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Mission and System Design for EROSS project: the European Robotic Orbital Support Services

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Abstract

The European Robotic Orbital Support Services (EROSS) project aims at developing and integrating the key European robotic building blocks to demonstrate and enable an autonomous solution for performing servicing tasks in orbit and many future rendezvous missions.

EROSS intends to assess and demonstrate the capability of the on-orbit servicing spacecraft to perform medium and close-range rendezvous, to grasp, capture and manipulate the satellite to be serviced. This latter is considered prepared and collaborative as it is designed with specific features to ease the capture phase and to perform servicing operations such as refuelling and payload transfer or replacement.

The project embeds key European Technologies by leveraging on actuators, sensors, software frameworks and algorithms developed in previous European Projects. EROSS focuses on boosting the maturity of these key building blocks and increasing their functionalities and performances in a synergetic way to enable their fast implementation on a space mission.

The current paper aims at presenting the mission scenario and the overall system design for both the servicer and the serviced satellites for such collaborative rendezvous missions. The different key building blocks will also be introduced, such as the sensors, the capture and docking interfaces, and the Guidance Navigation Control (GNC) subsystem of the servicer.

The mission definition and trade-off are presented followed by the system design and the building blocks to be implemented and integrated for the overall solution at a functional level for the demonstration of the main tasks foreseen: rendezvous, capture, refuelling, and payload replacement.

This project led by Thales Alenia Space in France brings together the following companies throughout Europe: GMV (Spain), National Technical University of Athens (Greece), PIAP Space (Poland), SENER (Spain), SINTEF AS (Norway), SODERN (France), Space Application Services (Belgium), Thales Alenia Space entities (Italy and UK), with support from MDA (Canada) and QinetiQ (Belgium).

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Keywords: On-orbit Servicing, space robotics, GNC, rendezvous, ground demonstration

Acronyms/Abbreviations

Acronym	Definition
CS	Client Satellite
ERGO	European Robotic Goal-Oriented autonomous controller (OG2 in the SRC)
EROSS	European Robotic Orbital Support Services
ESROCOS	European Space RObotics Control and Operating System (OG1 in the SRC)
FES	Functional Engineering Simulator
FOV	Field-Of-View
GEO	Geostationary Orbit
GNC	Guidance Navigation Control
GTO	Geostationary Transfert Orbit
I3DS	Integrated 3D Sensors (OG4 in the SRC)
INFUSE	Infusing Data Fusion in Space Robotics (OG3 in the SRC)
IOS	In Orbit Servicing
LAR	Launch Adaptor Ring
LEO	Low Earth Orbit
LLM	Latching & Locking Mechanism
OG	Operational Grant
ORU	Orbital Replacement Unit
SAM	Sun Acquisition Mode
SDS	Satellite Docking System
SI	Standard Interface
SIROM	Standard Interface for RObotic Manipulation of payloads (OG5 in the SRC)
SSO	Sun Synchronous Orbit
TC	Telecommand
TM	Telemetry
TRL	Technological Readiness Level
WRT	With Respect To

Glossary

Key Term	Definition
Berthing	*See "Mating".* For the berthing, the Client Satellite is captured by a manipulator on the servicer which grapples a Client Satellite fixture that must remain in a given capture box for some duration.
Centralized	Term used to characterize the GNC structure of a multi-element system where a unique controller manage all the elements at the same time. This controller gathers all measurements from the elements and provides the commands to all of the elements. It allows to coordinate the motion and autonomous behaviour of each element depending on the others. The global feedback loop requires a centralized computing unit to account for all measurements and send all the commands, and results to be slower than a decentralized architecture.
Prepared	Term used to characterize a Client Satellite whose design has been studied and optimized for a given task (i.e., for the rendezvous, capture and servicing with and by a servicer spacecraft). For example, a prepared client spacecraft should include visual markers, handles or other grapples fixtures, and a given mating interface compatible with the mission scenario (e.g., either docking or berthing interface).
Control	The process of computation of the forces and torques to be realised by vehicle's actuators such as steering controls, reaction wheels, thrusters, etc., needed to execute guidance commands whilst maintaining stability.
Collaborative	Term used to characterize the stable and safe behaviour of a client spacecraft being captured by servicer spacecraft. This hypothesis is of utmost importance for the rendezvous and capture phases since a non-collaborative Client Satellite may be tumbling on a varying axis of rotation, while a fully collaborative one would stand static while the servicer approaches.
Client Satellite	Client satellite is the satellite that will be passive during the rendezvous and servicing operations.
Decentralized	Term used to characterize the GNC structure of a multi-element system where specific controllers manage every element independently. Each controller gathers the measurement from its own elements and, based on this, provides the commands to this specific element. It results in an uncoordinated motion and autonomous behaviour of each element, independent from the others. The multiple feedback loops require distinct computing processes either on one processing unit or on multiple ones and result to be faster than a centralized architecture for some of the elements.
Docking	*See "Mating".* The docking starts from the first physical contact until the beginning of the latching process to lock the two spacecrafts together. This step implies the fastening of the rigid link between both vehicles, using either mechanical or magnetic latches. During this process, the GNC system of the servicer controls the vehicle states to remain within the docking interface tolerances of the Client Satellite vehicle.
Guidance	The process of calculating the changes in position, velocity, attitude, and/or rotation rates of a moving object required to follow

Key Term	Definition
	a certain trajectory and/or attitude profile based on information about the object's motion.
Mating	Capture phase of a rendezvous mission corresponding to the rigid connection between a "Client Satellite" and "servicer" spacecraft. This general term encompasses two main strategies: berthing and docking. The mating phase starts when the GNC system of the servicer has delivered the capture interfaces of the servicer into the reception range of those of the Client Satellite vehicle. This must be achieved within the constraints of the interface conditions in terms of approach velocity, lateral & angular alignments and rates.
Navigation	The process of determination, at a given time, of the vehicle's location and velocity (the "state vector") as well as its attitude.
Servicer	Orbital Support Services spacecraft that will be active during the rendezvous and servicing operations based on robotic features for capture and dexterous manipulation
Pose estimation	3D pose estimation is the problem of determining the relative 3D position and 3D orientation of an object with respect to the reference sensor frame (e.g., camera lens or sensor).

1. Introduction

Digital transformation is changing the satellite business model by creating new needs for connectivity at low cost which implies strong changes at all levels.

The traditional on-orbit satellite communication market (digital TV broadcasting) based on geostationary solutions will be overcome in time by services able to offer a bandwidth to each individual connected, therefore new satellites architectures in different orbits (such as LEO constellations) are being considered.

Modular architectures, prepared for on–orbit servicing, would be required to cope with rapidly changing market trends. A robotic servicing capability to change payloads , refuel and also repair the satellites, would result in global upload mass reduction with the twofold advantage of both reducing costs and improving space sustainability.

In the short term, while advanced robotic capabilities are being developed, specific (niche) markets such as the Telecom satellites tugging for life extensions, feasible with a lower level of technology, are being pursued with the purpose to finance further development.

The advent of new LEO mega-constellations will crowd even more the LEO zone which is already the most critical for debris population. This will dramatically increase the risk of collisions with consequent further creation of debris. 10 % of failed satellites has been estimated within large constellations, 10% that will not be able to dispose themselves autonomously. Therefore, the need of actively deorbiting them will be mandatory in order to avoid catastrophic risks and it is expected that space regulation for disposal will be modified in this sense.

The development of the servicing (robotic) capability, and of the technologies required, will also become an enabler for future Deep Space Exploration phases, either to reach the Moon, Mars or Asteroids, where the need of assembling /disassembling infrastructures on-orbit has already been recognized by many studies.

In the long term, beside institutional Exploration programs, advanced robotic servicing may also be required by commercial enterprises for construction of On-Orbit Factories and infrastructures for space tourism, and also for Asteroids exploitation.

The robotic technologies developed for servicing will be also a starting point for the re-use and re-cycle of space infrastructures and debris towards a more sustainable space exploitation.

As the space business is experiencing a change of paradigm, there is clearly a need to develop technologies in order to do space robotic operations for the future missions.

It is important to put EROSS into his context and understand really why this project is being done therefore clearly identify what EROSS purpose be and what will EROSS demonstrate for the future of servicing missions.

In this sense, EROSS will develop and boost the maturity of key robotic building blocks and demonstrate the key technologies required to offer an efficient and safe commercial service to operational satellites.

2. Mission overview

In order to perform a representative demonstration for EROSS project, a fictitious mission has been defined in order to set up the environment for the different robotics building blocks. The mission has been selected because of its likeness and timing w.r.t to finding a credible enabler therefore an European Institutional mission has been chosen.

2.1 Project goal

EROSS project objective is to develop a whole engineering solution to enable the autonomous realization of servicing tasks in orbit. The complexity involved in such missions pushes to consider space robotics solutions that requires key robotic building blocks to be designed, developed, integrated and validated in order to demonstrate an in-orbit servicing mission.

EROSS will prove the following capabilities to:

- Perform a rendezvous with a client satellite
- Capture a collaborative and prepared client satellite
- Perform servicing operations: refuelling and payload exchange

Therefore the following objectives needs have been fixed:

- Develop and integrate the hardware, software, GNC algorithms and avionics elements that needs to be adapted or improved to perform on-orbit servicing operations based on:
    - Previous Strategic Research Cluster (SRC) Operational Grants (OG) outcomes, i.e. ESROCOS, ERGO, InFuse, I3DS and SIROM.
    - Mating interfaces such as multipurpose gripper for capture, ASSIST for docking and refueling, LLM (Latching Locking Mechanism), SDS (Satellite Docking System) as an alternative for docking interfaces.
    - Specific GNC architecture and algorithms.
    - Software and avionics development to embed the proposed solution.
- **Demonstrate on-orbit servicing capabilities with a collaborative and prepared satellite in relevant environment. The proposed solutions will be validated by demonstration in representative facilities with the purpose of increasing their TRL.**
- Identify mature alternatives for actuators and sensors for the on-orbit servicing scenario.

2.2 Orbit selection

The first step of the mission design was to choose the orbit where the client satellites would be to perform servicing.

Thales Alenia Space is leading in the frame of EROSS, market analyses related to in orbit servicing. Even if not conclusive yet, the most recent outcomes have shown that GEO orbits are the most attractive segments for life extension, re-location, and gap filler services in the short term (<2025). On the other hand, MEO and LEO orbits are the most attractive segments for payload replacement and deorbiting services because of the higher launching rate expected in the coming years with satellites reaching their end of life by 2025-2028. LEO orbits are also concentrating the highest number of space debris.

2.2.1 GEO orbits

Indeed, it is important to highlight that several US solutions are being prepared for servicing in GEO. Some of them with commercial contract. For instance these services consist in mission extension by providing a capability of maneuvering and attitude control extending the telecom satellite operational lifetime.

Moreover these missions does not require any particular feature dedicated to servicing onto the client satellite. They generally use the apogee motor thruster for docking. Finally, no particular cooperation is expected from the client satellite.

This approach is basically the first step of the in orbit servicing and its scheme uses as a resource the existing chemical GEO satellites which were essentially limited in lifetime by their fuel capacity.

But on the other hand the last generation of GEO telecom satellite are generally using electrical propulsion. This technology improves significantly the overall life expectancy potential which is no more considered as the immediate limitation, compared to other characteristics like the payload obsolescence or the system reliability.

Of course, the previous analysis could be jeopardized if alternative propellants (such as Krypton), cheaper but less efficient are finally used in the future electrical propulsion subsystems.

Consequently, life extension missions of GEO telecom client satellites are considered an immediate but limited market.

However, life extension does not only include refueling, other services can be provided such as Orbital Replacements Units but it requires the satellites to be prepared and collaborative to perform a safe rendezvous.

The later arrival of European industries on the in-orbit services market allows us to better understand the market trends and evolutions. It can be considered as an advantage to better target the development of the right technology.

2.2.2 GTO/HEO orbits

Geostationary Transfer Orbits (GTO) and Highly Elliptical Orbits (HEO) are currently essentially populated by:

- Launchers upper stages elements
- Failed satellites which did not manage to reach their GEO orbit
- Science missions
- Molniya satellites

None of those categories are of interest for the in obit servicing to be demonstrated by EROSS even if it is important to notice that deorbiting (with controlled reentry) from these orbits is very economical in term of delta-V and that there is a lot of launch opportunities to reach them.

2.2.3 LEO orbits

It is then anticipated that most of the space object population growth will be in LEO, essentially because of the coming telecom constellations (OneWeb and Starlink, …) and observation missions requiring frequent revisit and then many satellites in several planes. Most of the Earth monitoring science missions are also in LEO. That makes LEO orbits an interesting choice for medium to long term servicing market (>2024) compatible with the post EROSS orbital demonstration mission.

Consequently for the next generation of services being focused on (inspection, robotic manipulation, deorbiting) and particularly in the frame of EROSS, LEO orbit appears the most appealing for medium and long-term market (>2024) both for institutional and commercial client satellites.

This orbit selection, made for the sake of the illustration of the demonstration mission, does not mean that EROSS will not consider other orbits anymore. Consequently the EROSS sub-system specifications and operations will also consider, along the study, the potential impacts of working on another (LEO, GEO) orbit in order to make the most versatile choices.

Table 1. EROSS Orbit selection trade-off

	LEO	GTO/HEO	GEO
Market	>2025 Important market Requires "servicing ready" client satellites	Limited market Failed satellites Debris removal Tugging towards GEO	Immediate (<2025) for life extensions Fuzzy beyond 2025 but requires "servicing ready" client satellites
Environment	Low radiation level Many perturbation forces and torques Eclipses (unless 6 LST SSO)	High radiation level (Van Allen belts crossing) Important aerodynamics force/torque Eclipses	Radiation level related to GTO transfer duration Few disturbances Very few but long eclipses
Versatility aspects	Various missions (size, mass, …) to deal with Duplication of the same mission in case of constellation	Allows migration towards LEO or GEO Its design and sizing allow to deal easily with LEO or GEO	Essentially telecom satellites with big client satellites
Manoeuvring	Easy when remaining in the same plane High DV required for plane modification Medium DV for re-entry	Low DV re-entry manoeuvre	Easy transfer from one satellite to another (only 1 plane) Impossible re-entry. Graveyard orbits only
Cost	Cheaper radiation shielding Smaller dimensions for a cheaper Servicer Smaller robotic arm	Expensive and heavy radiation shielding for all units	Large & expensive radiation shielding More expensive servicer by scaling up all units Long robotic arm

Table 2. GEO/LEO impacts on the design and spacecraft characteristics

Subsystem	GEO / LEO comparison
Power	In GEO, less eclipses, more guidance constraints on solar panels (to be mitigated by SADM)
Communication	Higher latency, higher power consumption, easier visibility of ground station in GEO
AOCS/GNC	In GEO: less agility requirements, less effective composite motion for large client satellites, longer impulsive relative manoeuvers (drifting for inspection or homing occurs at the orbital period), smaller Earth in the sensors FoV (STR or cameras), no MTB, relative manoeuvers less fuel consuming, client satellite harder to discriminate in GEO overcrowded orbit, equivalent GNSS ground performances in LEO/GEO (last technologies, more expensive).
Propulsion	Electrical raising longer in GEO, slot insertion more hazardous in GEO due to overcrowded orbit (increased risk with electrical prop.)
Thermal	No clear impact identified between GEO/LEO
Structure	Heavier Servicer in GEO due to shielding, stronger/heavier structure to support large robotic arm and heavy SC (servicer & client satellite)
DHS	Impact on the electronics shielding (heavier) in GEO
Robotics	Larger/heavier/slower robotic arm for (in average) larger client satellites
Interfaces	Same location and type of I/F in GEO (LAR always present, and at the –R-bar panel of the SC)
Characteristics	
Mass	Larger in GEO by scaling all units for servicing larger SCs
Size	Bigger spacecraft in GEO (impact on all units)
Availability	Client satellite mission interruption: depending on mission criticality (ex: observation SC in LEO during major crisis, or single telecom SC either in LEO or GEO; while least criticality for constellations)

2.3 Mission selection

After the orbit selection, a mission had to be defined to validate the different servicing tasks of EROSS project.

2.3.1 EROSS Reference mission scenario

The EROSS project will focus on the last steps of the rendezvous to increase the overall TRL of the GNC chain when a robotic capture and manipulation are involved.

As the most important criterion are the security and success of the capture operations, and considering that the client satellite is collaborative, the selected capture method is the robotic arm + berthing.

The most challenging parts of a robotics-based rendezvous and capture mission lies in the coordination of the platform and the robotic arm during the last steps, which are more critical due to the closeness of both the servicer and the client satellite. The first steps of the rendezvous are also at risk, especially with the client satellite searching, acquisition and tracking since all the GNC filters must be initialized accurately while remaining in a safe orbit, but the final forced motion and the servicing tasks imply a greater autonomy level and more challenge to coordinate the robotic arm motion with the platform one. Exciting challenges have to be dealt with in these phases on the system architecture side, and on the three components of G & N & C to take the most out of the servicer design in terms of performances and versatility.

In the scope of the EROSS project, the reference mission focuses then on the Mating and Servicing operations mentioned above. They are depicted below along with the different functions performed or monitored. It means that EROSS GNC architecture will be designed to be coherent with the full rendezvous mission introduced above, but that the GNC modes will be designed and tested only for these two Mating and Servicing operations.

In this scope, the first challenge is the mating of the servicer with the client satellite that must maximize the safety of both systems. In that sense, the robotic motion in such a constrained environment for the berthing is crucial and must be performed by a coordination of the platform and robot motion until capture. Then, the stabilization of the composite system is performed to dampen the vibrations generated at the impact during the mechanical contact. During these mating steps, the collision avoidance between both spacecraft and the related escape trajectories are constantly monitored.

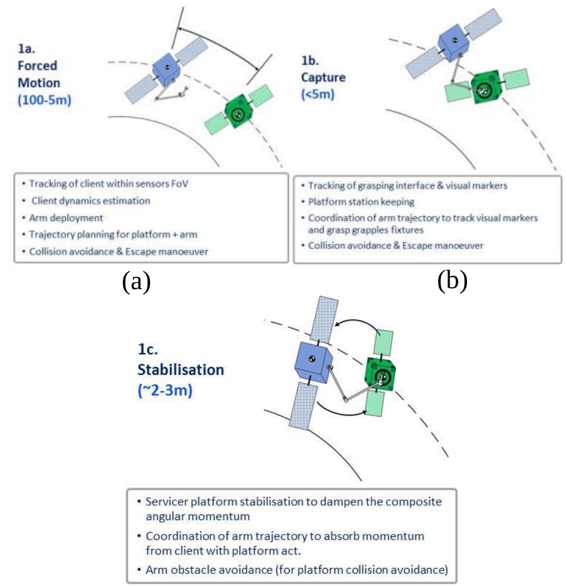

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Fig. 1. Mating operations considered for the EROSS reference mission

In a second step, the Servicing operations are mainly performed by mean of the robotic arm operating in a safer environment with interactions with element rigidly fixed to its base. Two main steps are performed to first move the whole servicer around the client satellite to dock the ASSIST interfaces to ensure both the mechanical link and the refueling service. Then, the robotic arm can release the grasping interface on the client satellite side to focus on the servicing operations including the manipulation of the Orbital Replacement Units (ORUs).

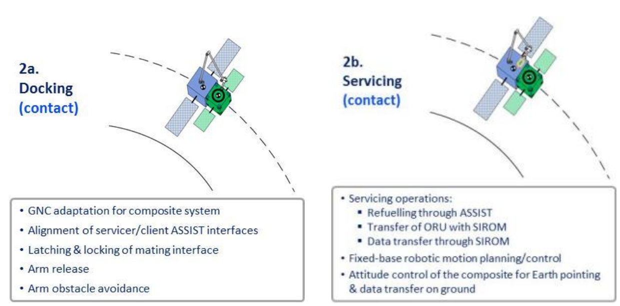

Fig. 2. Servicing operations considered for the EROSS reference mission

These two main phases will be used as EROSS baseline to derive the system requirements in terms of sensors and GNC algorithms performances. The dynamics FES simulator of EROSS will also be developed to validate these two phases only to remain compatible with the time frame and means of this project.

The reference mission focuses on the critical phases of the rendezvous that is why EROSS developments and demonstration are focusing on the two last steps of the servicing with the mating through a robotic capture, and the servicing through the refuelling and ORU exchange.

2.3.2 Simulation scenario

Along with this reference scenario, an alternative one has been proposed. The main goal of this side scenario is to take advantage of EROSS project to validate at a reduce cost and time the alternative solution of docking to the client satellite to perform tugging services like orbit raising or deorbiting.

The rationale behind this side scenario is to evaluate the versatility of the overall EROSS GNC architecture when a different capture mechanism is used. For a docking, it actually reduces the complexity of the EROSS baseline with a robotic capture since the robotic motion is only involved once both satellites are docked and servicing needs to be performed in a known environment with a fixed-base robotic arm. The main idea is then to replace the EROSS robotic payload by the two abovementioned interfaces to evaluate the potential of docking with the EROSS client satellite using the same EROSS framework (i.e., fusing the previous OGs with ESROCOS, ERGO, InFuse and I3DS works).

The Satellite Docking System (SDS) being developed is derived from the larger IBDM interface for station modules like the ones that could be used on the next Lunar space station, the Gateway. This system has the advantages of docking directly to the Launch Adaptor Ring (LAR) of the client satellite by mean of a mechanical ring mounted on a Stewart platform providing 6 Degrees-Of-Freedom (DOFs) in a reduced range. This design allows to cope with the servicer GNC errors when approaching the client satellite and also to endure strong forces/torques at the impact. The client satellite does not need to be designed for this specific task as long as it has a LAR, but the servicer must carry a rather heavy SDS system to perform this docking.

On the other hand, the Latching & Locking Mechanism (LLM) already developed and provided by TAS-I is based on a probe/cone system to dock to the client satellite. In this way, the client satellite design must be accommodated to provide the female interface with a string mechanical link to the spacecraft structure, but this interface is purely mechanical and passive. On the servicer side, the probe embeds all the moving and deployable elements and concentrates the interface complexity. This system is though much reduced in size compared to the SDS and would less impact the servicer design as long as an open panel is available to come close to the client satellite to accommodate this interface.

3. Preliminary System Design

EROSS project focuses not only on the integration of the previous Operational Grants of the Strategic Research Cluster outcomes but also bringing in new building blocks necessary for all their improvements and for mission demonstration.

3.1 EROSS building blocks

In order to reach these objective, key robotics building blocks have been gathered in the frame of EROSS project in order to perform the servicing mission:

- Sensors from I3DS sensors suite
- ARAMIS sensors provided by Sodern, new sensor to be part of I3DS that will provide 3D pose estimation
- SIROM as a Standard Interface (SI) for payload exchange
- ASSIST refueling and docking interface design information provided by GMV and with a HW breadboard model property of ESA to be used on loan in the frame of EROSS.
- Gripper for capturing the client satellite provided by PIAP Space
- Guidance, Navigation and Control Algorithms to drive the rendezvous and servicing operations provided by GMV, NTUA, SpaceApps, SINTEF and TASF

All of the previous elements are to be integrated into a coherent Software architecture led by SINTEF with the use of the previous Operational Grants building blocks, ESROCOS, ERGO, Infuse and I3DS. The Avionic architecture led by Thales Alenia Space in the UK will also be established to finalise EROSS architecture.

EROSS will answer a main scenario which is the capture by a robotic arm before doing the servicing operation such as refueling and payload exchange. However, in parallel, in simulation, another servicing operation will be studied as well being the tugging. For these two other mating interfaces have been considered being the Satellite Docking System provided by Qinetiq and the Latching Locking Mechanism provided by Thales Alenia Space in Italy.

Thales Alenia Space in France is leading the full mission and system analysis with MDA support for the robotic aspects to propose an efficient solution to enable the orbital support services.

EROSS different building blocks, hardware, software and algorithms have been put together in a preliminary product tree to have an easy understanding of the system.

On the Servicer side, there are:

- **RDV Platform sensors:** relative sensors for all the necessary measurement during the rendezvous, capture and release
    - High Resolution Cameras from I3DS sensors suite
        - 1 Wide Angle Camera
        - 1 Narrow Angle Camera
        - 2 Wide Angle Cameras for monitoring during berthing (as an option)
    - ARAMIS sensor provided by Sodern that provides 3D pose estimation
    - 1 Pattern Projector provided by SINTEF from I3DS sensors suite to be used both as an illumination device and Pattern Projector combined with High Resolution Camera to provide 3D measurements
- **AOCS sensors and actuators** for the attitude and position control
    - Inertial measurement Units
    - Star trackers
    - Coarse Sun Sensors
    - Reaction Wheels
    - Thrusters
- **Robotic arm sensors:** relative sensors during berthing and payload exchange
    - High Resolution Cameras from I3DS sensors suite
        - 1 Wide Angle Camera
    - 1 Pattern Projector provided by SINTEF from I3DS sensors suite to be used both as an illumination device and Pattern Projector combined with High Resolution Camera to provide 3D measurements
    - Force/Torque sensors provided by PIAP from I3DS sensors suite
- **Mating and Refueling interfaces**:
    - SIROMs for the payload exchange
    - ASSIST (male) for the refueling and docking
    - Gripper at the end of the robotic arm for capturing, berthing and stabilizing the client satellite
    - Latching Locking Mechanism (LLM) and Satellite Docking System (SDS) are proposed as option for tugging
- **Avionics Hardware:**
    - RCU (Robotic Control unit) to host the processing capabilities to run the GNC algorithms and command/control the sensors and the robotic arm control
    - The On-Board Computer to host the system software and command/control the servicer platform
    - Communication links to ensure the real time requirements needed by the system
- **Orbital Replacement Unit (ORU):** payload to be exchanged through SIROM interfaces
- **GNC components**
    - Guidance for relative orbital dynamics and collision avoidance manoeuvre
    - Navigation with data fusion and Kalman filters to provide a robust pose estimation of the system relative to the Client Satellite
    - Control of the platform, the robotic arm and the overall system according to different modes
- **Software components:** to integrate the previous OGs building blocks into a coherent and representative of a real satellite software architecture
    - ESROCOS, ERGO, InFuse and I3DS frameworks

Most of the elements are on the servicer however since the client satellite is assumed to be collaborative (equipped with specific features), it requires specific elements for the servicing operations.

- On the Client Satellite side:
    - Rendezvous features: visual markers to ease the pose estimation by the servicer
    - ASSIST (female) for the refueling and docking
    - SIROMS provided by SENER for the payload exchange
    - Orbital Replacement Unit (ORU) which is the payload to be exchanged through SIROM interfaces

The following figure introduces the EROSS Product Tree that has been described in detail in the previous paragraphs:

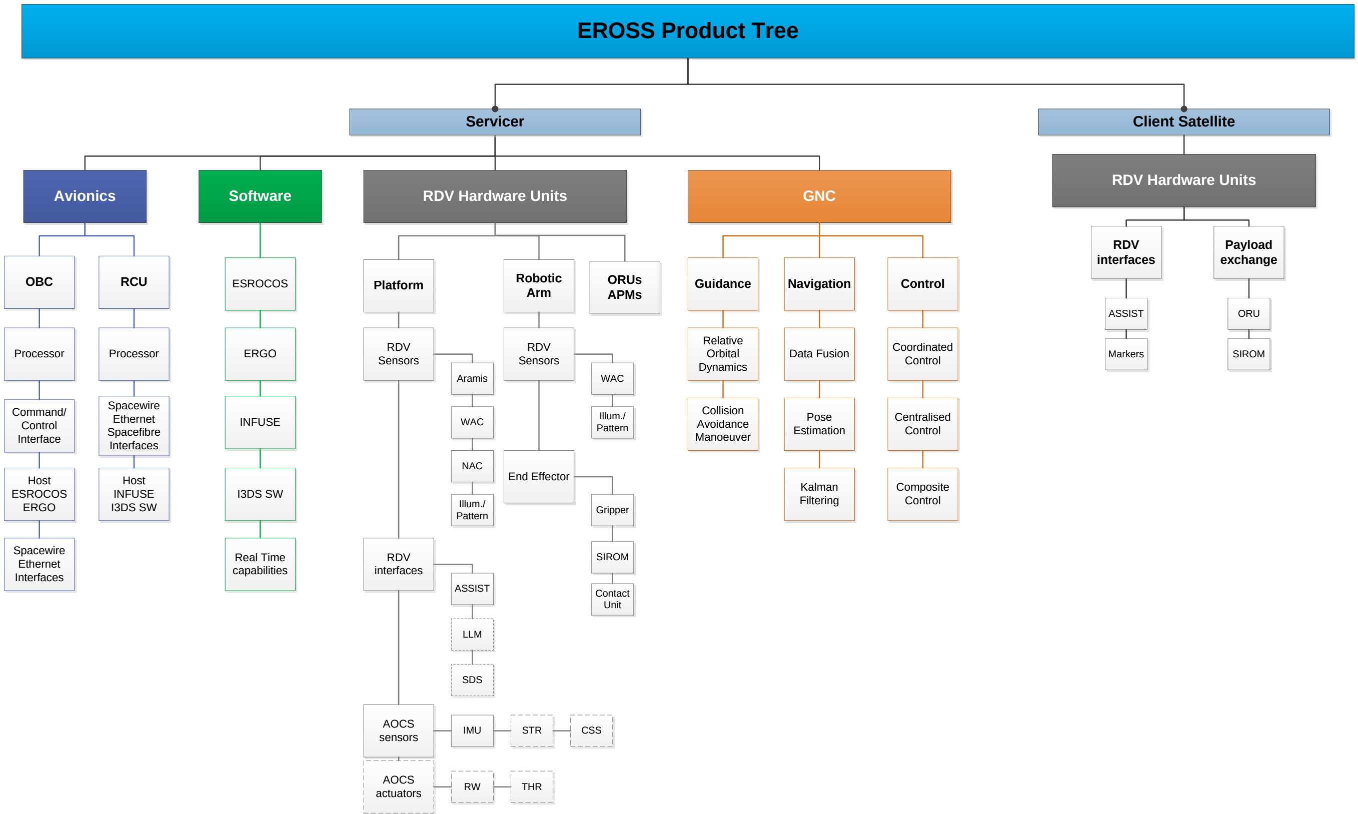

Fig. 3. EROSS Product Tree

3.2 EROSS Servicer

The Servicer design has been elaborated by Thales Alenia Space through several previous studies for CNES and ESA in order to be optimized for its servicing mission.

It is mainly an hexagonal platform of less than 5 m of diameter and 2 meter height. This shape rationale is to have a compact volume to ease the attitude control and clearance for rendezvous and capture, but also to maximize the upper robotic bay surface to accommodate on it the robotic arm, some of the navigation and rendezvous sensors and the kits to be placed onto the client satellite.

The upper side is dedicated to the robotic bay, accommodating the robotic arm, 10 Standard Interfaces (9 of them busy with a payload kit to be place on each client satellite, and 1 free to handle the kit transfer) and the sensors set for relative navigation, capture and robotic arm control.

One of the lateral panel is dedicated for docking. For this purpose it accommodates:

- The ASSIST refueling male interface
- 1 ARAMIS NIR camera
- An illumination device

The bottom hexagonal panel is dedicated to the electrical propulsion thruster and also accommodates the launch adapter ring directly connected to the central tube. The servicer is indeed intended to be a based on a hybrid propulsion system mixing an electrical main propulsion module for orbit transfer, and a fine chemical propulsion set for the attitude control and for the rendezvous manoeuvers.

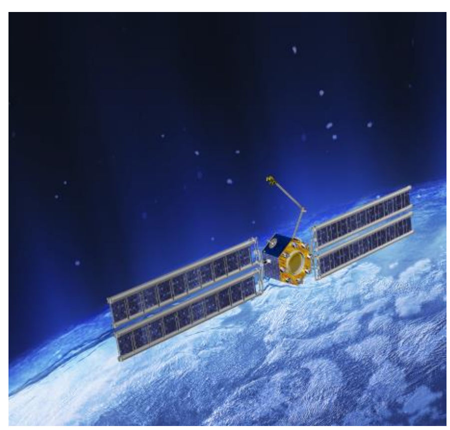

Fig. 4. EROSS Servicer Concept ©Thales Alenia Space

3.3 EROSS Client Satellite

The client satellite EROSS study will focus and elaborate its use case based on ESA Sentinel 3 mission with a fictitious scenario.

Fig. 5. Illustration EROSS potential client satellite based on the Sentinel 3 design © ESA

This client satellite is assumed to be active and collaborative at the time of its servicing and shall feature the following "servicing ready" adaptations to ease the rendezvous & capture and make possible servicing:

- ASSIST female interface outside of the Launch Adapter Ring (LAR) perimeter
- Passive rendezvous aids (e.g. reflectors and paintings) dispatched at several locations on the client satellite surface and particularly onto LAR panel and ASSIST female interface
- A payload element using a Standard interface (SIROM)

These elements are completed by the baseline LAR that will be used as the grasping interface during capture by the robotic arm.

4. Demonstration scenario

As mentioned before, EROSS main focus is to perform a demonstration of the different servicing operations. The following objectives have to be demonstrated:

- Autonomous rendezvous
- Capture with a robotic arm
- Docking
- Refuelling
- Payload exchange

The demonstration main steps are the following:

1. Forced motion in closed loop with navigation solution
2. Coordinated Robotic Control for the capture
3. Robotic motion for docking
4. Refuelling
5. LAR release from the robotic arm
6. Payload exchange steps :
    - Coupling of the manipulator Standard Interface (SI) with the first ORU SI on the CS (failed ORU)
    - De-coupling of the first ORU SI from the initial position on the CS
    - Transfer of the ORU to the OSS
    - Coupling of the first ORU SI on a SI recovering the failed CS ORU
    - Decoupling of the first ORU SI on the final position
    - Coupling of the manipulator SI with the second ORU SI (the new one) on the OSS
    - De-coupling of the second ORU SI from the initial position on the OSS
    - Transfer of the ORU to the CS
    - Coupling of the second ORU SI in the final position
    - De-coupling of the manipulator SI from the second ORU SI

The final demonstration is foreseen to be done at GMV platform Art © Facility in Tres Cantos, Spain.

6. Conclusions

This paper presented the EROSS project mission led by Thales Alenia Space whose goal is to design, validate and demonstrate all the key robotic building blocks needed to perform on-orbit servicing missions in the near future.

The missions targeted are the client satellites prepared and collaborative which is the medium term market whereas he immediate market for servicing is focused towards non-collaborative and non-prepared satellites that do not require the same technologies.

The final ground demonstration of EROSS is foreseen at the end of the year 2020.

This will enable for an in orbit demonstration around 2023-2024.

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