation of fuel Transfer”, is the HW building block in charge of implementing the docking and refuelling operations in the frame of EROSS project. The following figure represents the key elements of the ASSIST breadboard models to be mounted on EROSS Servicer mock-up (on top) and EROSS Client mock-up (at the bottom).

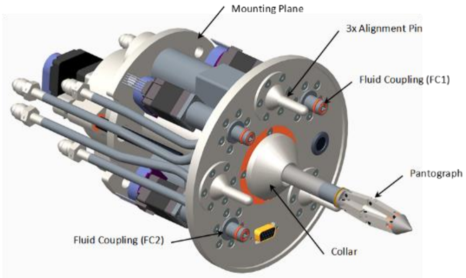


Figure 8: ASSIST Servicer active interface

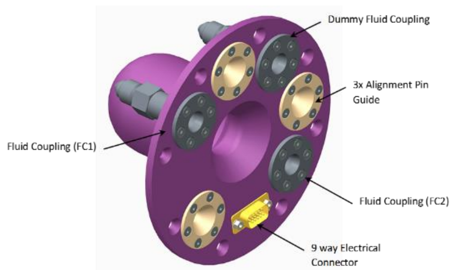


Figure 9: ASSIST Client passive interface

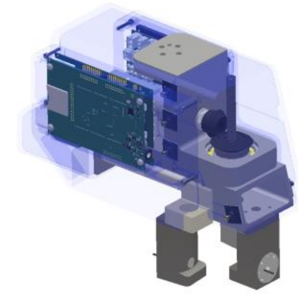
The Servicer “active” interface includes a grasping mechanism, which consists of an expanding pantograph located at the end of a probe. The Client “passive” interface consists of a ‘drogue’ type arrangement, which includes a central cavity into which the capture probe pantograph is inserted. The ‘drogue’ is part of the berthing fixture assembly, which includes fluid couplings and an electrical connector. The berthing fixture on the client S/C also includes three guide receptacles for pins alignment from active side.

In EROSS, ASSIST breadboard model elements will be integrated on Servicer and Client mocks-ups to validate the docking operations in GMV Platform-art© facility as part of EROSS Demonstration tasks.

Robotic arm

The robotic arm design is being provided by the support of the Canadian company MDA, world leader in the design, manufacturing and operations of space robotics equipments. The EROSS robotic arm allows to bring the agility required for such a challenging mission with the capture, mating and servicing phases. It features 7 degrees-of-freedom, and allows to reach a work span of 3m around its anchorage point.

Gripper design



The LAR Gripper is developed to ensure capturing, berthing and stabilizing the Client spacecraft. This design is expected to be compatible with multiple models of spacecrafts Launch Adapter Rings (LAR) to enable grasping/berthing to both monolithic and designed for servicing target satellites in a multi-mission perspective. This interface is very suitable for capture as LAR are typical element in most spacecrafts, has standard dimensions, high stiffness and no thermal blankets.

The gripper design consists of motorized articulated jaws designed to tightly grasp the satellite’s LAR profile. The movement of the motor and jaws is controlled by the gripper’s built-in controller and motor driver. The mechanical design allows for the gripper to be mounted on a robotic arm via force/torque sensor assembly to provide force feedback for the servicer satellite OBSW for the compliance control.

5. SW ARCHITECTURE

As seen in Figure 10, the EROSS software is distributed in nature, with I3DS sensor interfaces and InFuse processing on the RCU's and GNC implemented in ESROCOS / ERGO based on the TASTE framework running on the OBC. The communication from the GNC with actuators (eg, gripper, SIROM and ASSIST) are partly directly controlled from TASTE and through I3DS interfaces hosted on the RCU's. The I3DS interfaces are based on ASN.1 and abstract the implementation details of the sensors and actuators. I3DS and InFuse components have corresponding TASTE functional blocks to interact with GNC.

In total, three RCUs running Xilinx PetaLinux are used to distribute the computational load of the system around the OBC. One RCU is dedicated to the ARAMIS sensor (a smart sensor with an ASN.1 interface compatible with I3DS specifications) and 2x RCUs for handling cameras and other sensor / actuator interfaces (i.e., 1x for the robotic arm and 1x for the platform). The sensor interfaces on the RCUs feed their high-throughput data streams directly into the InFuse processing pipelines running on the same RCU taking advantage of the Xilinx FPGA for acceleration of algorithms. The processed output (i.e. pose estimates) can then be sent to the OBC for interaction with the GNC algorithms. This reduces both the latency and overall load on the GigE networks as well as the necessary size-reduction imposed by limitations in the TASTE framework.

6. AUTONOMY ARCHITECTURE

In the frame of EROSS the ESROCOS and ERGO building blocks are used for a real and task-oriented GNC architecture for on-orbit servicing missions.

Mission and Vehicle Management, denoted MVM, is the EROSS subsystem in charge of handling the different mission phases with an automated switching of the different GNC modes based on the interaction with the Ground Segment and the information provided by the Functional Layer. It is the key element to manage the autonomy during EROSS mission.

This component is implemented by the instantiation of the ERGO agent, adapted to EROSS scenario, as illustrated in Figure 11.The following components are integrated in EROSS MVM:

- **Ground Control Interface**: it will be in charge of processing TC received from Ground Segment and TM from/to Ground Segment and handling of the EROSS System Autonomy Level.
- **Mission Planner**: it will be in charge of managing autonomous operations in the frame of E3 autonomy level, i.e. it manages the event-based operations. The appropriate flight plans are prepared/processed and timelines are provided to the Command Dispatcher component.
- **Command Dispatcher**: it will be in charge of providing a common interface to the MVM allowing the exchange of goals (commands) and observations (data) between the Functional Layer component and the MVM.

Different elements are included in order to implement the different interfaces with the Functional Layer, e.g. GNC CmD or GNC Command Dispatcher is defined to implement the interface between MVM and the GNC subsystem.

7. GNC ARCHITECTURE

The Servicer GNC is the combination of the G-N-C algorithms within functional layers interfaced with the ERGO agent. An inter-connected GNC framework is used to control synchronously the platform and the robotic arm motion. **Guidance**

Platform Guidance function is in charge of providing the reference trajectory and attitude profiles for the final approach phase in order to reach the berthing point and start the capture, docking and servicing operations in compliance with the safety of the reference profiles. It is also computing the collision avoidance manoeuvre during final approach phase.

In the same way, the robotic arm guidance allows to plan the end-effector trajectory to grasp the Client with the gripper, to mate the ASSIST interfaces, and to perform the ORU exchanges.

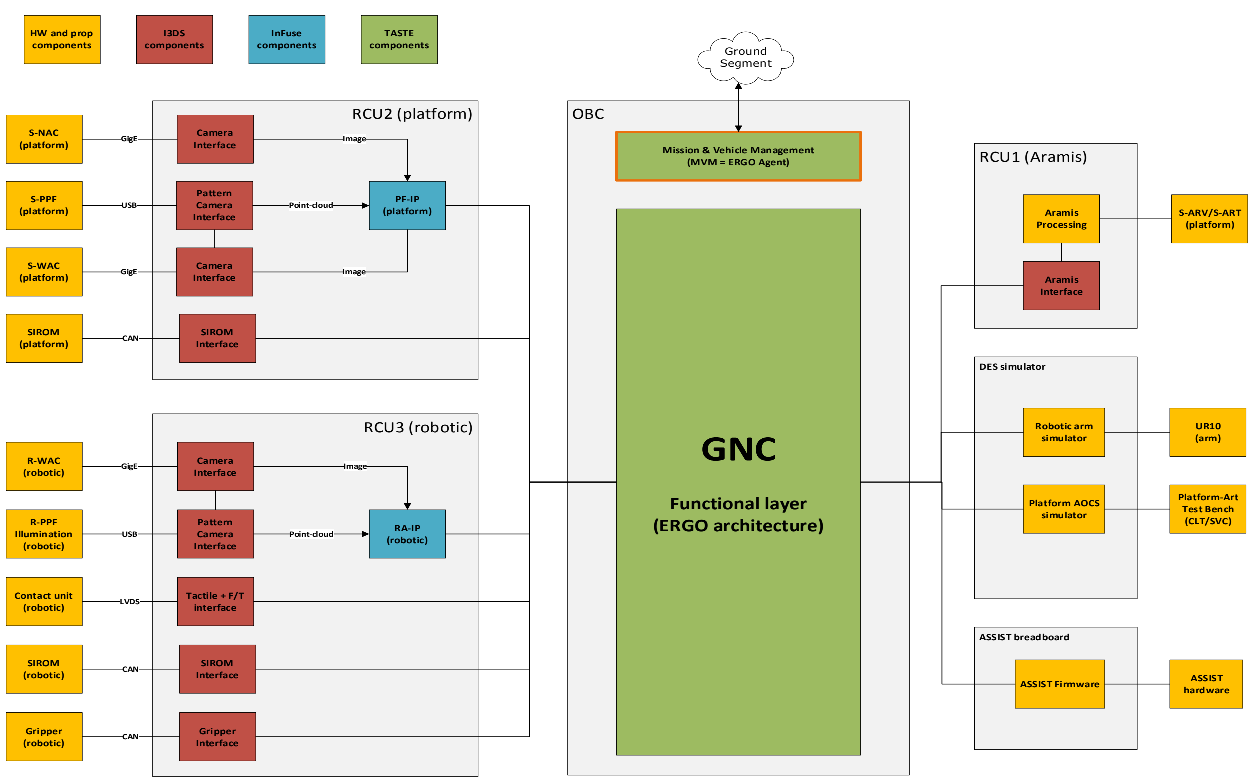


Figure 10: EROSS SW architecture

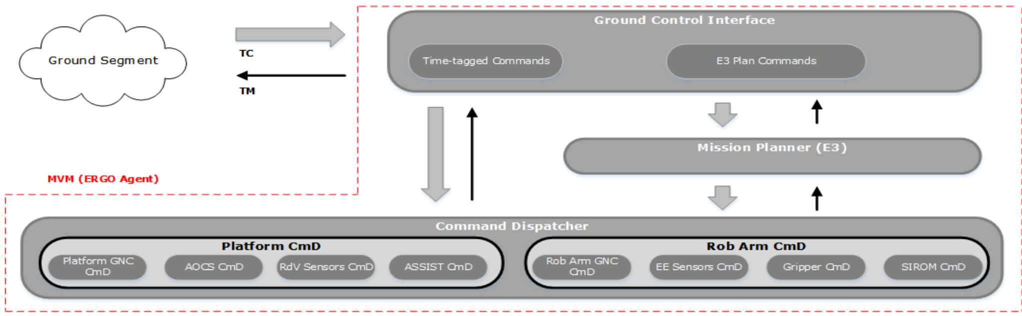


Figure 11: Mission and Vehicle Management Architecture

Navigation

For both the platform and the robotic arm, the navigation function is encompassing the data processing and fusion run on the different RCUs, and the navigation filter used in the OBSW to filter and propagate the raw measurements during the mission in case of sensor failure or loss of tracked data. The performances of this navigation function are described in dedicated parallel publications under revision.

Control

For most stages of the EROSS mission, the robotic arm is operated in a coordinated way with the platform, meaning that the robotic arm Model-based controller ensures both the tracking of a reference trajectory by the robotic arm (either in Joint-space or in Cartesian-space, depending on the required task of each stage), while maintaining the reference base attitude by a Model-based PD controller.

The arm performs a Cartesian-space Compliant control, in Inertial mode during the final arm deployment and subsequent Client capture, and in Relative with respect to the platform mode during the Servicer-Client platforms approach and subsequent ASSIST mating, and during the ORU exchange task. Finally, the arm performs a Joint-space PD control, during the system stabilization after the LAR grasping, and during the arm retrieval the ASSIST mating.

8. CONCLUSION

This paper presented the status of development of EROSS project while one entire year of testing and characterization remains to fully evaluate the performances of each unit, and the overall autonomy and GNC performances of the end-to-end OBSW controlling the Servicer for such a challenging mission.

Acknowledgement

The authors would like to thank our H2020 project officer, the European PERASPERA members reviewing the technical progresses of the project, and all the partners involved to make this project a success: GMV, NTUA, PIAP-Space, SENER, SINTEF AS, Sodern, Space Application Services and all Thales Alenia Space entities.

References

[1] Muñoz Arancón M., et al. (2017), "ESROCOS: a robotic operating system for space and terrestrial applications", in Proc. 14th ASTRA.

[2] Ocón J., et al. (2017), "ERGO: A Framework for the Development of Autonomous Robots", in Proc. 14th ASTRA.

[3] Dominguez R., et al. (2018), "A common data fusion framework for space robotics : architecture and data fusion methods", in Proc. i-SAIRAS, Madrid.

[4] Dubanchet V., Andiappane S. (2018), "Development of I3DS: An integrated sensors suite for orbital rendezvous and planetary exploration", in Proc. i-SAIRAS, Madrid.

[5] Vinals J., et al. (2018), "Multi-Functional Interface for Flexibility and Reconfigurability of Future European Space Robotic Systems", in Advances in Astronautics Science and Technology, vol. 1, pp.119–133.

[6] https://eross-h2020.eu/. *Last access: 17/09/20*.

[7] J. Vinals J. et al., "Future space missions with reconfigurable modular payload modules and standard interface – an overview of the SIROM project", in *69th International Astronautical Congress*, Bremen, Germany, *IAC-18-d3.2*, 2018.

[8] SENER Aeroespacial - Standard Interface for Robotic Manipulation. Available at: *https://www.aeroespacial.sener/en/products/standard-interface-for-robotic-manipulation-sirom*

[9] J. Vinals, J. Gala, G.Guerra. Standard Interface for Robotic Manipulation (SIROM): SRC H2020 OG5 Final Results - Future Upgrades and Applications. In: *i-SAIRAS 2020.*

[10] ECSS-E-70-11C, "Space Engineering - Space segment operability", Requirements & Standards Division, ESA-ESTEC, 31 July 2008. section 5.7.3