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PERASPERA In-Orbit Demonstration

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

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Stardust-R – Second Global Virtual Workshop

16th September 2021

European Commission

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004151

Consortium

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AIRBUS

gmv INNOVATING SOLUTIONS

SENER Aeroespacial

spaceapplications SERVICES

DFKI German Research Center for Artificial Intelligence

ISISPACE

easn Technology Innovation Services

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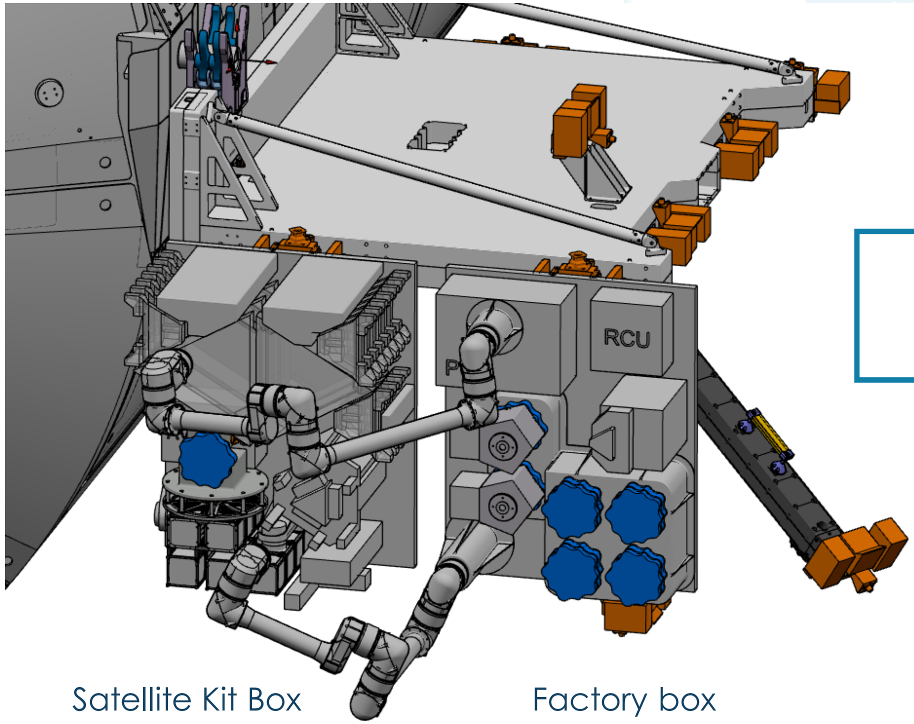
Objectives

In-orbit demonstration of manufacturing on ISS:

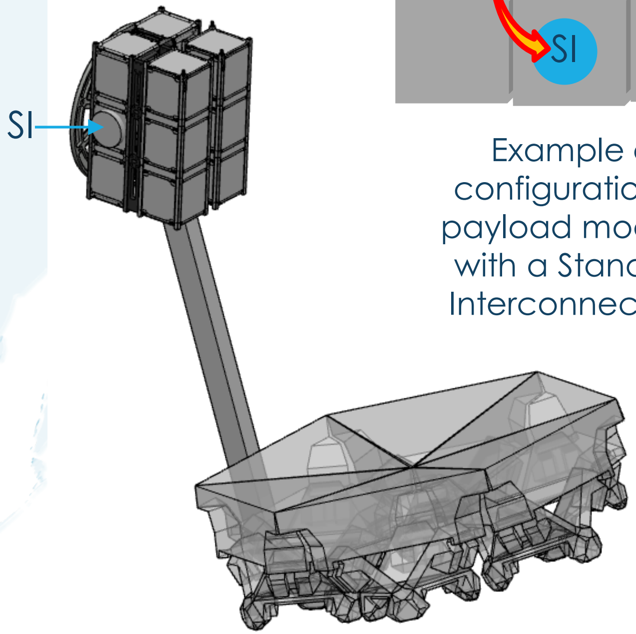
Attachment of satellite modules in orbit from a kit with a robotic system

From a satellite kit with Standard Interconnects (SI)

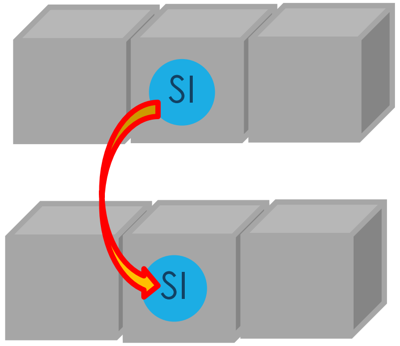


Satellite Kit Box

Factory box



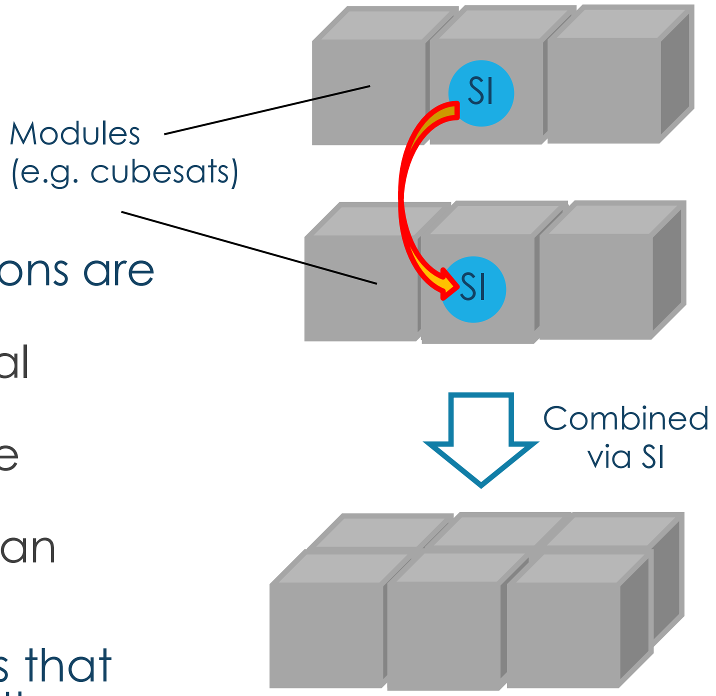
...into a functioning assembled satellite, including inspection, reconfiguration, attachment, refuelling.

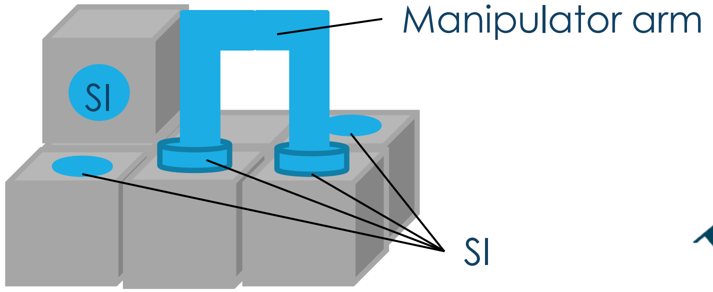


Example of configuration of payload modules with a Standard Interconnect (SI)

Role of a Standard Interconnect (SI) in space

- Multifunctional Interconnector with
  - Mechanical connection
  - Electrical connection
  - Data transfer
  - Thermal transfer
- Attached on modular subsystems (e.g. cubesats), various configurations are possible. For example
  - Assembly and / or reconfiguration of a satellite with individual modules (=modular subsystems)
  - in the event of malfunctions in a module, the module can be replaced
  - Attached on both ends of a manipulator, the manipulator can "walk" on the modules and also configure the modules
- The main goal is to reduce space debris by using modular subsystems that are combined (or be replaced in case of malfunction) according to the required tasks via the attached SI.
- Up-to-date there is no recommended Standard Interconnect for (re)configurable modular subsystems in space





SI Benchmarking

- Focus is on in-orbit use (planetary use is also possible but here other environmental conditions must be considered)
- Evaluation of the performance of the involved Sis for the specific demonstration scenario and associated requirements
    - Attachment of satellite modules in orbital factory (on the Bartolomeo Platform)
    - Satellite reconfiguration in orbital factory (on the Bartolomeo Platform)
- Identification of most suitable candidates for further maturation
    - Recommendation of one SI solution for the phase B2 of the demonstration mission
    - Improve recommendations on the design and operations of SIs
- Long term goal is to define recommendations and golden rules for future in orbit robotic operations

SI benchmark development methodology

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Demonstration scenarios

Identify and analyze **characteristics** of **demonstration scenarios / mission operations**

Standard Interconnects

Identify and analyze **critical functions / characteristics of SIs** to be tested

Standards

Select applicable **standards and requirements**

Requirements

Complete and harmonize **applicable requirements**

Test plan

Draft **test plan**

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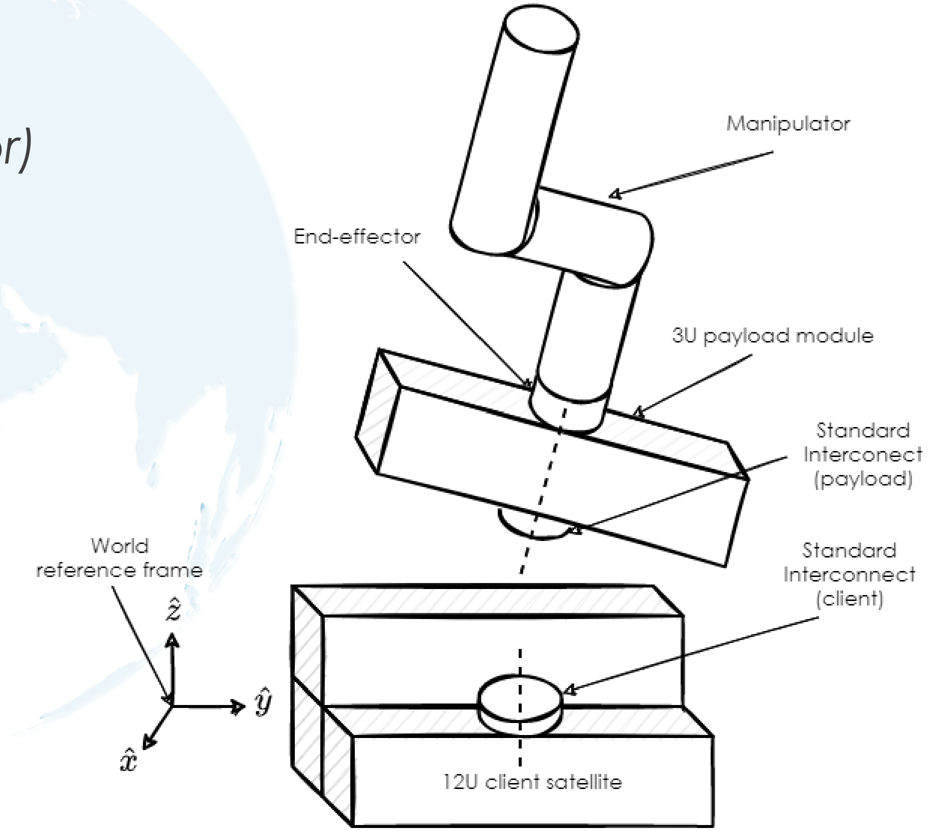
Relevant operational phases

- **Assembly/reconfiguration of client satellite**
  1. *(Grappling of capture interfaces by manipulator)*
  2. Transfer to the mating port
  3. Insertion into reception interfaces
     1. Velocity reduction and misalignment correction
     2. Satisfy reception ranges of berthing ports
  4. Interfaces capture
  5. Interfaces retraction and structural alignment
  6. Structural connection
  7. Utilities connection
     1. Power, data, etc.
  8. *(Repeat steps in reverse for reconfiguration)*



Sketch of a demonstration scenario to be replicated during benchmark

Relevant characteristics: mechanical (example)

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Mechanical characteristic	Definition
Method of connection	Type of connector offered, e.g. pogo pins, crown spring, etc.
Materials	Type of materials used on the SIs, e.g. insulator material, contact material, etc.
Size and mass (*optional*)	Physical dimensions of the SIs
Ingress protection (*optional*)	Degree of protection provided by mechanical casings and electrical enclosures against intrusion, dust, accidental contact, and water
Keying/symmetry	Prevention/allowance of mating in an “incorrect” orientation
Locking/unlocking mechanism	Mechanisms preventing inadvertent disconnection or poor environmental sealing
Force on EE during capture	Force exerted on the EE of robot during capture of opposing SI
Contact retention	Force exerted on the opposing SI during structural connection
Mating lifetime	Number of mating cycles defining the service life of an SI
Transfer motion characteristics	Path characteristics of robot EE to achieve reception range SIs
Reception range	Range within which physical contact between the two SIs occurs and capture is possible

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Relevant characteristics: electrical & data (example)

Electrical & Data characteristic	Definition
Insulator resistance	Electrical resistance of the insulator material of the connector
Maximum voltage	Maximum voltage allowed by the electrical interface of the connector
Working voltage	Nominal voltage allowed by the electrical interface of the connector
Contact current rating	Connector contact's current limitation, i.e. maximum current the connector contacts can withstand
Data bandwidth	Maximum rate of data transfer allowed by the connectors
Data protocols	Type of protocol supported by SIs for data transmission

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List of applicable standards

Standard	Applicability	Justification
ECSS-S-ST-00C Rev.1	TBD	ECSS system description
ECSS-M-ST-40C Rev.1	TBD	Configuration and information management
ECSS-Q-ST-30-02C	TBD	Failure modes, effects (and criticality) analysis
ECSS-Q-ST-60C Rev.2	TBD	Electrical, electronic and electromechanical (EEE) components
ECSS-Q-ST-70C Rev.2	TBD	Materials, mechanical parts and processes
ECSS-E-ST-10- …	TBD	List of system engineering standards (E-10 discipline)
ECSS-E-ST-20- …	TBD	List of electrical and optical engineering standards (E-20 discipline)
ECSS-E-ST-30- …	TBD	List of mechanical engineering standards (E-30 discipline)
ISO 9283:1998	TBD	Manipulating industrial robots — Performance criteria and related test methods, URL

Benchmark environment high-level requirements

- Functional tests shall **resemble operational phases** (i.e., assembly, reconfiguration)
- **“Fixed” SI shall be mounted on a horizontal surface** to minimize torques on the EE due to the force of gravity
- **“Floating” SI shall approach the “client” from above** to minimize torques on the EE due to the force of gravity
- **Relative position accuracy** during manipulation **shall mirror** performance characteristics of **KUKA LBR iiwa**
- **Reception range** of SIs shall be measured using **LBR iiwa in Cartesian position control**
- “**Crawl, walk, run” methodology** shall be applied:
    - **Start with baseline**/nominal conditions for approach and attachment
    - **Progressively increase deviation** from nominal conditions
    - **End at limits** allowed by SIs (e.g. max reception range)

KUKA LBR iiwa motions (credit: KUKA AG 2021)

Benchmark baseline/nominal conditions
(*to be detailed along with technical requirements*)

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Characteristic	Value	Comment
Relative position	[0,0,0.1] ± 0.001 m	Relative position of SIs at start conditions in x, y and z
Relative orientation	[0,0,0] ± 1 deg	Relative orientation of SIs at start conditions in x, y and z
Repeatability	± 0.15 mm	Position accuracy (ISO 9283) of KUKA LBR iiwa 14 R820
Force on end-effector	0 N	Force on end-effector required by an SI to achieve capture within reception range
Maximum voltage	12-16 V	Maximum unregulated voltage supported by the bus of client satellite(*to be confirmed*)
Maximum amperage	3-4 A	Maximum amperage supported by the bus of client satellite (*to be confirmed*)
Data protocols	I2C, UART, SpaceWire	Data protocols supported by the bus of client satellite in case of low, medium and high-speed data interfaces (*to be confirmed*)

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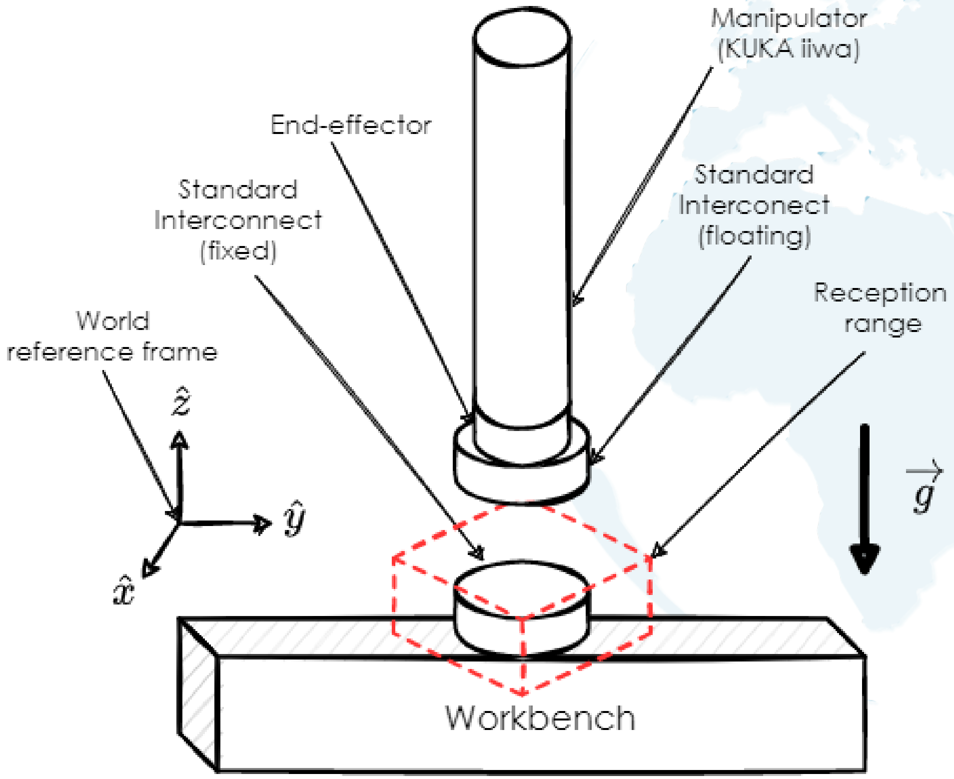
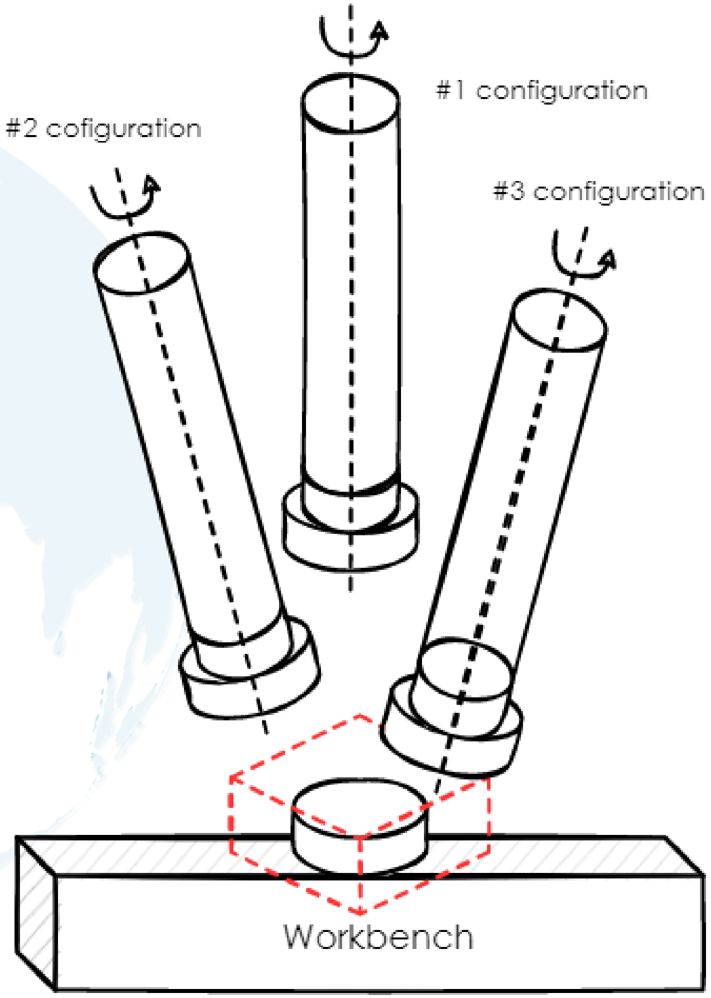
Benchmark environment configurations I

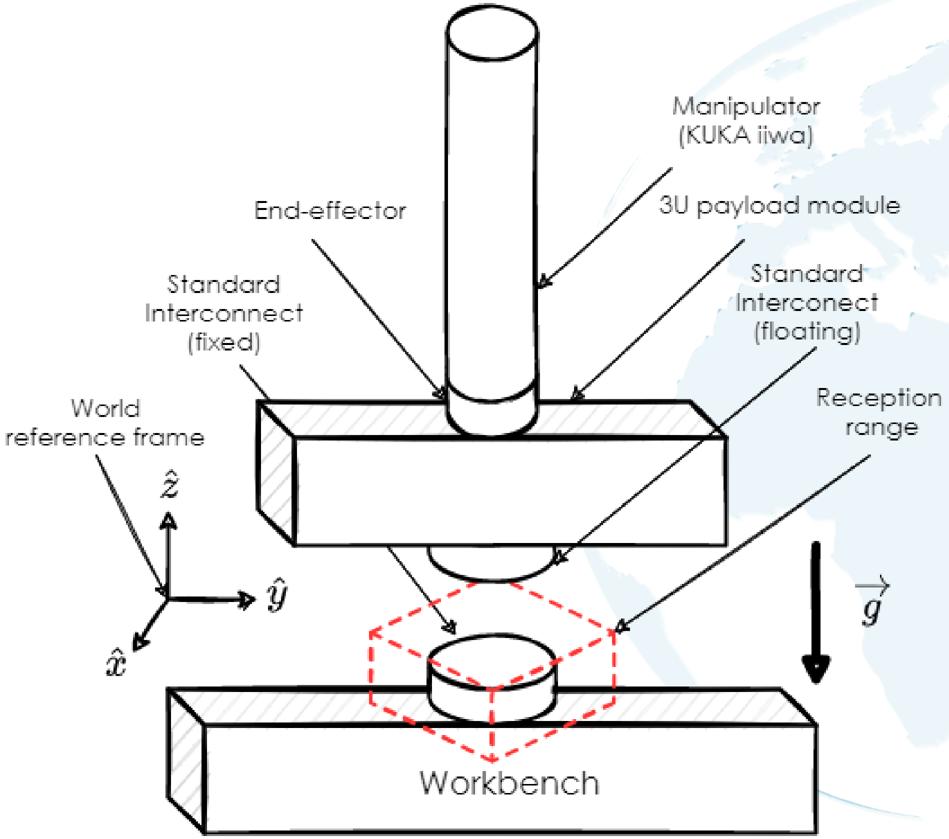


"SI only" base configuration

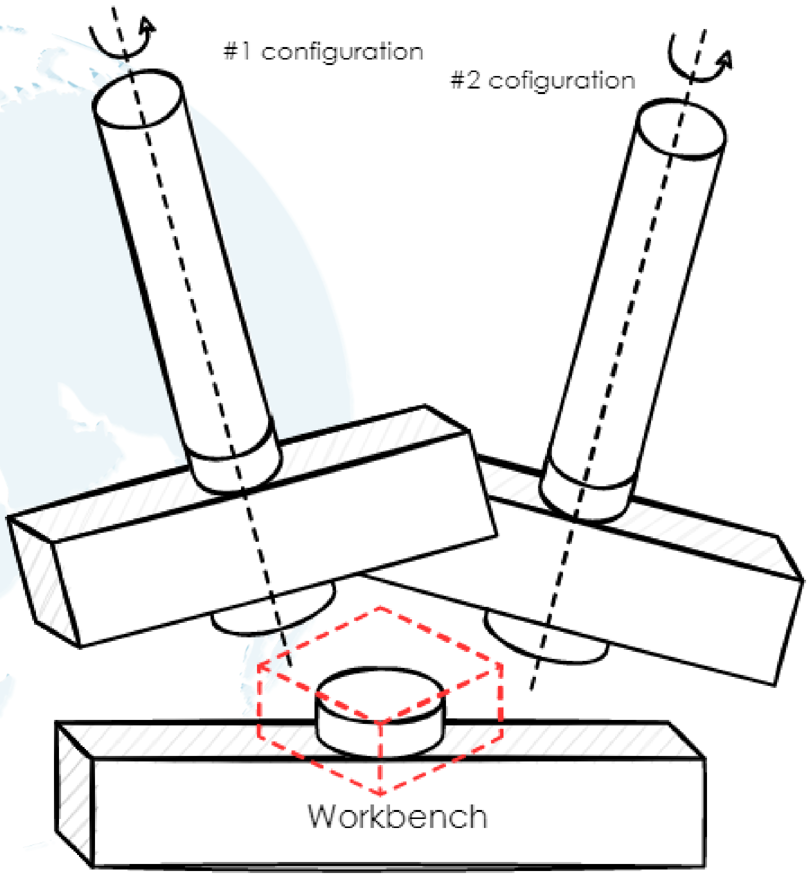


"SI only" benchmark configurations

Benchmark environment configurations II



"Payload" base configuration



"Payload" benchmark configurations

Benchmark test procedures: “payload” configuration (example)

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1. **Acquire manipulator start state**
    a) Position robot’s EE to neutral/base position (P_0)
    b) Position robot’s EE to position P_1 (having a defined misalignment w.r.t. P_0)
2. **Execute predefined approach maneuver**
    Transfer floating SI to fixed SI (position control), i.e. to P_2
3. ***Achieve reception range of fixed SI***
    1. *Apply force to float SIs (admittance control) to reach P_3*
4. **Attempt SIs capture and structural connection**
5. **Attempt utilities connection**
6. **Repeat 10-30 times** (ISO9283:1998(E))

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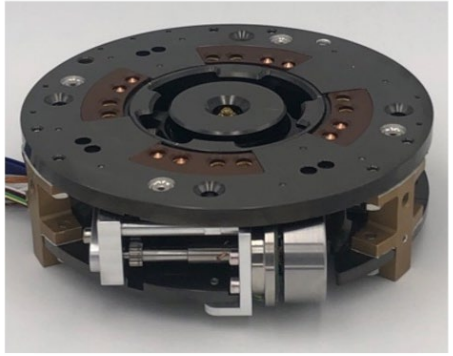
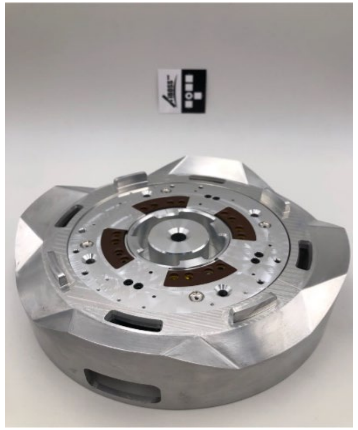
iSSI® version characteristics I

- **Main configuration:**
  - Two active 3-in-1 iSSI® interfaces (mechanical, power, data 2x optical: Ethernet + CAN-Bus)
- **Additional configurations:**
  - Active iSSI® with additional FormFit for increase loads and misalignment tolerances
  - One active and one passive iSSI® (mechanical, power, data 2x optical: Ethernet + CAN-Bus)
- **iSSI® characteristics:**
  - **Dimensions**:
    - Active: Ø138 x 46.45 mm
    - Passive: Ø138 x 46.45 mm (geometry a); Ø138 x 15.00 mm (geometry b)
    - With FormFit (customizable) baseline: Ø 202 x 56.4 mm
  - **Weight**:
    - Active iSSI®: 0.9 kg *(+ 0.375 kg external Electronic Box current baseline, full integration in development)
    - Passive Geometry A: 0.28 kg / Passive Geometry B : 0.15 kg / FormFit: + 0,8 kg (customizable)
  - **Misalignment Tolerance**:
    - Radial: ±3 mm Angular: ±15° (assuming robotic impedance)
    - With FormFit (customizable) baseline: Radial ±15 mm Angular: ±15°
  - **Capture range (gap between SI before mating):** 8 mm for mating pins, 0 mm for locking
  - **Rotational Symmetry**: 90°, androgynous design
  - **TM / TC**: CAN-Bus protocol
  - **Power Supply**: Interface Control Unit: 24V / CAN-Bus Data I/F: 5V



iSSI® Space active (credit: iBOSS)



iSSI® with customized FormFit Add-on-Module for increased coupling tolerances and loads (credit: iBOSS)

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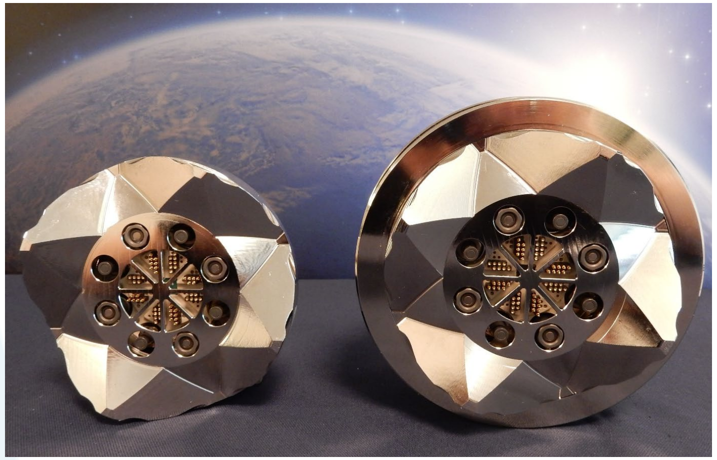
iSSI® version characteristics II

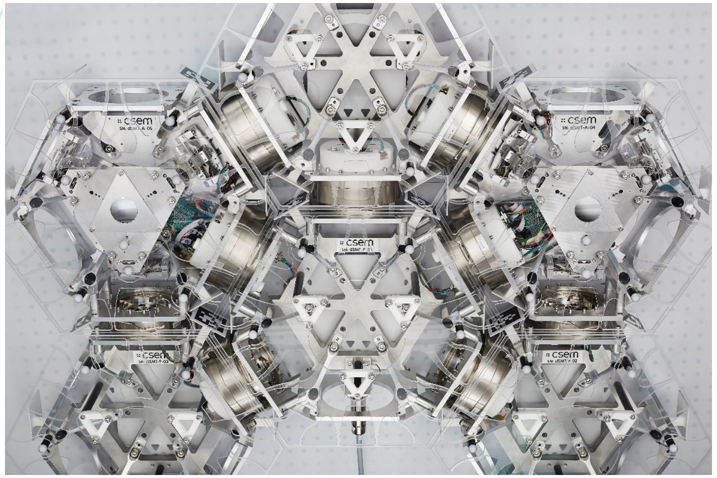
- **Mechanical Interface:**
  - **Fixation**: External:
    - 1. Option - Rear mounting 3x M6
    - 2. Option - Side mounting 3x M6
  - **Mechanical Loads (Baseline)**:
    - Traction / Compression: 6000 N
    - Lateral: 400 N
    - Bending / Torque: 100 Nm
  - **Mating Duration**: 5 to 15 sec, adjustable coupling speed
- **Data Interface**:
  - Current baseline: CAN-Bus, Ethernet (in development SpaceWire, UART, 1553B, I2C, SPI …)
  - External: Ethernet Harwin Datamate J-TEK connector + CAN-Bus Harwin Gecko connector
  - Internal: Optical Ethernet + Optical CAN-Bus
- **Power Interface**:
  - up to 5 kW (50 A @ 100 V)
  - External: Harwin Datamate Mix-Tek connector
  - Internal: 8x Electrical pins to canted coil spring
- **TM and TC**
  - External: Harwin Datamate Mix-Tek
- **Software**: n/a, TM and TC via CAN-Bus protocol
- **Environment**: operational -40 to +70 °C, non-operational -120 to +180 °C

HOTDOCK version characteristics I

- Active and Passive HOTDOCK **MOSAR** versions
- Without integrated thermal sub-system (although fully compatible)
- Final features to be confirmed after PM1
- Benchmarking HOTDOCK characteristics:
  - **Dimensions (including casing)**:
    - Active: Ø 148.5 x 92.4 mm
    - Passive: Ø 120 x 45.6 mm
  - **Weight**:
    - Active: 1.28 kg
    - Passive: 0.26 kg
  - **Form-Fit Misalignment Tolerance**: ± 15mm radial, ± 10°
  - **Attraction Range**: 2mm axial, 2mm radial, ± 2°
  - **Diagonal (Dis)Engagement**: up to 60°
  - **Rotational Symmetry**: 90°
  - **TM / TC**: CAN (termination resistor on demand), Micro-D
  - **Power Supply**: 24V (power consumption max 3W, inrush 1.8A for 8ms), Micro-D (shared with TM/TC)

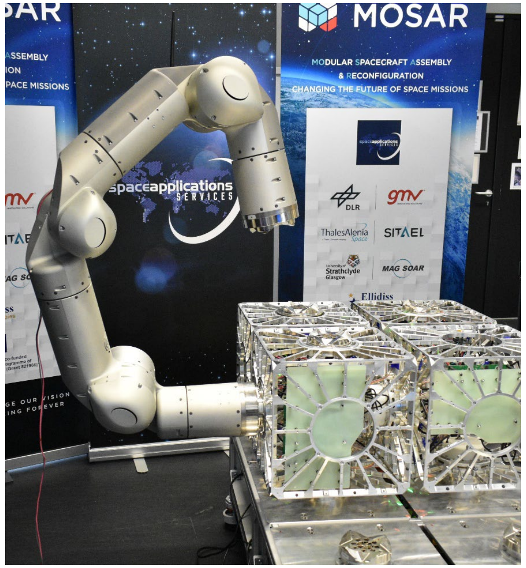


HOTDOCK (credit: SpaceApps)

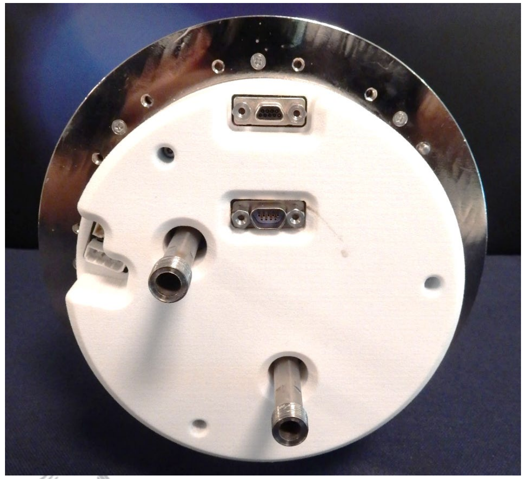


PULSAR's integration of HOTDOCKs (credit: SpaceApps)

HOTDOCK version characteristics II



MOSAR's integration of HOTDOCKs (credit: SpaceApps)



View of HOTDOCK's external side (credit: SpaceApps)

- **Mechanical Interface:**
  - **Payload External Fixation**: 16 x M3
  - **Mechanical Loads** (active to passive, validated):
    - Traction / Compression: 3.5kN
    - Bending: 350Nm
- **Data Interface**:
  - CAN or SpW (TBC for benchmarking, TBD if other protocol)
  - External: Micro-D
  - Internal: POGO pins (POGO board layout TBC for benchmarking)
- **Power Interface**:
    - Max 10A @ 100V, Micro-D
    - External: Phoenix
    - Internal:: POGO pins (POGO board layout TBC for benchmarking)
- **Thermal Interface**: N.A. (TBC for benchmarking)
- **Mating Duration**: 20 sec
- **Software**: Ketchup (free), for control, monitoring (CAN) and firmware update (UART)
- **Environment**: Laboratory conditions

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SIROM version characteristics I

- Active and Passive SIROM 3.0 versions
- Without integrated thermal sub-system
- Capture switch included (triggers when SIROMs can latch, i.e. below capture range)
- SIROM characteristics:
  - **Dimensions (max envelope)**:
    - Active: Ø 145 x 126.5 mm
    - Passive: Ø 145 x 73 mm
  - **Weight**:
    - Active: 1.2 kg
    - Passive: 0.4 kg
  - **Capture Range (gap between SI before mating):**
    - R (roll) & P (pitch): ± 9°; Y (yaw): ± 7°; Radial: ± 6mm; Axial: +13.5mm
    - 6 DOF combination (μ;σ): RPY (0°;1°), Radial (0mm; 2mm, Axial (5mm; 2mm) ➔ 98.8% success rate
  - **Form-Fit Misalignment Tolerance**: ± 11mm radial, ± 20° (R,P,Y)
  - **Latching compatibility with arm back drive (gravity or robot forces are not required for latching)**
  - **Diagonal (Dis)Engagement**: up to 70°
  - **Rotational Symmetry**: 120°
  - **TM / TC**: CAN (main & redundant)
  - **Power Supply**: Range: 20-34V (nominal 28V); internal isolation included

SIROM active (left) SIROM passive (right)
(credit: SENER Aeroespacial)

SIROM version characteristics II

- **Mechanical Interface:**
  - **Payload External Fixation**: 8 M3 holes & 1 M3 pin hole
  - **Mechanical Loads** (active to passive, tested):
    - Traction: 820N
    - Bending: 98Nm
    - Torque: 50Nm
- **Data Interface**:
  - CAN or Ethernet. SpaceWire (TBC for benchmarking)
  - External: two DMM connectors (daisy chain connection possibility)
  - Internal: POGO pins
- **Power Interface**:
  - 20A non-controlled (SIROM by-pass)
    - External: Dsub9
    - Internal: POGO pins
  - 28V at 3.5A controlled
    - External: two DMM connectors
    - Internal: POGO pins
- **Thermal Interface**: N.A. for benchmarking
- **Mating Duration**: 20 sec minimum. Lower speeds can be selected to adjust to robot compliance behavior.
- **Software**: C (Atmel Studio Development Environment IDE). Control & monitoring: CAN2.0B (CAN Open optional). SW update: SPI
- **Environment**: TRL6 tested

Outlook

- Preparation of the test set up
- Implementation of the SI benchmarking tests
- Evaluation and recommendation
- Create basis for definitions of recommendations and golden rules for future in orbit robotic operations
  - participation on European Operations Framework, October 2021

European Operations Framework

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Any questions?