STANDARD INTERFACE FOR ROBOTIC MANIPULATION (SIROM): SRC H2020 OG5 FINAL RESULTS - FUTURE UPGRADES AND APPLICATIONS

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ABSTRACT

The capabilities of space robotics for applications such as on-orbit servicing, refueling, space-based assembly or planetary exploration, among others, depend critically on the creation and availability of a standard interface simplifying the operations involved. Within this context, the developed interface in the SIROM (Standard Interface for Robotic Manipulation) project [1] is a solution that combines four modular functionalities (mechanical coupling, electrical, data and fluid connectivity) in an integrated and compact form. The general idea behind this project has been to develop the next generation of "interface space USB".

1 CONTEXT

1.1 H2020 SRC - SIROM

Space robotics has been identified by Europe as a key technology for improving the competitiveness of the European space sector. As a result, the European Union through the Horizon 2020 Programme has funded the project PERASPERA, which aims to deliver key enabling technologies and demonstrate autonomous robotic systems for on-orbit satellite servicing and planetary exploration. The goal of PERASPERA is to develop a roadmap of activities for a Strategic Research Cluster (SRC) in Space Robotics Technology. The overall objective of the SRC is to deliver, within the 2023/2027 framework, key enabling technologies and demonstrate autonomous robotic systems at a significant scale for on-orbit satellite servicing and planetary exploration. These activities are performed by means of consecutive Calls in order to achieve these long-term goals. Call 1 (2016-2017) aimed at developing five key technologies or "building blocks" that will be used in later stages. These are:

- OG1- European Space Robotics Control & Operating System (ESROCOS)
- OG2- European Robotic Goal-Oriented Autonomous Controller (ERGO)
- OG3- Infusing Data Fusion in Space Robotics (InFuse)
- OG4- Integrated 3D sensors suite (I3DS)
- OG5- Standard Interface for Robotic Manipulation of Payloads (SIROM)

SIROM project [2], from Call 1, focused on the design, prototyping and testing of a robotic interface for operation in space environments (orbital and planetary). SIROM allows interconnection of manipulators to payloads and payloads to other payloads.

SENER [3] was the coordinator of the SIROM consortium and responsible for the development, design, manufacturing, assembly and integration of the SIROM mechanical interface, including the allocation of the rest of interfaces (namely data, electrical/power and fluid). SIROM OG5 project finished on February 2019. This paper describes the final test and project results and provide an overview of future upgrades and applications.

1.2 Interface Description

SIROM [4] is a multi-functional (4-in-1 functionalities) intelligent interface combining the following in a single and integrated form:

- Mechanical interface to allow load transfer.
- Electrical interface for power transmission.
- Fluid interface for heat regulation and fluid transmission.
- Data interface for data, telemetry and telecommand (TM & TC) transmission.

Figure below shows a view of SIROM mechanics.

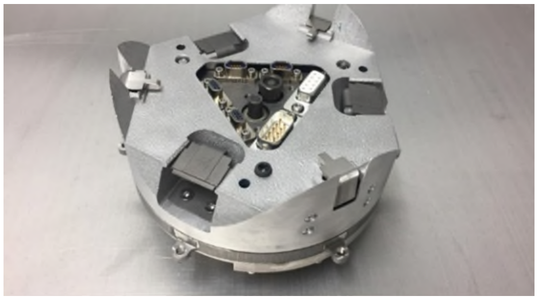

Figure 1: SIROM mechanics

To summarize SIROM performances, it can be highlighted the following:

- Androgynous interface.
- Low mass (electro-mechanics mass < 1.5kg).
- It only requires one SIROM to be actuated during the connection of two SIROMs.
- It has an independent latching mechanism based on SENER heritage with the International Berthing and Docking Mechanism (IBDM). [5]
- It features a connectors plate, fully customizable.
- Redundant connections in case of line failure.

Regarding the mechanical interface, it is formed by three capture hooks (or latches) evenly distributed every 120º that enter inside the opposite SIROM pockets and retract. The latches retraction preloads the opposite SIROM capture tabs, resulting in the approximation and compression of both SIROMs. Additionally, the guiding petals correct misalignment errors during approximation. This way, the latching mechanism allows capturing a SIROM before contact between the interfaces. This relaxes robot manipulator positioning and force tolerance, since it only needs to position SIROMs at a safe distance.

2 TRL4 DEMONSTRATION

2.1 Mission description

Two reference missions are taken as baseline for the final demonstrations. On the one hand, an orbital scenario of on-orbit servicing is considered where a servicer satellite repairs a defunct module from a client satellite. The demonstration mission, featured a small satellite system that, through robotic technology can deploy/reconfigure/extend itself, thus allowing the spacecraft mission to evolve.

On the other hand, the planetary scenario consists in the exploration of a lunar crater by means of rover. For both missions, SIROM is a key element enabling the necessary interconnections between payloads (orbital or planetary), robot manipulator and satellites or rover.

2.2 Final tests

SIROM has been verified both at equipment and system levels achieving a Technology Readiness Level 4 (TRL 4). Also, SIROM has been functionally tested in both orbital and planetary test set ups. The thermal interface has been demonstrated on its own in a separate close-loop heat exchange test bench due to the complexity of validating all functionalities in a single functional test. The list of the tests performed is the following:

- Equipment/subassembly tests performed by equipment responsible.
- SIROM Mechanical Verification at AIRBUS DS Bremen.
- SIROM Data and Power Verification.
- Orbital test at DLR.
- Planetary test.
- Thermal interface test.

Main orbital test is presented hereafter in detail. SIROM demonstrated its capabilities to support on-orbit satellite servicing, assembly and reconfiguration of satellites in a representative orbital scenario.

The demonstration presented several robotic operations between a mockup servicer satellite docked to a mockup client satellite. The servicing tasks were performed by a servicer light-weight robot (KUKA LBR iiwa 14 R820 at AIRBUS DS BREMEN and KUKA LBR4 at DLR) which end effector is a SIROM interface.

Both servicer and client satellites are provided with active payload modules (APM) that have SIROM interfaces at its flanges. This way, the robot can grab, change, replace and communicate with APMs thanks to SIROM standard interface. Figure below shows SIROM mounted on robot manipulator at AIRBUS DS.

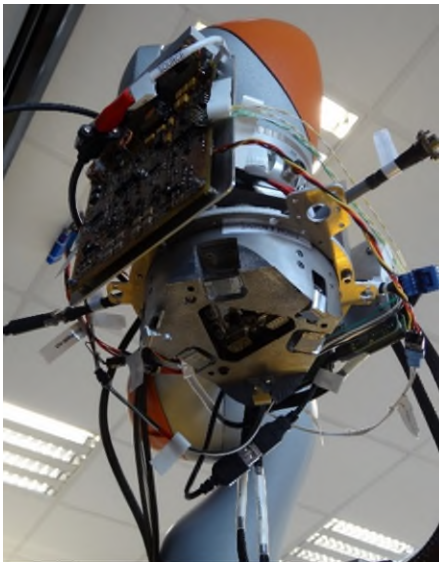

Figure 2: SIROM on KUKA robot

At the beginning of the test, the servicer satellite is provided with APM-1, provided with a payload camera. On its side, client satellite is provided with APM-2, representing a failed payload.

First, the robot manipulator connects to APM-1 thanks to SIROM interconnections and performs some electrical, TM&TC and data transmission. Payload camera is commanded to take pictures of the surrounding environment by means of an On-Board Computer (OBC), and the data is sent back from the camera to the OBC. OBC provides the required power supply to the payload via 24V lines (100V lines are used to charge batteries for the planetary test), communicates via CAN protocol and transfers the data via SpaceWire (SpW) communication. Figure below shows the orbital test set up.

Figure 3: Orbital test set up at AIRBUS DS

Regarding the robot control, starting from an initial configuration, the robot is commanded through four teached steps in joint position control mode. Once the robot places SIROM at the teached position, the control is switched to impedance mode, so that the arm limits the reaction force while SIROMs are being self-aligned by the latching system and guiding petals. Then, before manipulating the payload (APM-1), the mass, centre of mass position and tool frame are updated in the model. Figure below shows the force components measured by the Force Torque Sensor (FTS) at the end-effector before, during and after SIROM latching.

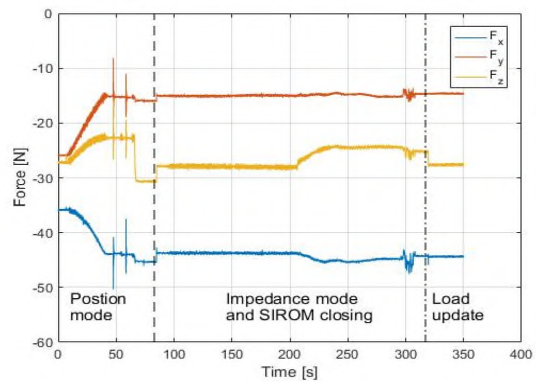

Figure 4: FTS measurements

From this measurement it is observed:

1. A small jump in force in the z-direction occurs when switching from position to impedance control mode (t=84.5), as expected, due to the changing dynamics.
2. During SIROM latching, force in the z-direction increases (205 < t < 245 s). A zoom in of this time interval is shown in the next figure. The force exerted by the SIROM is in the order of 4 N.
3. After the update of the load inertial parameters, the controller introduces another small force jump.

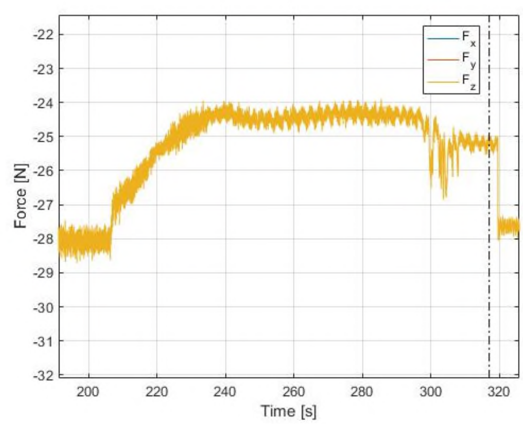

Figure 5: FTS measurement. Detail of SIROM latching time interval

This test validated the main SIROM functionalities such as data, telemetry, telecommands and electrical transfer as well as mechanical latching redundancy.

3 ELECTRO-MECHANICAL INTEGRATION

The first version of SIROM that was developed during H2020-OG5 project 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 combining the mechanics and electronics suitable for flight, resulting in a simple and compact mechanism. Figure below shows a view of the developed solution.

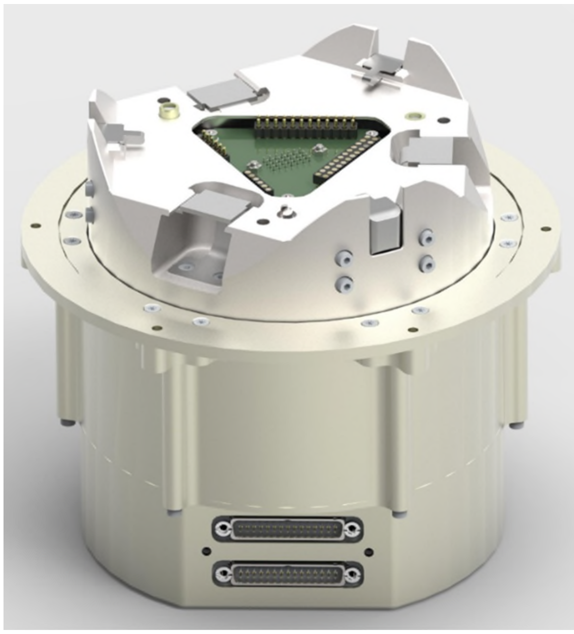

Figure 6: SIROM electro-mechanics upgrade

As an asset, this new SIROM version also features spring-loaded pins allowing the implementation of more transmission lines for power and data transmission, in comparison with previous connectors used. Also, other modifications have been introduced based on the lessons learnt from OG5, such as decreasing the latching time (down to 15s), smoother guiding petals geometry, removal of latch backlash, reduction of the number of moving parts, optimization of assembly procedure, etc.

4 FLIGHT ELECTRONICS DESIGN

SENER's heritage in production of electronics for Defense is being brought into Space applications.

High reliability depends not only on the component package but also on the assembly process.

Implementation of obsolescence management systems for COTS.

Robust component selection & design practices were implemented to achieve high reliability figures and radiation tolerance.

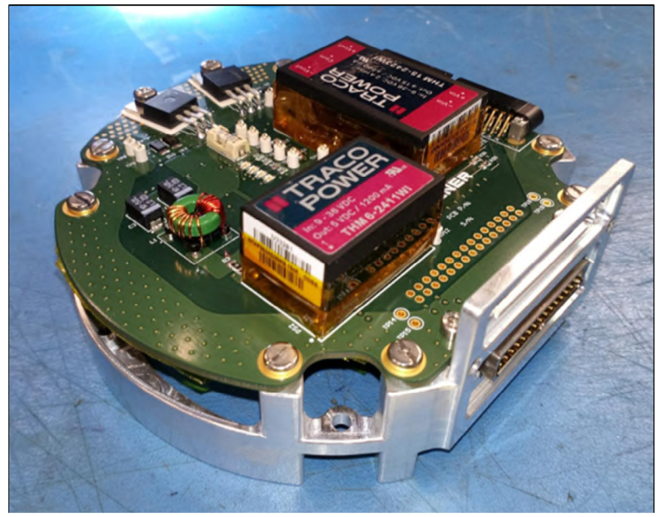

Figure 7: SIROM electronics

The architecture of the electronics consists on the following:

- Power supply and transfer
- Motor and Control PCA

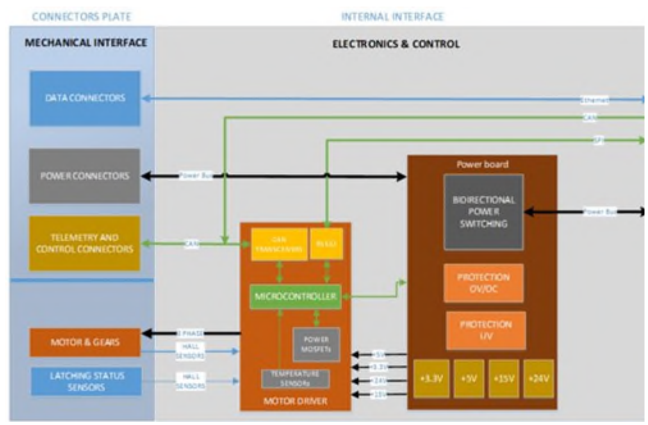

Figure 8: SIROM electronics architecture

5 APPLICATIONS

SIROM has the ambition of becoming the standard for a number of robotic applications that may be grouped in four areas: mission support services, recovery services, life extension services and disposal services.

- Regarding mission support services, SIROM as a standard interface will be used to perform the assembly in-orbit of very large structures that cannot be launched in an assembled configuration because they are bigger than the launcher capacity. SIROM will be attachment points between the sub-assemblies.

- Another promising application is the recovery of failed satellites. In fact, changing from the traditional satellite architecture to a more flexible system composed of multiple payload modules interconnected with SIROMs, one could identify failure of a module and send the new spare unit with a servicer satellite.
- Apart from that, applications such as re-fueling are under study with SIROM.
- Regarding disposal services SIROM can assist deorbiting by providing an attachment point between the satellite to be deorbited and the servicer satellite.

5.1 On-going projects

Following H2020 Call 1, the second Call on Space Robotics Technologies aims at integrating the developed common building blocks (OG1, OG2, OG3, OG4 & OG5) into demonstrators on ground. One of such projects is "EROSS" (European Robotic Orbital Support Services) [6] that will assess and demonstrate the capability of the on-orbit servicing spacecraft (servicer) to perform rendezvous, capturing, grasping, berthing and manipulating of a collaborative client satellite. Inside EROSS, SIROM is the standard interface allowing Orbital Replacement Unit (ORU) transfer and replacement between satellites.

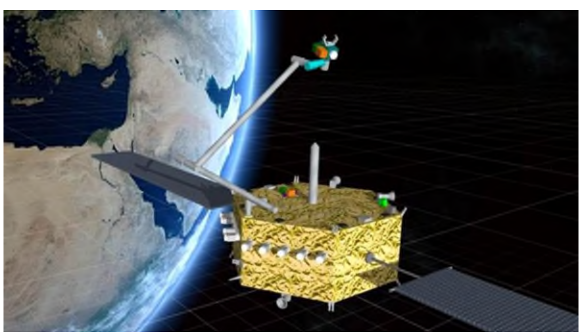

Figure 9: Illustration of EROSS servicer in deployed configuration. Courtesy of Thales Alenia Space

Also, SIROM is the baseline mechanism for an application of assembly of hexagonal mirror tiles to form a larger structure, named "MIRROR" (Multi-arm Installation Robot for Readying ORUS and Reflectors). In this sense, preliminary tests have been already conducted with satisfactory results showing a triple docking operation.

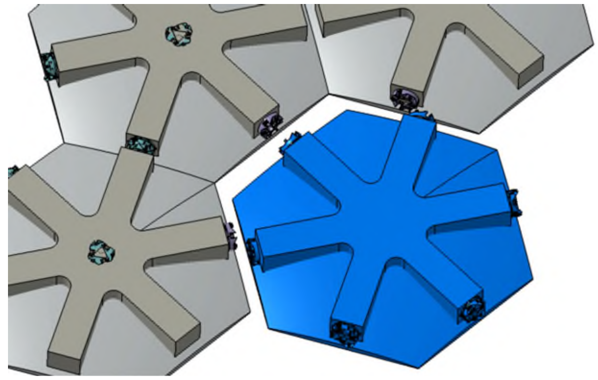

Figure 10: Representation of a triple docking for MIRROR

Additionally, studies are being conducted in the frame of "Prototyping of Spacecraft Refuelling" project (ESA Contract No. 1520089425 with Thales Alenia Space France), to study the implementation of a fuel valve in SIROM connection plate.

5.2 Future applications

Regarding possible applications in future missions, SENER has assessed SIROM applicability for intravehicular robotics in the Lunar Orbital Platform Gateway (LOP-G). Studies conducted describe a system consisting of a mobile manipulator provided with SIROM interfaces to cover the following scenarios:

- Logistic management (unloading/loading & cargo waste stowage).
- Data/power transfer to IVR.
- Preparation for crew arrival.
- Preventive maintenance.

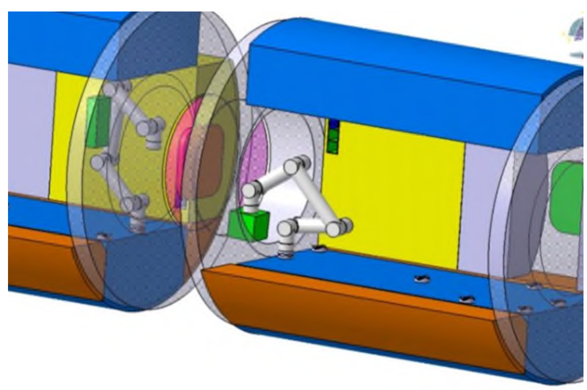

Figure 11: Walking manipulator inside iHAB module

Continuation of SIROM applicability is also under final negotiation inside the framework of SRC H2020 Call 3. The objective of the third call is to prepare the technologies for demonstrators planned to be implemented in the 2023-2027 timeframe, and to validate relevant applications for both orbital scenario.

6 CONCLUSION

SIROM has been improved and updated from OG5 version, introducing new mechanical concepts (external petals configuration, decrease of connecting time, etc.) and with an electronic solution already integrated and compact with the mechanical assembly. This new SIROM version is the baseline for several proposals presented as shown in above paragraphs.

The State of the art design of the SIROM gives the possibility to access to new markets (constellations) and approaches (New Space) offering competitive recurrent prices.

Internally, SENER has foreseen a specific test campaign to reach qualification level (TRL5-6) by January 2021 to keep up with increasing interests in space robotics. This timeframe coincides with Kick-Off (KO) of SRC Call 3 projects, and will allow a good positioning of SIROM.

Also, additional framework programmes will be explored to consolidate SIROM TRL, in order to be ready for In Orbit Demonstration (IOD) inside SRC PERASPERA program.

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