69th International Astronautical Congress (IAC), Bremen, Germany, 1-5 October 2018.
Paper ID: 45699

IAC-18-D3.2: 45699

FUTURE SPACE MISSIONS WITH RECONFIGURABLE MODULAR PAYLOAD MODULES AND STANDARD INTERFACE – AN OVERVIEW OF THE SIROM PROJECT

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Abstract

The SIROM (Standard Interface for Robotic Manipulation of payloads in future space missions) project, funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 730035, aims to develop a standardized and multi-functional interface with capabilities to couple payloads to payloads, payloads to robotic manipulators and client to server. This interface is designed in an integrated form where mechanical, data, electrical and thermal connections are combined. The possible applications of the developed interface go from on-orbit satellite servicing, satellites re-fuelling, assembly of modular and reconfigurable orbital satellites to manipulation of payloads in planetary surface exploration. Within this context, a suite of hardware is also developed to support the demonstration and verification of SIROM capabilities: Active Payload Modules (APMs) provided with SIROM interfaces, an End-Effector allowing installation of the interface onto a robotic manipulator, an Electronics Ground Support Equipment (EGSE) providing power, data and controlling communication. All developed and incorporated systems will be verified in orbital and planetary test scenarios. The objective for the orbital scenario is to demonstrate the successful transport of an APM from an initial to a final operational location: a robotic arm with a SIROM interface attached to its End-Effector couples an APM equipped with a camera, then it sends a command to take pictures of the test environment and finally it attaches the APM to another APM. The planetary test demonstrates an application of battery pack management with a mobile rover. Here an APM consisting of an auxiliary battery is to be connected to another APM that consists of a transportable solar based battery charging system. The SIROM thermal interface provides a fluidic port which allows thermal transfer from one APM to another. Thus, a separate close-loop heat exchange system between two APMs is also developed and tested on its own. This paper gives an overall overview of the SIROM project including the development of the interface and its controller, the orbital and planetary APMs, the End-Effector and the EGSE, as well as the verification tests to be performed and first results.

Keywords: space robotics, space interface, standard interface, orbital missions, orbital payload, modularity

Acronyms/Abbreviations

Active Payload Module (APM), Interface (IF), Standard Interface for Robotic Manipulation of Payloads in Future Space Missions (SIROM), Electrical Ground Support Equipment (EGSE), On-Orbit Servicing (OOS), low Earth orbit (LEO), multi-robot system (MRS), On Board Computer (OBC), Strategic Research Clusters (SRC), Operational Grant (OG).

1. Introduction

Make the space affordable to a larger number of customers by reducing costs and increasing standardisation of space missions is an important challenge for improving the competitiveness of the European space sector. Using Space Robotics as a key Technology, the 2016 call for the EU H2020 Strategic Research Clusters (SRC) attempts to address these needs. SIROM project, as one of the six Operational Grants (OG) from this call, focuses on the design, the prototyping and testing of robotic building blocks for operation in space environments (orbital and/or planetary).

With the development of this first of its kind connector where mechanical, thermal, electrical, data connections are combined in a single device [1], SIROM project [2] is applying a novel approach and considers a number of unique design requirements:

- IF standardization and modularization of the different components in an integrated form (where mechanical, thermal/flow, electrical, data connections are combined) or a separated form.
- To allow creation of large clusters of modules based on the Standard IF. APMs are considered for demonstration, validation and verification of all properties of the standard IF. APMs will be connected via standard IF to other modules and satellite bus.
- An end-effector for a robotic manipulator will be designed according to the layout of the standard IF and coupling functions to be supported.

The present paper gives a broad overview of the project, introducing how the interface requirements were selected and how the device developed intends to become a standard for the upcoming space missions. More description of the application scenarios, demonstrating the full potential of the interface, is also introduced.

2. The state of the art

Reconfigurability is a key technology within the space section. It ensures different combinations with modular building blocks in on-orbit servicing (OOS) or with different robotic systems on extra-terrestrial surfaces. In OOS, robotic can be applied in 3 distinct activities:

- Servicing of space System already in space and not prepared for servicing
- Servicing of systems prepared to service and being serviced
- On orbit assembly

A combination between such space modules or robotic systems is possible with an interface. For OOS, systems are already used or currently under development, the iBoss [3] is the only device that combine all aforementioned connections therefore there is a high interest for such device. In addition to the OOS, SIROM interface could be used in planetary mission and therefore should be compliant with this environment.

Using of a reconfigurable robotic system, the so called multi robot system (MRS) on extra-terrestrial surfaces in order to extend the mission scenarios and tasks is still a new territory. A reconfigurable MRS is a system consisting of several subsystems that can be connected and disconnected physically or virtually to form new functional units or associations in order to be able to fulfil various tasks. A scenario for a reconfigurable robotic performance in space exploration context is described in [4].

MRS built from individual rover systems have been considered for space exploration and infrastructure setup on extra-terrestrial surfaces two decades ago [5]

A feasibility study of a heterogeneous modular MRS for a robotic logistics chain for sample return missions can be found in [6]. The mission scenarios and tasks of the MRS can be combined and extended by using of the electro-mechanical interface [7], which is equipped on all involved robotic systems.

SIROM goes a step beyond due to the development of a standardized interface, which shall be able to connect modular building blocks in OOS as well as shall be applicable on extra-terrestrial surfaces. This required an interface which needs to withstand different extreme conditions and needs to cover mechanical interconnection, electrical and data transfer possibility as well as thermal transfer.

In order to answer a large range of space mission requirement, a standard interface has to provide the following features:

- Transferring mechanical loads
- Transferring power
- Transferring data
- Transferring heat loads (optional)
- Transferring fluids (optional)

2.1 Mechanical interface

The mechanical interface has to provide a rigid connection between two building blocks capable to resist and transmit expectable mechanical load. For this purpose, latches are often used. Hook, rotational lock, clamp and carribena are the most suitable mechanisms. Each of them has its advantages and disadvantages depending on the requirements on the interface, which are discussed in [8].

2.2 Electrical interface

The transfer of electrical load in space environment is analogous to terrestrial applications with the difference that cold vacuum create high temperature range which require the usage specific cables. Four types of power transfer interfaces, pin, tabs, slip rings and wireless power transmission; have been identified and described [8].

2.3 Data interface

The requirement for unmanned bus answer to the current trends in space-based computing, with the replacement of centralized processing by distributed processing. Seven main data buses have been highlighted from literature review, Milbus, CANbus, SpaceWire, Standardized Serial Interface, Time-Triggered Bus, Firewire, Time Triggered Ethernet, and are here briefly presented in [8].

2.4 Thermal interface

Thermal management is a fundamental part of any space mission. A spacecraft will face a broad range of temperature conditions and internal temperature gradients. A proper thermal management is required for the spacecraft structures and electronic which are especially sensitive to temperature variations and usually have limited operation temperature range. Regarding the control strategy, thermal systems could be classified in two main groups; passive or active systems. Some of the most common thermal management methods, inventoried through technology review [8], are the followings: heat pipes, thermal straps, blankets and coatings, fluid loops, coolers and heaters among others. These systems are generally focused on the thermal control inside the spacecraft. However, just a few concepts have studied the heat transfer between two modules [9], [10].

2.5 Transferring fluids

A satellite can be equipped with a refuelling system and a fuel tank to extend operational of future space missions and in-orbit satellites. The final design of the SIROM focus on the Mechanical, Electrical, Data and Thermal interface. But as it’s equipped with fluid connector, it leaves a door open to an eventual upgrade for refuelling.

3. Ambition of the project

3.1 Design of a standard for space missions

The technology output from this project intend to address the Future Space mission, with low cost, exchangeable, expandable and extendable space payload module; therefore, this interface should be able to be used in a various range of space missions. The requirements of the SIROM were defined as a Standard, using traits shared between interfaces used for robotics and space applications.

From the overview of classifications of power, data, mechanical, thermal interfaces in robotics and space applications conducted in the project [8], some critical observations about the current sample of interface designs has been made; the requirements that defined the standard developed in the SIROM, using basic function of interface, are listed below:

- Rotational Symmetry
- Scalability
- Rigid mechanical latching
- Functional element redundancy
- Androgynous design
- Passive connection retention
- Inclusive design
- Low complexity, mass and volume
- Rotation and axis of symmetry
- Reusability
- Space environment robustness
- Moderate positioning tolerance
- Compliance with launch load
- Keep existing standards where applicable
- Common maintenance standards
- Connection without restriction on the relative module orientation
- Cost efficient development

Some excelling design traits where also inventoried and have been listed here:

- Particle mitigation
- 6 DoF misalignment tolerance
- Fail-safe docking/undocking

By using these key principles as design requirements, the basic functionality required for successful interface design is introduced. Some novelty was also brought to this system by integrating design features unseen in previous designs.

3.2 Benefits of modularity and reconfigurability

The importance and benefits of spacecraft modularity and reconfigurability can be found through the spaceflight history and were proven vital for the life extension of several Earth-orbiting spacecraft (e.g. the Hubble Space Telescope (HST) and SolarMax spacecraft) [11]. Moreover, it has enabled the assembly of large orbital structures, such as the International Space Station (ISS), that would otherwise be impossible to launch from ground.

Nevertheless, modularity comes at a cost of additional structural mass and thus overall mission cost when compared with a typical highly integrated spacecraft [11]. Moreover, the total life-cycle cost of a spacecraft and its scientific return could also be negatively impacted by an advanced spacecraft modularity, which calls for a careful trade-off between the benefits and downsides of the modularity and reconfigurability of a spacecraft when compared with a traditional monolithic design [12].

The modularity and reconfigurability of a spacecraft or planetary rover in this paper defines the level of subdivision of its overall system in standardized and replaceable modules, connected with the main bus or interconnected between them via a standard interface [11].

The individual modules are envisioned to be able to contain any number of replaceable subsystems such as inertial reference units, payload, electronics, power distribution units, batteries, etc., that would otherwise be tightly integrated within the overall system [13].

Over the years, different levels of spacecraft modularity have been implemented and are outlined hereafter [14].

Typical contemporary spacecraft/rover generally consists of a multitude of highly optimized and integrated components developed with cost and mass in mind not meant for serviceability nor reparability [11]. This monolithic design, enables the overall system to singlehandedly carry-out all the required mission tasks for an extended period but does not permit an easy way to upgrade the main platform on-ground and/or in orbit should some components fail or become obsolete [14].

This fact has been partially overcome by introducing a minimally modular spacecraft, such as the contemporary commercial communication spacecraft, which generally consist of a platform having two to three large modules that allow parallel integration and testing (I&T) and provide significant cost savings, but not necessarily on-orbit servicing [11].

In order to observe the benefits of modularity and reconfigurability, it is necessary to achieve the serviceable modularity or modularity at the component level as in case of the HST and ISS. In this case, the platform mainly consists of individual serviceable components integrated onto the main bus via a standard interface. Thus, allowing on-orbit reconfiguration of the system at the component level via tools and procedures specifically developed for each component separately due to the lack of serviceable modules [14].

This complication can be avoided by developing systems consisting of serviceable modules, i.e. having the degree of modularity at the subsystem level, which can be easily removed/replaced on-ground as well as in-orbit. Examples of such type of spacecraft are the Multimission Modular Spacecraft (MMS), the SolarMax spacecraft, and the Reconfigurable Operational spacecraft for Science and Exploration (ROSE). These spacecraft allow a great deal of flexibility both on-ground, during I&T activities, and in-orbit, while at the same time manage to keep the complexity of those tasks at the minimum [11].

Nevertheless, in order to enable future autonomous robotic on-orbit servicing and assembly an even greater degree of modularity is required. It can be observed in the intelligent Building blocks for On-orbit Servicing (iBOSS), Autonomous Assembly of a Reconfigurable Space Telescope (AAReST), DARPA's Satlets and Self Assembling Wireless Autonomous and Reconfigurable (SWARM). In these concepts, the overall spacecraft is composed out of compact interconnected modules, each with a limited functionality comparable to cells in a living organism. Each module is envisioned to be interconnected to another via an intelligent plug-and-play interface, allowing almost total in-orbit reconfiguration and assembly, with the highest level of flexibility in mind [11].

The type and number of individual modules shall be determined in advance based on an optimization process that will depend not only on engineering metrics, such as the cost and mass, but also on other less quantifiable metrics, such as future market uncertainties/projections and influence of stakeholders [12], [15], [16].

The goal of the SIROM project is to extend further this advanced modularity by providing a platform that could be used both in orbital and planetary environments with minimal adjustments.

4. Capabilities of SIROM interface

4.1 Couple payloads to payloads

SIROM is a combination of devices that allow to couple active payload modules (APM) among themselves, and allows transferring of mechanical loads, electrical signals and data as well as thermal flux between the coupled modules in a reliable and optimised manner.

SIROM is considered an IF that can couple and decouple using one side’s latch. Being able to connect to a defunct module opens up options for repair or removal; by also opening up the ability for the attaching IF to power the APMs other functions. This method means that in cases of drained power or a power IF malfunction on another side, the module can operate normally.

4.2 Couple payloads to robotic manipulator

For the possibility of reconfiguration, it is necessary to be able to relocate APMs. For this purpose, a manipulator must pick them up. It is appropriate to equip the end effector of the manipulator with an SIROM as well, so that the APMs can be mechanically connected to the manipulator and provided with energy, data transfer and thermal control capabilities through the manipulator during transfer from one location to another. For the coupling process between the manipulator and an APM the relative position between them has to be known or perceived with a high accuracy to be able to calculate an appropriate motion trajectory for coupling both interfaces. However, this is usually not sufficient, so that the manipulator must provide a compliance control as soon as the two interfaces get in contact to support the final joining.

4.3 Control bus redundancy management

A control bus is used to control both the SIROMs and the APMs. In case of failure of this bus, a FDIR mechanism is to be provided to allow automatic reconfiguration of the control means on a redundant bus. SIROMs are connected as slave nodes on this control bus and support this redundancy mechanism.

4.4 Control bus dynamic reconfiguration

For planetary missions, there will be scenarios involving a set of APMs to be detached from a rover or lander and assembled to form a new autonomous system. This will require the nodes of the control bus interconnecting the APMs through SIROMs to be capable of being dynamically reconfigured to respond to the command of a new master as will take place when the control need to be transferred from the OBC of the rover/lander to the controller of an APM of the detached system. SIROMs are always slave nodes of the control bus but their bus controller needs to support such dynamic reconfiguration.

5. SIROM project: an overview

5.1 SIROM IF

With a mass lower than 1,5kg SIROM is a cylinder with an external diameter of 120mm, 30mm height above and 30 mm height inside APM. Fig. 1 shows SIROM main parts. Due to the need to be operative in planetary missions, the external housing and dust cover prevent contamination that would interfere with the proper functioning of the interface.

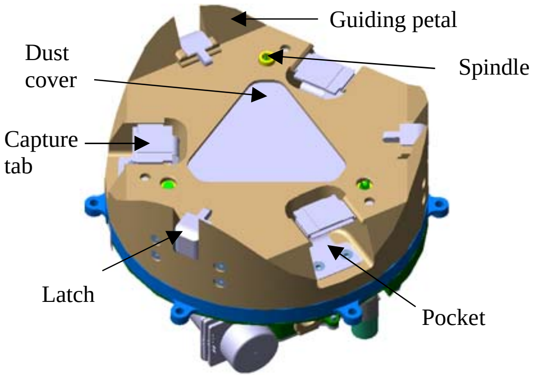

Fig. 1. SIROM main parts- SENER ©

SIROMs are directly bolted to APM structure and in general, an APM could be provided with any number of SIROMs.

SIROM design not only features mechanical, electrical, data and thermal connections in an integrated and androgynous form, but it also presents main and redundant connections in case one of the lines fails. Electrical, data and thermal IFs are located in the so-called Connectors plate while the mechanical IF is on its own. Fig. 2 shows the functional interfaces.

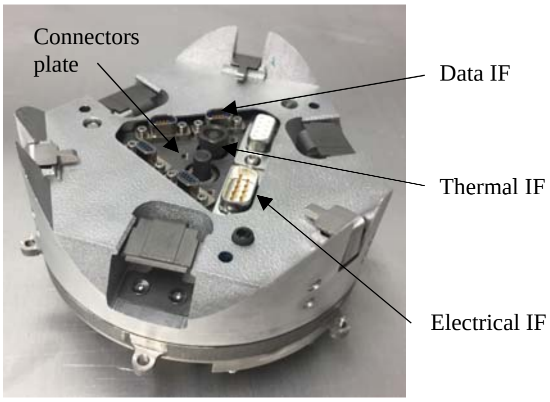

Fig. 2. SIROM functional interfaces- SENER ©

Regarding the mechanical IF, it is basically 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, misalignment errors are corrected by the guiding petals during approximation.

The main performances of SIROM are summarized in the Table 1:

Table 1. SIROM performances

Mass	<1,5 kg
Dimensions	128 mm diameter 76,6 mm height
Temperature range	Non-operational: -128ºC to 50ºC Operational: -110ºC to 50ºC
Endurance time	10000 cycles
Voltage power lines	▪ 100 V ▪ 24 V
Electricity transfer	▪ 120 W for 100 V line ▪ 30 W for 24 V line
Data transfer rate	▪ SpW: 100 Mbit/s ▪ CAN: 1 Mbit/s
Heat exchange	2500 W
Power consumption until connection	19 W
Latching force	1020 N
Misalignment tolerance	▪ 10 mm axial ▪ 5 mm other axes ▪ 1,5º all axes
Latching time	60 s
Connection time	102 s
IF to APM	6xM3 bolts at 128 mm diameter circumference
Other performances	▪ Active – Passive SIROM coupling redundancy ▪ Electric, data and

	thermal lines redundancy

5.2 SIROM controller

This avionics component is the brain of SIROM. It is connected as a slave device to a dual redundant CAN bus and receives its commands from a master device (OBC from spacecraft, planetary rover or APM). The controller runs a set of algorithms that monitor and control:

- the locking and coupling mechanisms of the SIROM;
- The Electrical Interface System (EIS) responsible for switching the 100V and 24V power lines across the SIROM;
- the dynamic switching of the SIROM controller to the redundant CAN bus in case of the nominal bus failure in compliance with the ECSS-E-ST-50-15C CAN bus extension protocol.

The controller has no control on the data and thermal interfaces as these are implemented as passive connections at the level of the SIROM.

The project has designed a preliminary hardware architecture of the SIROM controller suitable for flight qualification of its avionics. It comprises a PCB with a SoC and peripheral components such as memory units, CAN transceivers and a serial interface for debugging purpose. Fig. 3 presents this preliminary architecture. The SoC is based on a radiation hardened FPGA comprising a number of IP Cores populating a LEON processor, the CAN controllers, an I/O controller for digital and analogue inputs and outputs and memory and DMA controllers to efficiently control the access to all memory units. This SoC qualified for space exploration missions would be suitable for controlling the SIROM as well as for commanding APMs requiring limited computation capabilities.

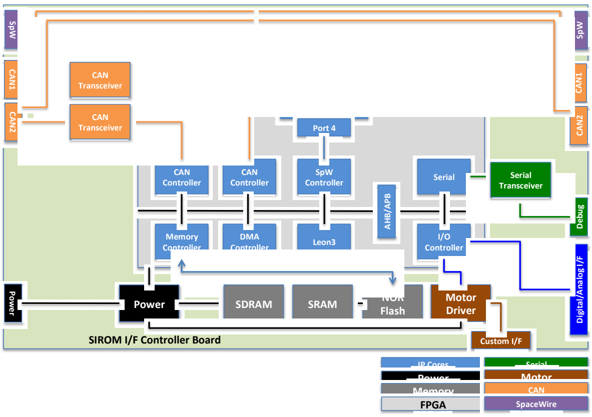

Fig. 3. Preliminary Architecture of a Space Grade Controller for SIROM I/F and APMs

For implementing the SIROM controller, suitable flight proven FPGA technologies exist as e.g. the RTG4, RTAX and RT ProASIC3 chips from Microsemi or the Virtex-4 or Virtex-5 chips from Xilinx. However, as these components are manufactured in the US and distributed under EAR regulations, the new European FPGA designed by NanoXplore and to be manufactured by STMicroelectronics in 2019 is also considered as an interesting alternative.

In order to meet the budgetary and programmatic constraints of the SIROM H2020 project, the level of maturity and representativeness imposed on the avionics selected for developing the SIROM controllers is only at TRL4 (breadboard functional validation in laboratory environment). Therefore, readily available low-cost COTS components are used for developing the SIROM controllers but offer the same functional blocks as their space grade counterparts.

Fig. 4 presents the hardware architecture and COTS components that have been selected for the breadboarding of the SIROM I/F controllers.

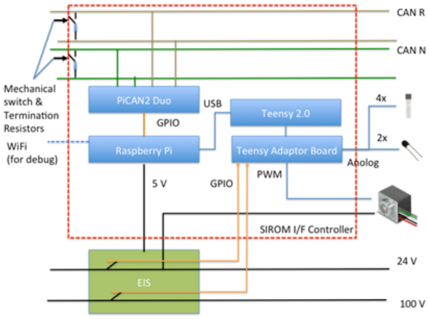

Fig. 4. COTS Breadboard of the SIROM I/F Controller

Because of the low level of integration of the COTS selected for the breadboarding of the SIROM avionics, there is not enough room to accommodate it inside the SIROM mechanical housing and is thus housed inside the APM volume. The SIROM I/F controller consists of 4 main components:

- Raspberry Pi Zero is to control overall operation of the SIROM interface (communication, control and monitoring).
- Teensy 2.0, provides additional I/O interfaces (including analogue I/O) and controls I/O operations such as reading the sensors and latching switch status, and controlling the motor.
- Teensy 2.0 adaptor board is a simple board consisting of passive components and connectors for interface and conditioning of the actuator/sensors.
- PiCAN2 Duo is to communicate via CAN bus.

The SIROM provides a mechanical switch to properly terminate the CAN bus by a 120 Ohm resistor. When a SIROM is at the end of the bus, the switch is maintained in closed position and this terminates the bus by the resistor. When two SIROMs are connected in the middle of the bus the SIROM switches are mechanically forced to open, disabling the termination resistors. This is shown in Fig. 5.

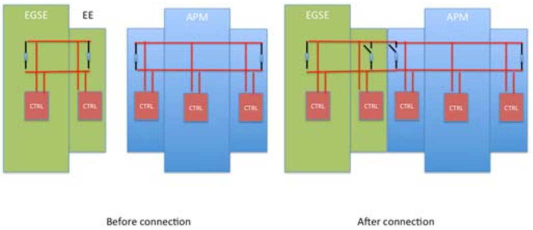

Fig. 5. Termination resistors

5.3 Thermal IF subsystems

Two thermal interfaces are being developed within the SIROM project:

- A low power thermal interface with the capacity of transferring 20-50 W by pure conduction between two solid surfaces in the interface
- A high power thermal interface with the capacity of transferring up to 2.5 kW, focused on high power applications and future human precursor missions. Heat exchange is provided by a Close-Loop Fluid Heat Exchange Module (CL-FHEM). The SIROM thermal IF is mainly composed of:

  - Two fluid quick connectors; male and female
  - Two flexible lines; metallic bellows with a total stroke of 9mm
  - A fixed user interface; mainly composed of a 1/8” NPT male connection.
  - Two NTC temperature sensors

Fig. 6 shows a view of the high power thermal IF main components.

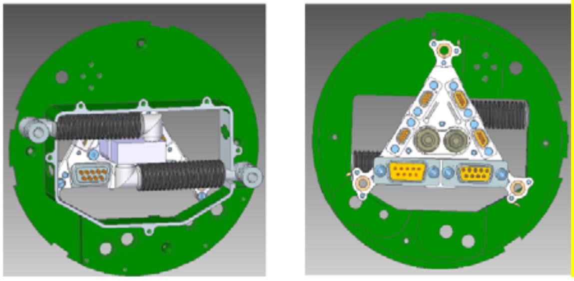

Fig. 6. SIROM high power thermal interface

5.4 Orbital APMs

In the context of SIROM project, two orbital APMs have been designed to support the tests [17]. One of them, the so called orbital APM 1, is equipped with a payload camera and necessary components needed for the function of the interface and orbital APM 1 while the other APM, the orbital APM 2, does not have any payload for special tasks but just provides a realistic operation.

The orbital APM 1 consists of a housing with footprints of 150 x 150 mm and a height of 180 mm, whereas the housing of the orbital APM 2 has the dimensions of 150 mm x 150 mm x 150 mm (see Fig. 7)

Fig. 7. The orbital APMS with heights of 150 mm (APM 2, left figure) and 180 mm (APM1, right figure) (credit: DFKI GmbH)

The orbital APM1 will be attached with 2 SIROM interfaces, one on top and one on the bottom of the module. Furthermore, following equipment will be housed:

- (2x) SIROM controllers: RPi-zero + Teensy 2.0 board + PiCAN2 DUO board
- (2x) Electrical Interface Systems
- SpaceWire-USB brick Mk3
- APM controller: RPi-3 + PiCAN2 DUO board
- APM payload: RPi camera module V2

The orbital APM 2 will be attached with one SIROM on the top of the housing and with a plate on the bottom which allows to fix the oribital APM 2 on the mock-up of the orbital test scenario.

5.5 Planetary APMs

Two planetary APMs are developed in the SIROM project to validate and demonstrate the use of standard interfaces in the context of a planetary mission. The first APM is solar power charging station, the so called Primary Active Payload Module (P-APM). It has been designed to be transported in folded configuration under the body of the SHERPA-TT rover that is provided by DFKI to support the planetary validation test campaign. The P-APM is an autonomous payload that, once dropped on the surface, deploys orientable photovoltaic panels towards the Sun and delivers electrical power to charge a number of swappable battery packs. This APM comprises a payload controller, internal power bus protections, a battery management system and a photovoltaic charge regulation system. Fig. 8 presents a model of the P-APM in folded and deployed configurations. The second APM called auxiliary APM (A-APM) is a battery pack comprising a controller, a battery charge/discharge regulator and a battery management system. The P-APM hosts as well a camera recording video images from the scene surrounding the P-APM and feeding a SpW link with the video data. Fig. 9 presents a model of the A-APM. Fig. 10 shows a mockup of the P-APM attached under the body of the SHERPA-TT rover and A-APM attached to the tip of its manipulator arm during preliminary integration tests at DFKI. The SIROMs provide power, control, data and thermal interfaces between these APMs and to the end-effector of the robotic arm.

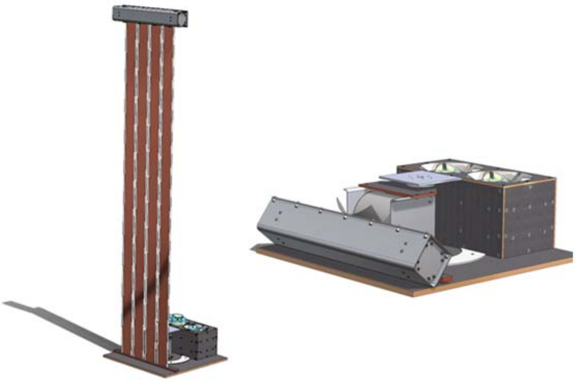

Fig. 8. Model of the P-APM in folded and deployed configurations.

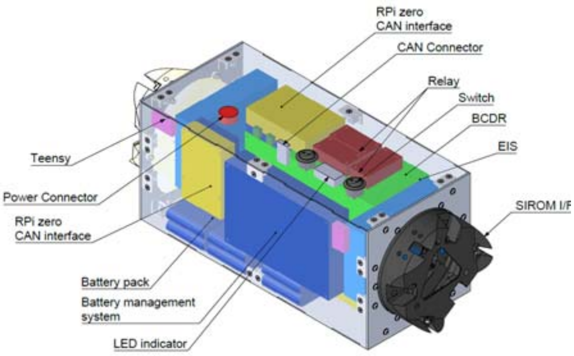

Fig. 9. Model of the A-APM.

Fig. 10. Preliminary integration tests performed at DFKI with a mockup of the P-APM attached in folded configuration under SHERPA-TT body and a mockup of the A-APM attached to the tip of its robot arm manipulator. (credit: DFKI GmbH)

5.6 End-Effector

An end-effector has been designed to be used in both the orbital and planetary scenario. The end-effector provides the mechanical interfaces necessary to connect a manipulator of a robotic arm to SIROM, in order to allow handling of the different APMs.

It includes two flanges, to allow the robotic arm used in the OG6 tests to sustain the part of SIROM which physically requires to be at the end tip of the robotic arm.

The end-effector also accommodates, by means of purposely designed supports, the electronic parts which are installed inside the APMs in the other cases and needs to be close to SIROM. These parts include:

- EIS (Electrical Interface Subsystem)
- Raspberry PI
- Teensy
- PiCAN2 DUO

The Fig. 11 bellow shows a preliminary design of the end-effector.

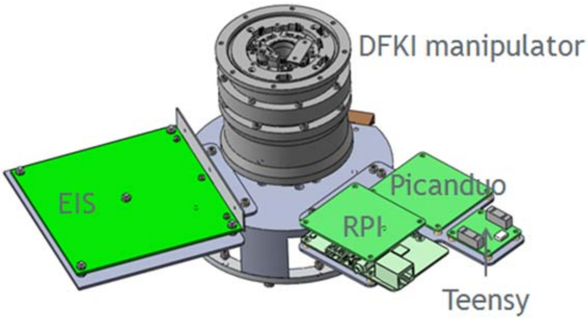

Fig. 11. End-effector preliminary design

5.7 EGSE

In the scope of SIROM project an EGSE manufactured by TELETEL is used for the functional verification and demonstration of the SIROM interfaces and APMs. The EGSE is based on iSAFT-PVS which is an integrated powerful HW/SW environment for the simulation, validation & monitoring of satellite/spacecraft on-board data networks and discrete interfaces supporting simultaneously a wide range of protocols (RMAP, CPTP, TM/TC, CANopen, etc.) and interfaces (SpaceWire, MIL-STD-1553, CAN, Discrete I/O, Power Suplies, etc.). For the testing activities and the command, control and monitoring of the SIROM interfaces and APMs the EGSE is equipped with a 4 port SpaceWire PCIe board, a 4 port CAN/CANopen PCIe board and a Power Front End equipped with 30V and 100V programmable power supplies with overcurrent and overvoltage protections. The control of EGSE and the testing activities are performed using the iSAFT user friendly graphical interface and Python scripts using the iSAFT Python APIs.

6. Application scenarios

6.1 Orbital scenarios description

SIROM will demonstrate its capabilities to support on-orbit satellite servicing, assembly and reconfiguration of satellites in a representative orbital scenario. The demonstration mission, that is the final goal of the scenario, will feature a small satellite system that, through robotic technology can deploy/reconfigure/extend itself, thus allowing the spacecraft mission to evolve.

The demonstration will present several robotic operations between a mockup servicer satellite that is docked to a mockup client satellite. The servicing tasks will be performed by a servicer light-weight robot KUKA LBR4 responsible of grabbing and changing active payload modules (APM) between both satellites. This is possible thanks to the standard SIROM interfaces mounted on the robotic arm end effector and on the orbital APMs, namely APM-1 and APM-2.

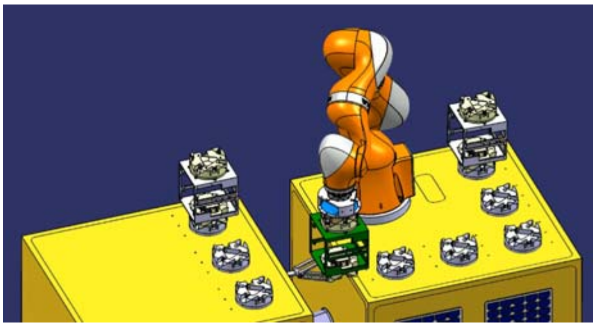

Fig. 12. Robot servicer performing an upgrade of the client satellite

The Fig. 12 above shows a virtual representation of the test set up. The satellite servicer is on the right and the client satellite is shown on the left; both satellites are provided with SIROM interfaces that are needed to attach, upgrade and reconfigure APMs. The test consists on the servicer satellite provided with two APMs removing a failed dummy payload from the target spacecraft (grey APM on the left) and replacing it with a new dummy APM (grey APM on the right). Additionally, the servicer robot grabs a functional APM, the so-called APM-1 provided with a payload camera, and attaches it to APM-2 (not represented in the figure) to create a structure where the SIROMs connect the two APMs to each other. Thanks to the 4-in-1 functional interface, the satellite servicer on-board computer (OBC) can interact with APM-1 payload, providing the required power supply, commanding the camera to take photos/videos via CAN communication and transferring the data back to the OBC via SpaceWire communication. Although not envisaged for this test (APM-2 does not contain any payload), it is to be highlighted that the servicer OBC could also establish communication with APM-2 even if the robot arm is directly connected to APM-1, as long as the latter is connected with SIROMs to APM-2. This is one of the benefits of modular satellites.

This test will validate most of SIROM functionalities such as data, commands and electrical transfer as well as mechanical latching redundancy. Regarding the thermal/fluid transfer functionality, it is to be said that it will be validated on its own due to the complexity of validating all 4 functionalities in a single orbital test.

6.2 Planetary scenarios description

The planetary scenario selected to demonstrate SIROM is a robotic mission to detect the presence of volatiles in the region of the lunar poles. The mission involves extended rover operations in shaded lunar craters. For example, the Shackleton crater that lies at the southern lunar pole has an interior that is in permanent darkness while crater rim spends ~80-90% of the time in sunlight. The reference scenario involves a lunar rover navigating to a crater rim and releasing the solar power charging station (P-APM) onto the surface in the Sun illuminated area. Battery packs (A-APMs) are connected to the P-APM by means of SIROMs that provide power, control, data and thermal interfaces between these devices. In this scenario, the rover has to explore a permanently shadowed region of the crater, so cannot use its own solar panels for recharging its batteries when searching for lunar volatiles. Therefore, it will have to return to the P-APM each time it needs a recharge to perform a swap of a depleted A-APM with a fully recharged one. Thanks to this, the rover greatly extends its autonomy and can return in the shadowed area of the crater as often as needed.

6.3 Future Applications

Today´s satellite systems are tailor made very expensive single shot devices. There is a need to get more benefit from the space systems already launched by extending their lifetime, to overcome the limitations of the launchers set up by the fairing size and to establish satellite platforms which are prepared of being serviced by providing standardized interfaces for APMs. In the last years projects have started e.g. MEV from Orbital ATK or SpaceTug from AIRBUS Defense & Space which intend to extend the operational lifetime of space system already in space by offering On-Orbit servicing services e.g. refuelling. The target group for these projects are operating satellites which are already in space and not prepared for being serviced. Therefore, the services and the business case for this systems are limited. Much bigger business perspective arises if both servicer and client are prepared to service and being serviced.

The space industry will directly benefit from incorporating standardized payload modules with standard interfaces into their spacecraft´s. Failed payloads can be replaced rather than launching a new spacecraft. Satellite platforms can be adapted or upgraded to new missions just by adding new subsystems. This would be even more relevant for new satellite constellations e.g. future GPS system, where the performance of the system could be secured, extended or improved by the exchange of valuables equipment e.g. atomic clocks.

New business opportunities will follow. Examples on earth like the introduction of containers (logistics) or the USB drive (IT applications) show the huge potential of standardization.

Utilization of modular building blocks equipped with standardized interfaces offers the opportunity to overcome launcher limitations by assembling on orbit the components launched with successive launches. This leads to space system architectures of large structures which are no longer affected by ground effects and the need of very big launchers.

Future planetary missions will also benefit from a modular architecture. Modularity allows to extend the mission by the exchange of power modules and gives greater flexibility to adopt the system to mission changes or variations.

7. Discussions and conclusions

With the obsolescence of some space systems, the emergence of a new commercial model alongside the development of entrepreneurial in space, the growing interest in exploration of the surfaces of celestial bodies, the European space industry is currently facing and will be facing some big challenges to ensure the competitiveness and the viability of its commercial model in the next years.

The 2016 call for the EU H2020 Strategic Research Clusters (SRC), has addressed these challenges by supporting the development of Space Robotics Technologies. The first activities of the SRC, have been involving the design, the prototyping and the tests of reliable and high-performance robotic building blocks for space operation.

SIROM project produced a suite of hardware by which robots can interact with other robots or payload modules. The output technology of this project has the ambition of becoming the standard, in on-orbit servicing as in planetary explorations, for the next 10-years space missions by supporting the increase of:

- Robotic collaboration
- Spacecraft autonomy by allowing refuelling for equipped devices.
- Spacecraft lifecycle with the possibility of inspection and maintenance on space systems
- Modularity and upgradability of space devices

By this means SIROM intend to reduce spacecrafts cost as well as their operational cost and therefore could potentially give access to space to a new kind of user and participate to the transformation process which is currently taking place in the space activity sector.

Following work will consist in integrating the interface alongside with the common building blocks, prepared during the first activities of the SRC, into demonstrators. This will allow the validation of the capabilities and to demonstrate the performance of the SIROM as a standard interface for robotic manipulation of payloads.

Acknowledgements

The authors would like to thank all the supporting staff and partners of the SIROM Project: SENER (Spain), Airbus DS Ltd. (UK), German Research Center for Artificial Intelligence (DFKI), Robotics Innovation Center(Germany), the University of Strahclyde (UK), Airbus DS GmbH (Germany), Thales Alenia Space S.p.A (Italy), Leonardo S.p.A. (Italy), TELETEL (Greece), Space Applications Services N.V. (Belgium) and MAG SOAR S.L. (Spain). SIROM is part of the PERASPERA project on Space Robotics Technologies, and has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730035.

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