Preliminary definition of a Standard Interconnect Benchmark for On-Orbit Servicing Demonstrator

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Summary
The use of modular robotic systems plays a key role in orbital robotics. Here, different modules with different payloads can be combined with each other to create, for example, a satellite. To connect the modules, so-called standard interconnects (SIs) with multifunctional features, e.g. allow mechanical and electrical connection as well as data transfer and, if necessary, also regulate the heat distribution, are required. In the operational grant (OG) PERIOD of the EU Horizon 2020 project PERASPERA, three SIs will be evaluated with the help of a benchmarking concept to give a recommendation on the most suited one to be used in the orbital demonstration mission of PERIOD. This presentation will highlight the planned demonstration scenario in PERIOD, the SIs involved and the structure of the benchmarking concept.

Keywords: *space robotic, Standard Interconnect, in-orbit demonstration,*

1 Introduction
The PERASPERA In-Orbit Demonstration (PERIOD) project is one of the operational grants (OGs) of the third phase of the European Union's Horizon 2020 Space Strategic Research Cluster on Space Robotics Technologies with an objective to increase the maturity of space technologies and prepare them for an in-orbit demonstration, planned within the 2023-2027 timeframe. Specifically, the project will build upon the work of previous OGs to raise the technology readiness level of core technologies and define an orbital demonstration concept for on-orbit servicing and assembly.
The specific objectives of the project are:
a) Definition of a demonstrator concept based on an orbital factory, integrated on the Bartolomeo platform of the International Space Station, to manufacture and operate a spacecraft in-orbit.
b) Further development of core space robotics software components up to the technology readiness level five.
c) Evaluation of the current state-of-the-art standard interfaces in a benchmark scenario.
d) Evaluation of all the core components for assembly on a breadboard.
e) Implementation of communication and dissemination activities to inform the space community and potential customers on the capabilities of on-orbit servicing and assembly as well as provide transparency on risks and mitigations.

2 Demonstration Scenario
Space robotics technologies are maturing, bringing new capabilities for In-orbit Services, Manufacturing and Assembly (ISMA). These capabilities will generate on-orbit services improving the orbital infrastructure, creating in turn a very promising business opportunity in terms of market volume. The establishment of a European capacity is necessary for building this new space infrastructure and to capture a fair part of this market.

The PERIOD Consortium is proposing a very ambitious demonstration scenario and Factory concept. A satellite will be manufactured in an Orbital Factory and injected in LEO (Low Earth Orbit) for operations. The manufacturing includes the fabrication of an antenna, the assembly of the satellite components and its reconfiguration and inspection in the Factory. The Bartolomeo Platform (see Figure 1) on the International Space Station (ISS) is envisioned for the orbital Factory.
Throughout the demonstration mission, the PERIOD setup will be upgraded to extend the level of capability validation from assembly and manufacturing of structures to attachment and refueling experiments. This demonstration covers the short and mid-to-long term ISMA business cases and will support the transition into the in-space services, assembly, and manufacturing paradigm.

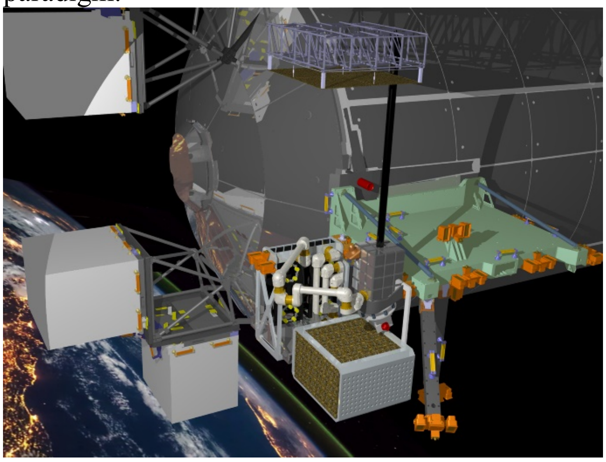

Figure 1. The Bartolomeo Platform (credit: Airbus Defense and Space GmbH)

3 Role of Standard Interconnects

Standard Interconnects (SIs) are getting more and more important in the modular space robotics. By using them, it will be possible to connect different modular subcomponents in such a way that different configurations are possible. For example, a satellite can be assembled from several individual components and reconfigured if necessary, or in the event of malfunctions in a module, the module can be replaced. This means that every module needs at least one SI to couple with another module also containing an SI. An SI is usually considered to be a multifunctional interface, which can connect mechanically, transmit power and data, and has the option for thermal transfer if required [1].

In PERIOD there are three different SIs involved. Two of these SIs were developed in the previous OGs. There is SIROM, developed in OG 5 and HOTDOCK developed during the second phase of PERASPERA. Both SIs were involved in different studies of in-orbit demonstration scenarios.
The third SI is the iSSI by iBOSS GmbH.

SIROM

SIROM design is a 4-in-1 integrated interface combining mechanical, data, electrical and fluid connectivity in a single and compact envelope (Figure 2). The mechanical interface allows coupling of payload modules providing a robust and reliable connection and provides the housing for the whole system. The electrical interface allows bi-directional power transfer between mated SIROM pairs. The data interface enables telemetry (TM), telecommands (TC) as well as high speed data transmission supporting SpaceWire (SpW), Ethernet or similar protocols. The fluid interface allows the transmission of fluids between SIROMs for a variety of uses such as heat regulation, refueling, resupply (coolant, water, etc.).
To summarize SIROM performances, it can be highlighted the following [2]:

SIROM has an androgynous interface and only requires one SIROM to be actuated during the connection of two SIROMs. Furthermore, it has an independent latching mechanism based on SENER heritage with the International Berthing and Docking Mechanism (IBDM). Redundant connections allow functionality also in case of line failure. SIROM features a fully customizable connector plate and has a low mass (electro-mechanics mass < 1.5kg).

SIROM has participated in H2020 SIROM, H2020 FACILITATORS and H2020 EROSS projects. This technology has reached TRL6 at the beginning of 2021.

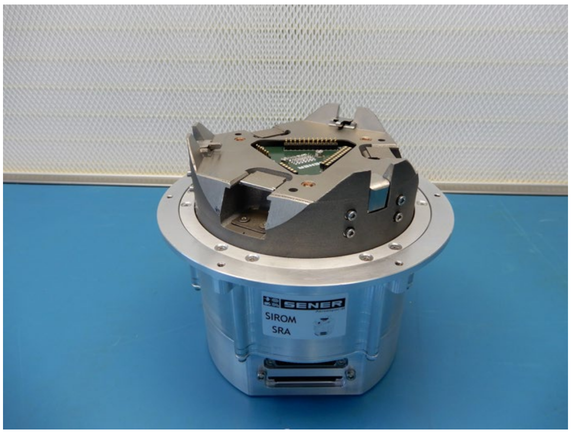

Figure 2. SIROM (credit: SENER)

HOTDOCK
HOTDOCK is a multi-functional interface designed to address On-Orbit Assembly and Manufacturing (OSAM) challenges – with an initial focus on capabilities required, and application cases identified in H2020 MOSAR, H2020 PULSAR and H2020 PRO-ACT projects.

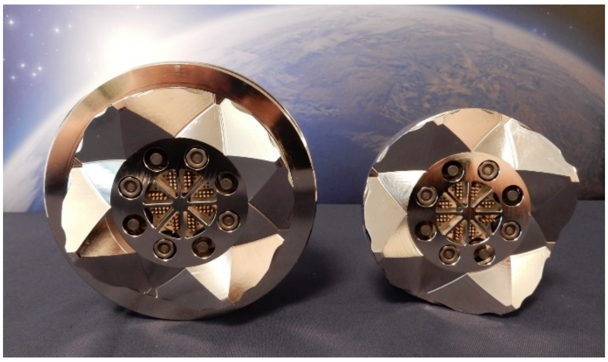

Figure 3. HOTDOCK (credit: Space Applications Services)

HOTDOCK is a mating device providing androgynous coupling to transfer mechanical loads, electrical power, data and (optionally) thermal loads through a single interface (Figure 3). Integrated to spacecraft and payload structures, it provides mounting points for components assembly and reconfiguration. Mounted at the tip of a robot arm, it works as an end-effector for quick connect/release of spacecraft modules during their manipulation or as a quick tool adaptor. HOTDOCK eases the replacement of failed modules as well as swapping of payload elements and provides chainable data interfaces for building spacecraft modules assemblies. HOTDOCK exists (and was demonstrated at TRL4) in 3 variations: *Active* (fully featured), *Passive* (all connectors, but no actuated locking) and *Mechanical* (simple grappling site, without connectors). HOTDOCK has a full (mechanical, data and power connectors, and fluid interface connectors) 90 degrees symmetry. Its form fit geometry allows guiding the final approach of the interface before starting the mating process. This is furthermore supported by Hall-effect sensors embedded in the mechanical structure, that are used for proximity measurement as well as verification of alignment and relative orientation of the two mated interfaces [3].

iSSI
The iSSI (intelligent Space System Interface) Modular Coupling Kit by iBOSS GmbH is a multi-functional connector solution addressing and serving both OSAM (space) and growth markets as robotics, logistics, inter-modal transport, e-mobility and more (Earth) [5].
The iSSI core unit (Figure 4), can be equipped with multiple extension and variation options via add-on modules and hence, works as a fully modular coupling set.

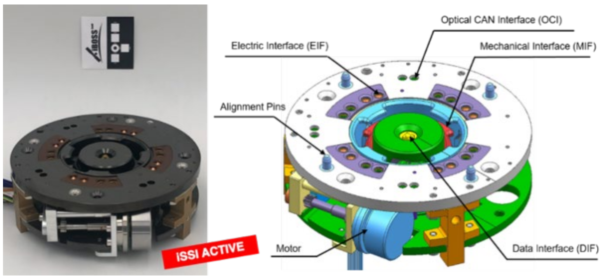

Figure 4. iSSI ACTIVE Core Unit Hardware and CAD (credit: iBOSS)

The basis is the 2-in-1 interface core (mechanical and electrical), whereas the power interface can be activated or not while the power pins in any case remain part of the coupling process. Other coupling sets contain a 3-in-1 interface (mechanical, electrical and data) as well as 4-in-1 interface (mechanical, electrical, data and thermal).
The so-called Add-On Modules span alignment pins for increased misalignment tolerances and loads, a form fit (customizable per use case) enabling docking and berthing, increased misalignment tolerances and load, and broader diagonal engagement, a dust cover for planetary missions and a launch lock supporting launch loads.

The iSSI is geared around OSAM needs and aims at providing highest flexibility. Key features of the iSSI are – besides its multi-functionality (mechanical, power, data thermal), androgynous design and 90°-Degree rotational symmetry - especially: flat surface, lubricant-free mechanism, fail-safe system (with respect to de-coupling), full modularity, lightweight (1kg-range for core unit), scalability (customization, and per functionality) and multi-mounting options.
The iSSI has reached TRL 6 and will be demonstrated in space aboard ISS later part 2021.

4 Benchmarking Concept

The selection of an appropriate SI is crucial not only for the assembly and operations but also for the design of critical equipment like the manipulator with an impact to their development effort and costing. An SI putting too much constraint on the manipulator (in terms of accuracy, force/torque, sensors) will lead to increased costs, development time and operational complexity. Therefore, a careful trade-off will need to be assessed between the performance requirements of SIs and manipulator. As a first step of this tradeoff, it is foreseen to implement a benchmark on the existing SIs to assess their maturity and performance according to the requirements of the project. The considered SIs are SIROM, HOTDOCK and iSSI. Tests will be implemented by DFKI as an independent body to evaluate the performance of the SIs in relevant demonstration scenarios and in full transparency to the Consortium members. This will lead to a recommendation of a preferred interface to be considered during the B2 phase of the project.

For the definition of the baseline of the SI benchmarking the ECSS-E-HB-11A handbook and related standards are used as guidelines.
Additional requirements to be considered by the benchmarking will come from the mission scenario of the PERIOD project.

Within the mission a Client Satellite provided by ISISPACE will adhere to the CubeSat standard, which in turn introduces constraints on the SI architecture and design. First and foremost is the physical characteristics of the SI. The CubeSat form factor is made up of modular blocks called "Units", where one Unit is 10x10x10 cm in size. Although no requirement exists on the power draw of the SI itself, it should be minimized as CubeSats have limited power generation capabilities. The average mass of a single Unit should not exceed 1.33 kg, although the SI itself can be heavier if other Units compensate, while keeping in mind the center of mass of the whole platform to avoid negatively impacting the attitude and orbit control system.
The SI should also be compatible with the electrical and data interfaces commonly used in CubeSat applications. A typical electrical interface is an unregulated 16V power bus, while common data interfaces include I2C, CAN, SPI, or RS232/422/485. Specifically tailored adapters may also be considered for more custom-built architectures.

The current baseline for the benchmarking is considered to be similar to a typical technology readiness assessment (TRA) process which consists out of the following steps a) preliminary definition of performance requirements and relevant environment, b) identification of critical functions of SIs according to the PERIOD's mission scenario, c) drafting of the critical function test plan, d) definition and implementation of the benchmarking environment, e) testing and analysis of results, see also [4, Table 5-1].
Similarly, the current baseline for the performance metrics mirrors the generic description of the TRA criteria. The main areas covered by them are [4]:

- general evaluation aspects like a) element definition status, b) performance requirements status and c) verification and validation status.
- documentation for TRA like a) preliminary definition of performance requirements and of the relevant environment, b) identification and analysis of critical function of an element and c) preliminary design of the element, supported by appropriate models for the verifications of the critical function of an element.

Due to the envisioned demonstration scenario, the currently identified critical functions of the SIs to be tested during the benchmarking cover the mechanical, data and power functionalities of the SIs.
The benchmark environment will be implemented at the "Mensch-Roboter Kollaboration und Industrie 4.0" (MRK) laboratory of DFKI-RIC in Bremen and will employ LBR iiwa manipulators visible in Figure 5.

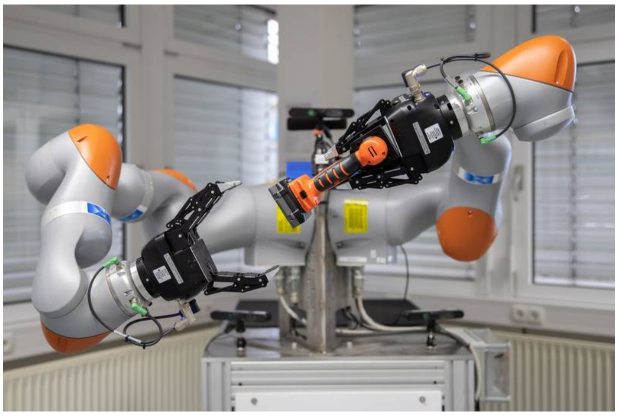

Figure 5. LBR iiwa system at the MRK laboratory of DFKI-RIC (credit: DFKI GmbH)

5 Conclusion and Outlook

The ECSS standards are necessary to ensure a fair and neutral basis for the evaluation of a suitable standard interconnect. The planned tests with the LBR iiwa manipulators are intended to prove whether the SIs can comply with the required deviations.

6 Acknowledgements

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