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A methodology for electromechanical evaluation of multifunctional interconnects for on-orbit servicing demonstration

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Contents

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Introduction - The PERASPERA In-Orbit Demonstration (PERIOD) project

- PERIOD 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.
- PERIOD aims to increase the maturity of space technologies and prepare them for an in-orbit demonstration.
- PERIOD targets to raise the technology readiness level (TRL) of core technologies and define an orbital demonstration concept for on-orbit servicing and assembly.
  - development of core space robotics software components up to the TRL 5

Introduction - The role of interface

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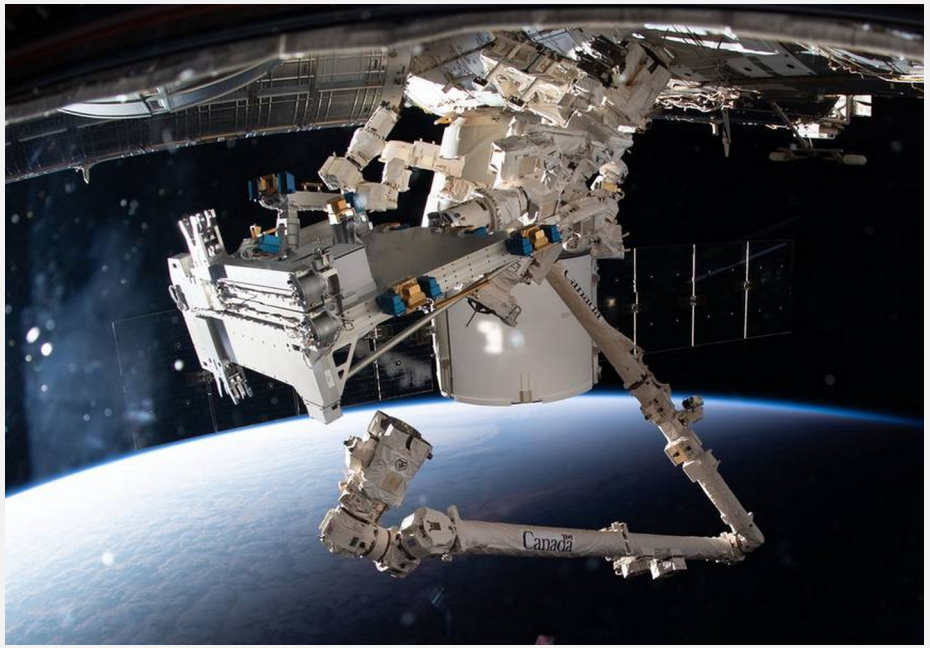
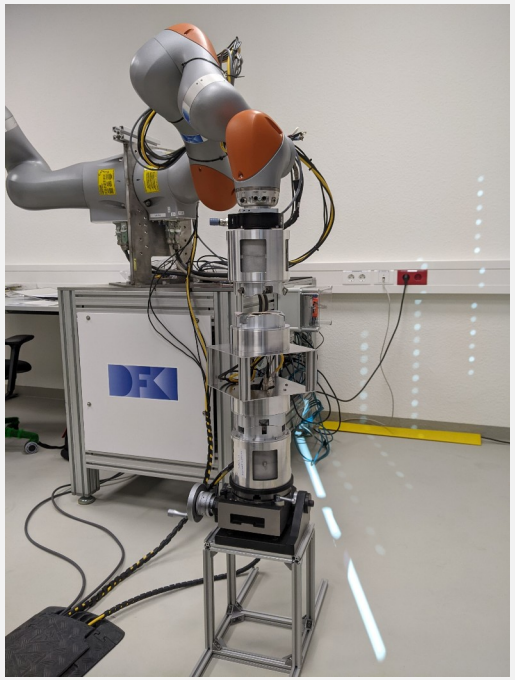
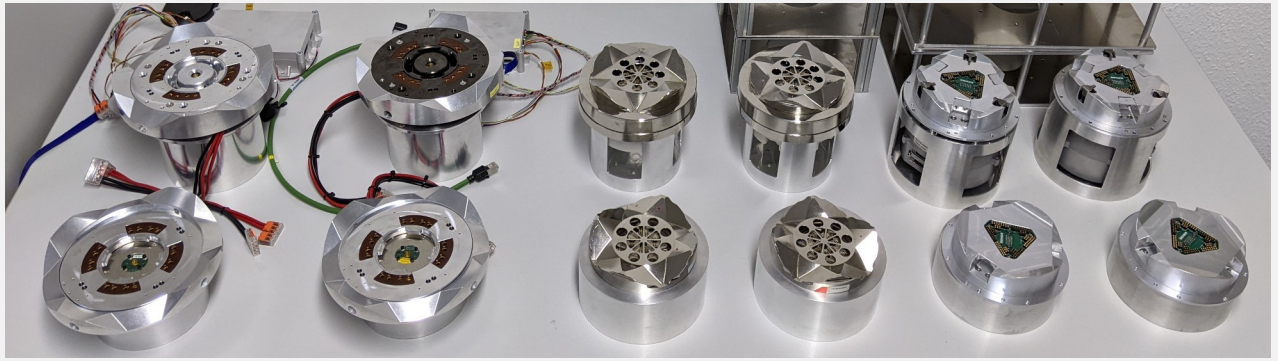
- To transport the large scale object in the orbit is challenging task
  - Autonomous assembly of large structures in space is a key challenge for future missions
  - Idea: **self-deployed objects** single piece (**in orbit factory**)
    - Standard interconnect (SI) to connect (sub)systems in a (re)configurable way.
- Robotics: Interface is necessary for modularity
- Interface is a mechatronic device,
  - covers **electric, mechanics** and **software** domains



Credit: Nasa

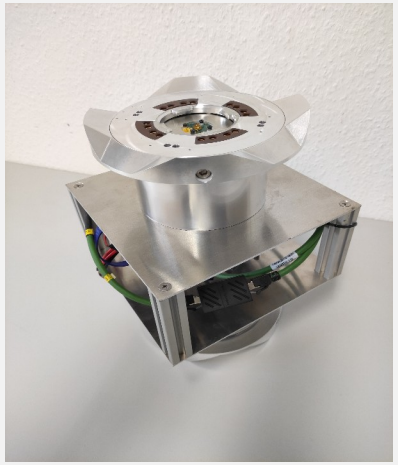
Introduction - Benchmark Interfaces and Payload mock-ups



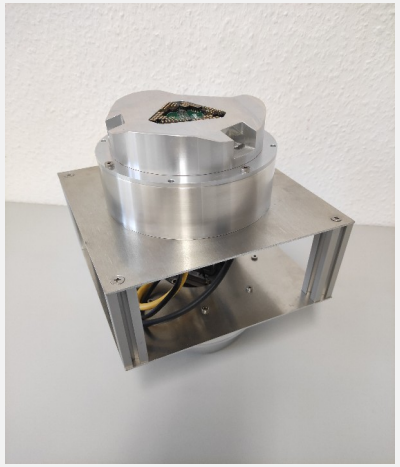


All SIs and their adapters (from left to right: iSSI® , HOTDOCK, SIROM)

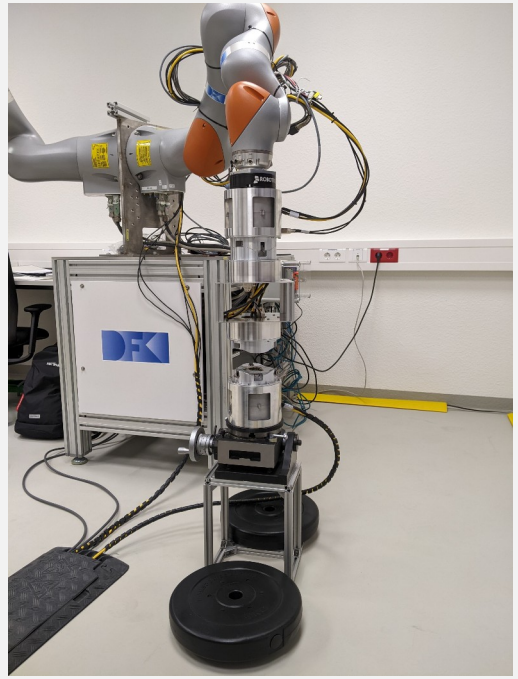
Passive HOTDOCK on 4U payload mockup



Passive iSSI® on 4U payload mockup



Passive SIROM on 4U payload mockup



The SI providers are (from left to right):HOTDOCK from Space Applications Services, iSSI® from iBOSS GmbH, and SIROM from SENER Aeroespacia

Introduction - Need for Benchmark

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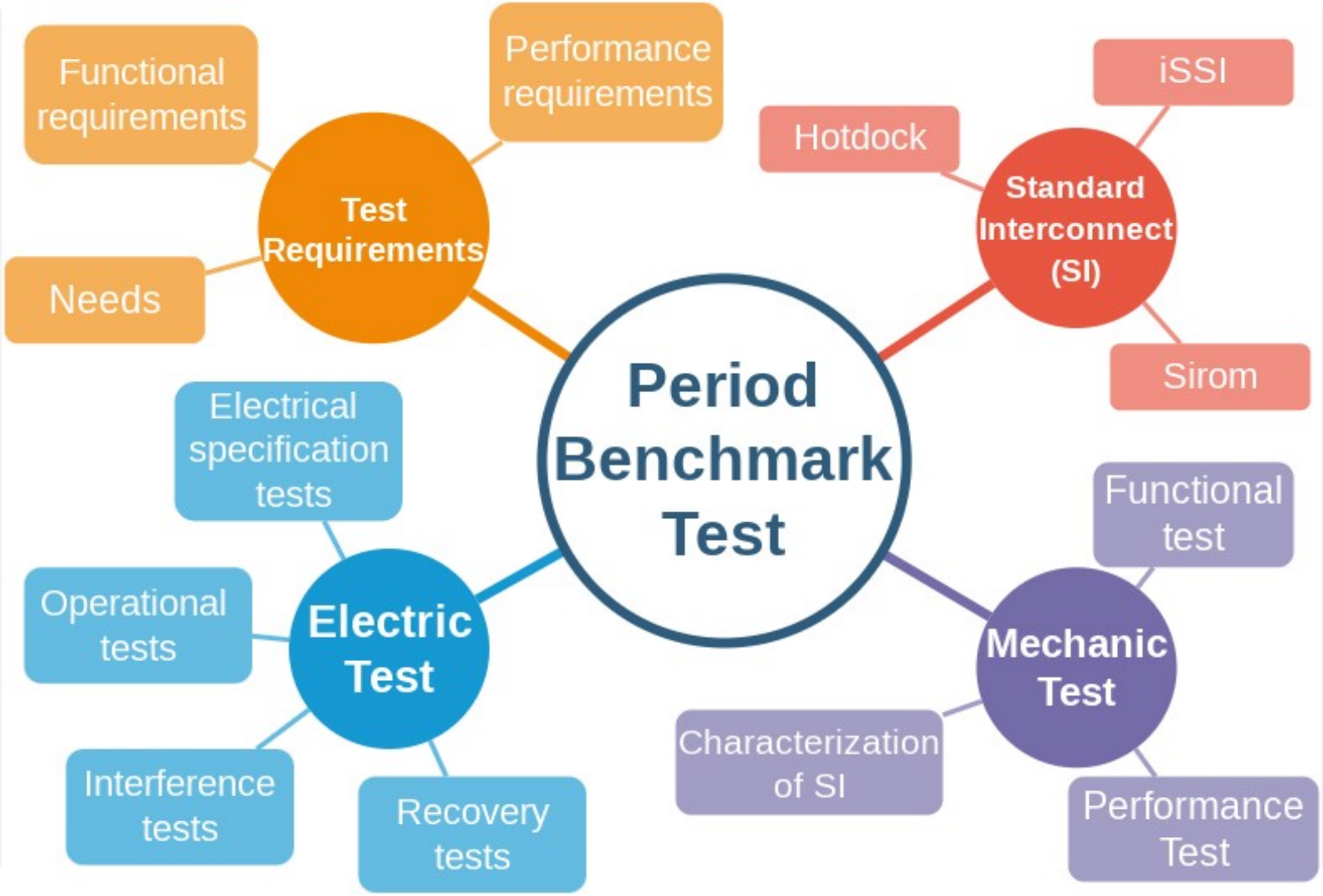
- Test of Standard Interconnect (SI)
  - currently no standard defining a set of features and/or performances
- TRL might be used for this purpose but...
- to perform a TRA
  - a fixed set of performance requirements
  - definition of the operational environment
  - beyond the scope of the current project deliverables
  - TRA is not intended as a method for advancing technologies.
- Our target is **to provide valuable improvement feedback for SI** manufacturers following its potential deployment for robot factories in orbit as a possible demo scenario.

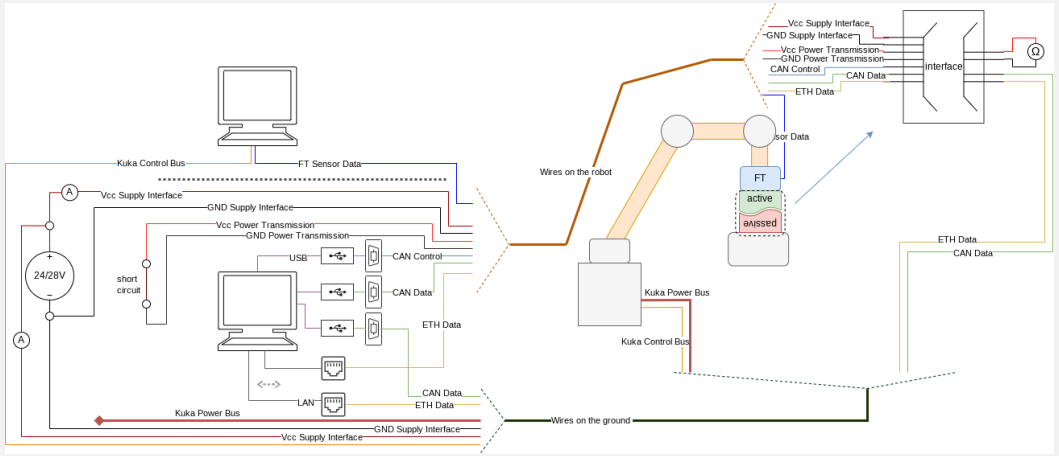
An examplar view for future in-orbit factory
Credit: PERIOD project
https://PERIOD-h2020.eu/about/orbital-factory

Introduction - DFKI's Task : PERIOD Benchmark Test

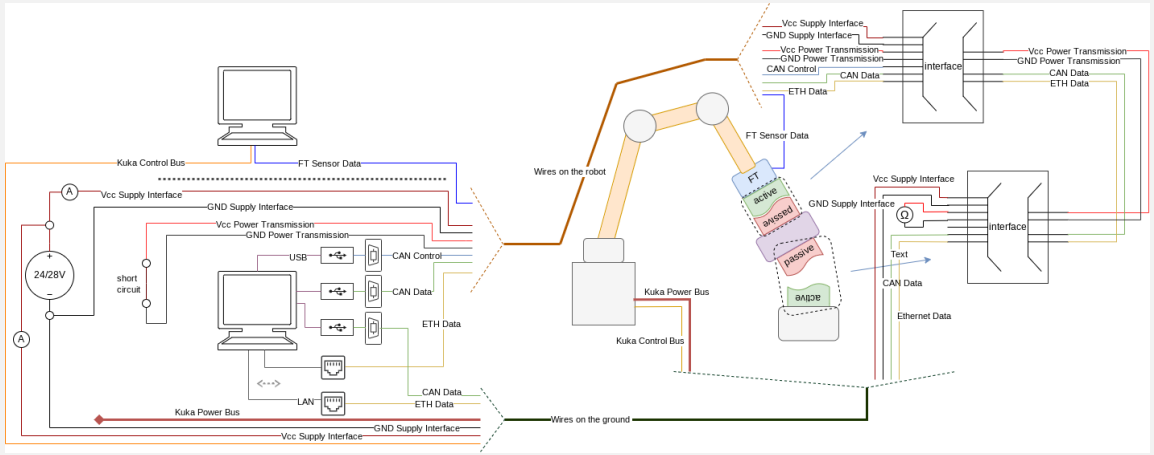


Development of the test methodology

- Mechanical benchmark test
  - Test Structure:
    - Characterization of provided SI versions
    - Functional tests of SIs
    - Performance tests of Sis
  - Test Configuration
    - with floating payload mock-up
    - with fixed payload mock-up

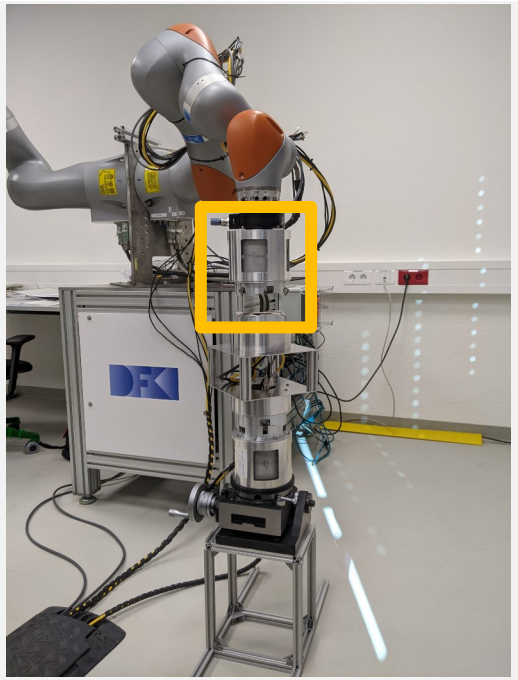


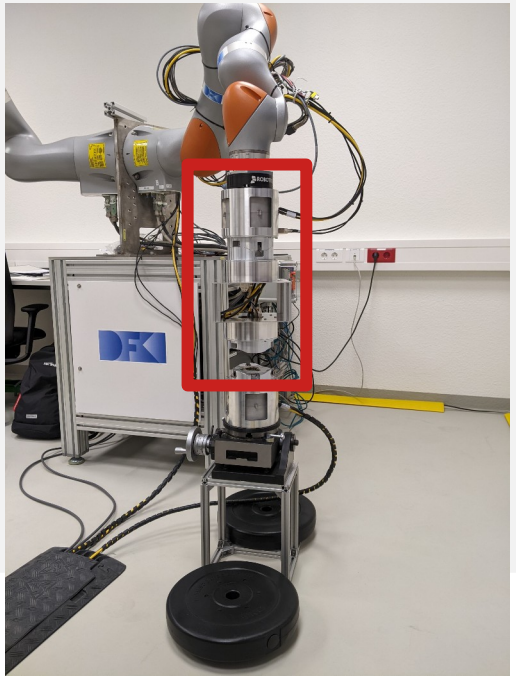
with fixed payload mock-up

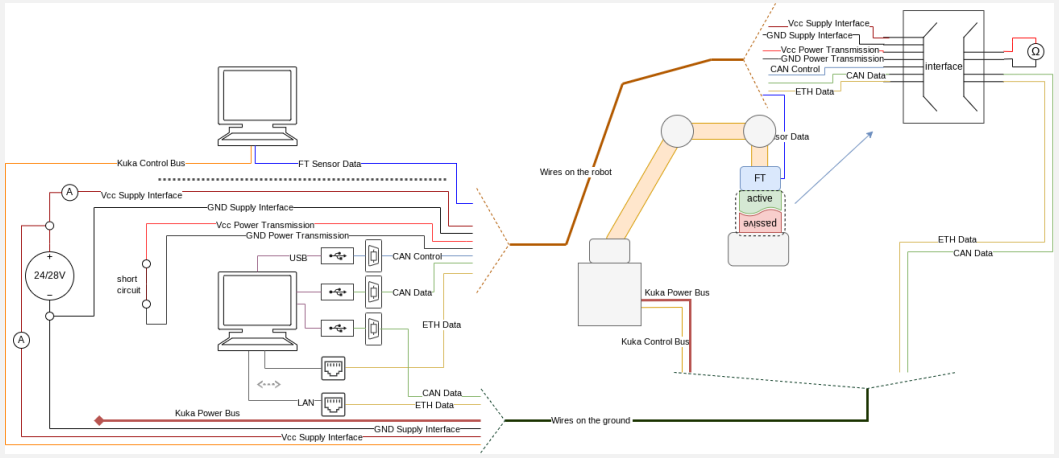


with floating payload mock-up

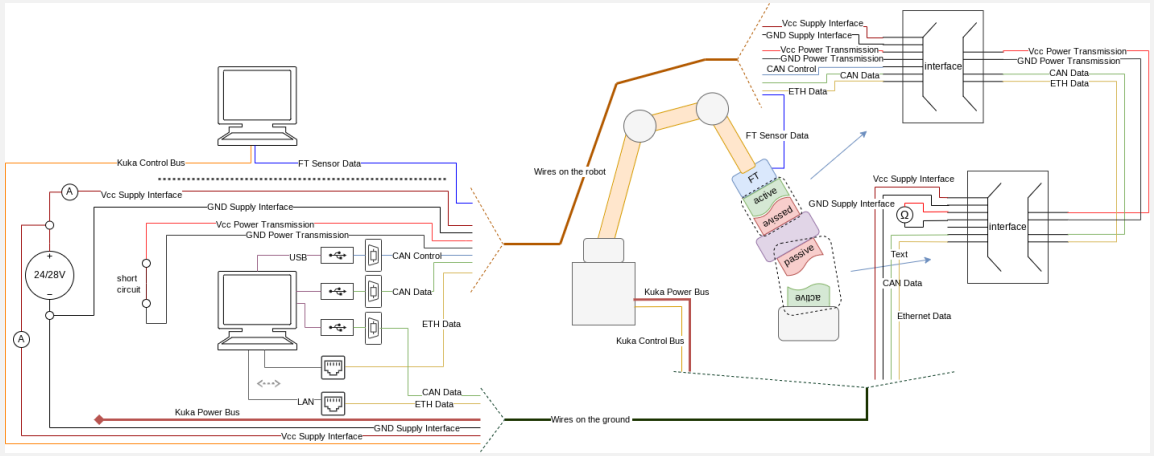
Development of the test methodology







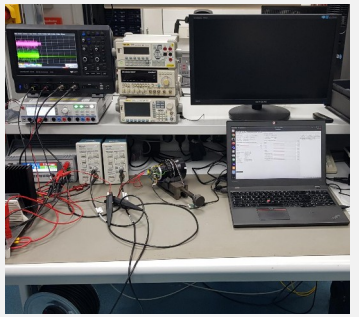
with fixed payload mock-up

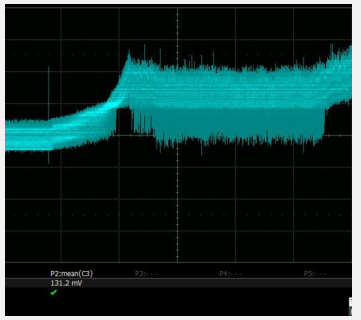


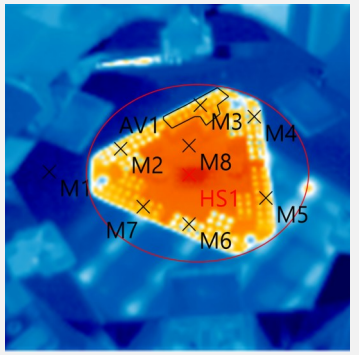
with floating payload mock-up

Development of the test methodology

- Electrical benchmark test
  - Operational tests
  - Electrical specification tests
  - Interference tests
  - Recovery tests

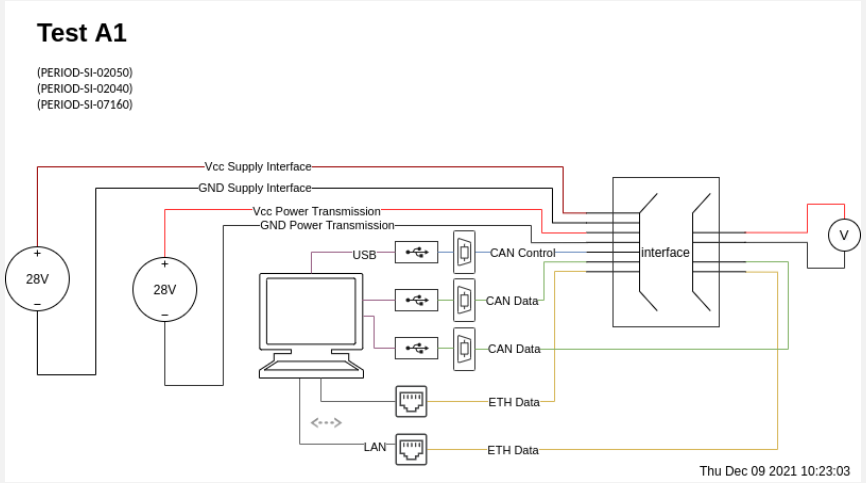


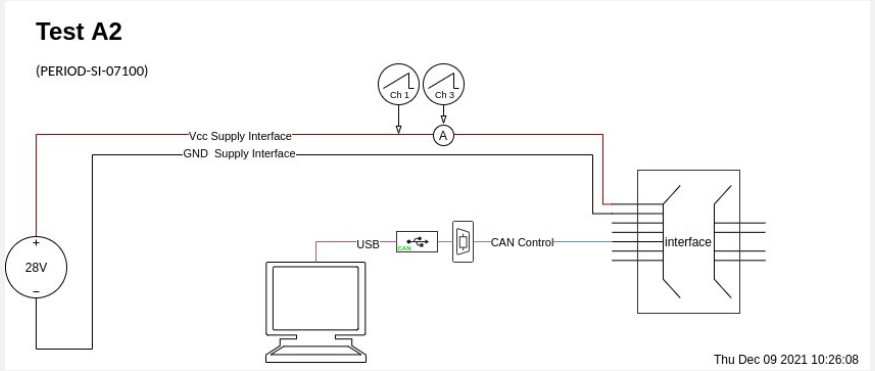




Development of the test methodology to evaluate the SI for electrical aspects

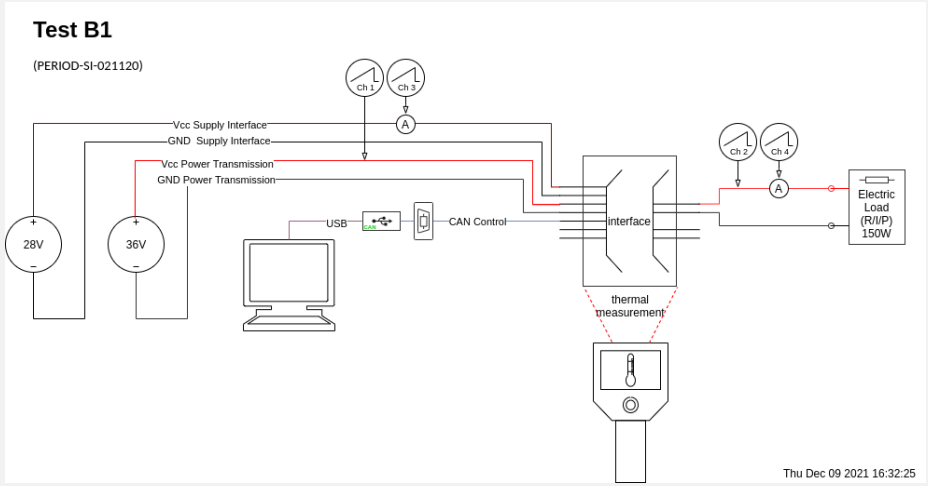
- Operational tests
  - Controllability of interface
  - Primary functions check
    - Coupling
    - Measurement of electrical parameters
    - Transceive of data
  - Functionality in symmetry,
  - Inspection of the specification parameters
    - Consumption in standby, (un)docking process





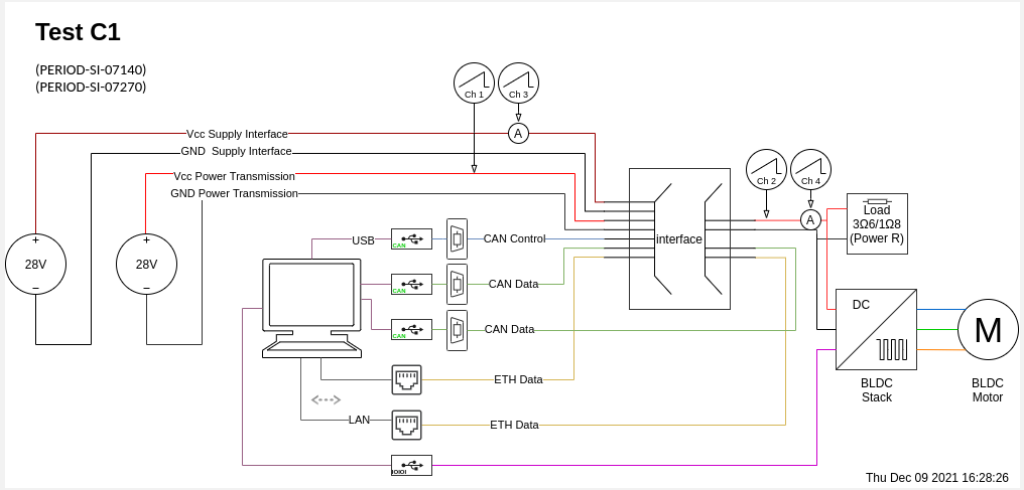
Development of the test methodology to evaluate the SI for electrical aspects

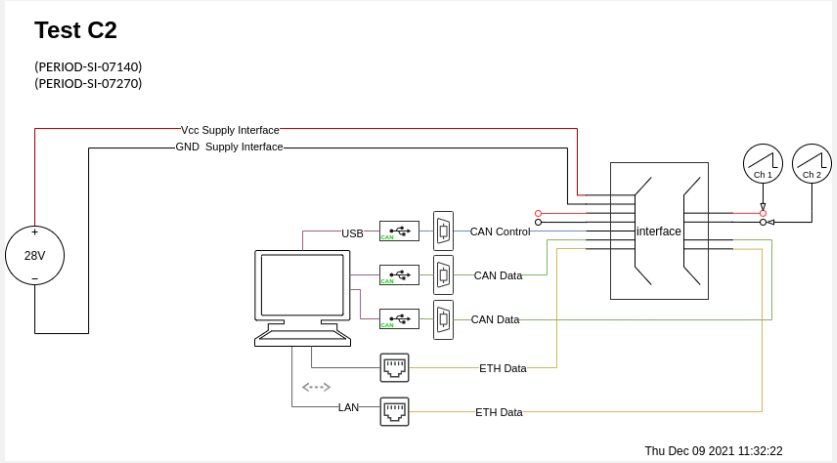
- Electrical specification tests
  - Power line test
    - Power supply and various resistors
  - Data line test
    - Ethernet bus test
    - CAN bus test



Development of the test methodology to evaluate the SI for electrical aspects

- Interference tests
  - External interference on Data buses.
    - Up to 6A peak on DC 20A @ 28V
    - 100Hz
  - Mutual influence on power bus
    - Ethernet bus
    - CAN bus





Development of the test methodology to evaluate the SI for electrical aspects

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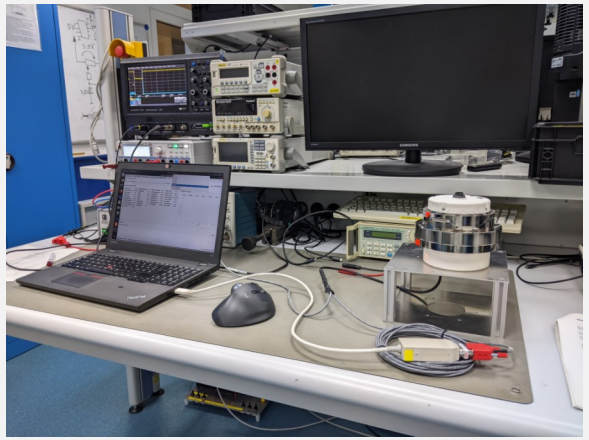
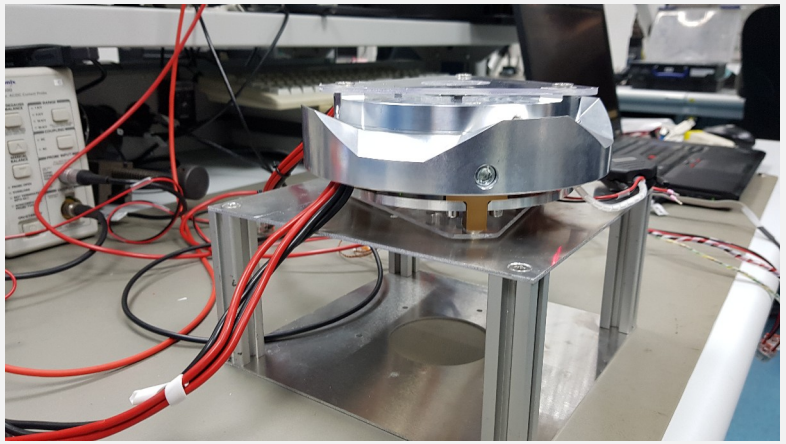
- Recovery tests
  - Realistic recovery cases as critical operating condition critical moments of the SI's
    - coupling state(s)
    - coupled state(s)
    - decoupling state(s)
  - The SI **able** to start in an undetermined state, **recognize** its current state, and **continue** operation **without** further problems, malfunctions, or damage.
  - Test issues
    - interruption of CAN control communication
    - interruption of power supply

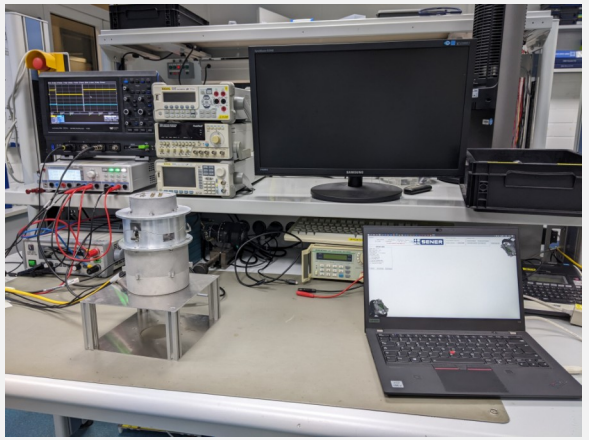
Performance of the benchmark electric tests



Electrical tests with HOTDOCK
from Space Applications Services NV



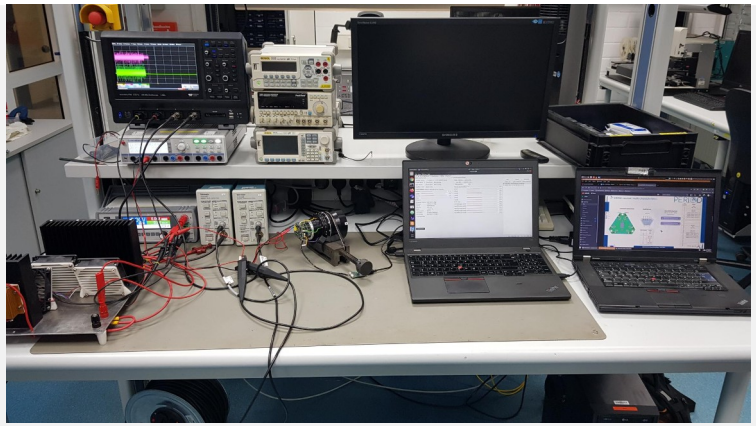
Electrical tests with iSSI®
from iBoss GmbH



Electrical tests with SIROM
from SENER Aerospacial S.A.

Performance of the benchmark electric tests

- Power transmission test
  - 100-600 W
- Data transmissions test
  - Ethernet bus : Iperf3
  - CAN bus: Debian can-utils



Initial test setup of electrical tests

Power Bus Test		Ethernet Bus Test		CAN Bus Test	
Test Voltage	Test Current	Target Ethernet Speed	Number of simultaneous connections	CAN Bus bitrate	Delay between packages
36V	3.5A	1 Mbit/s	1	1 Mbit/s	200ms
28V	15A	10 Mbit/s	5	800 Kbit/s	100ms
28V	15-23A*,	100 Mbit/s	10	500 Kbit/s	50ms
Spec.†	Spec.†	1000 Mbit/s	25	250 Kbit/s	10ms
		max speed ‡	50	125 Kbit/s	5ms
				20 Kbit/s	1ms

Table 1: Test parameters of benchmark electric and data tests for SIs.
(*) The variable current value used during the interference test.
(†) The other test values correspond to the specification of the respective SI
(‡) No forced speed is specified, instead the maximum speed is attempted to be determined

Test results management and evolution

- Based on the individual test protocols of each tested interface
- To compare SI we rank them using the benchmark test metric
  - Includes 12 evaluation criteria derived from korcut[1] ontology.
    - General criteria
      - Maturity
      - Operability
      - (software) compatibility
      - reliable design and robustness
      - energy consumption
      - telemetry, transmission by rotational symmetry
      - recoverability (resilience, prevention and robustness to external disturbance)
    - Specific criteria [75% / 25%] (Req/Spec)
      - data transmission CAN
      - data transmission LAN
      - power transmission
      - thermal development
  - four-point rating scale (1 poor, 4 best)

[1] Knowledge-based Open Robot voCabullary as Utility Toolkit

Test results management and evolution

- Need for an ontology
  - **Each interface has its own specific properties** that are not directly comparable and can play an important role depending on the application
  - **Rich test results** need to be **represented in a uniform** and rich way, allowing dynamic querying or traceability for variable use case requirements
  - **Specifications and capabilities** of interfaces can be analyzed individually with additional information (e.g. test method)
  - **Ontology** represents a **generic model** for the **mechatronical level** of an interface in a uniform way, which can be used for further tasks (e.g. control of robots)

Test results management and evolution

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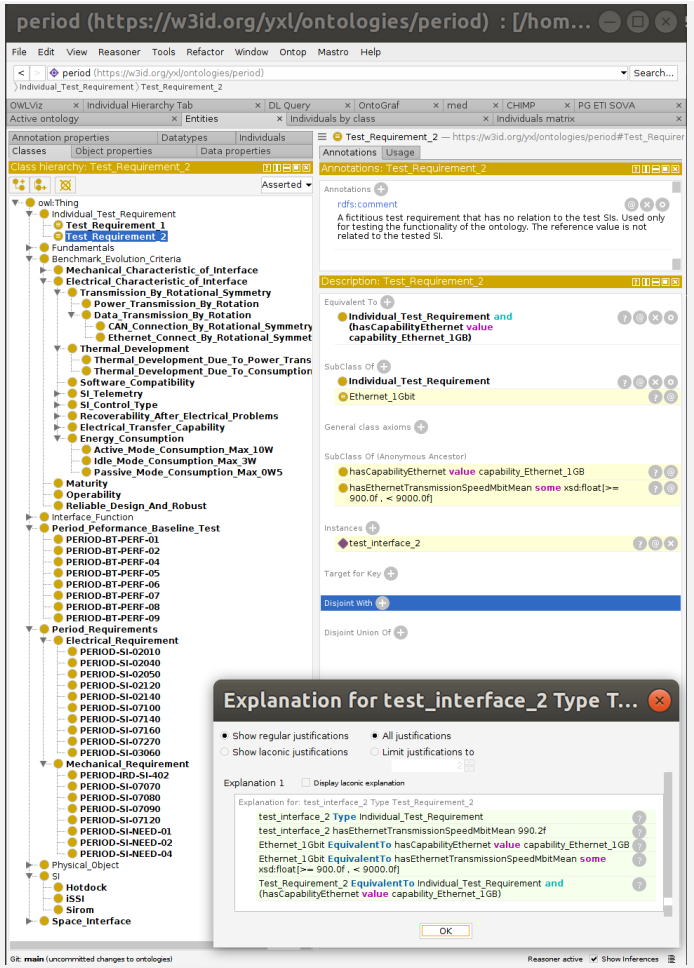
- Development of PERIOD ontology
  - Competency questions.
    - What are the electrical properties of the benchmark SI model?
    - Which are the coupling states of the interface?
    - Can a specific interface transmit power / data with certain values?
    - What kind of misalignment capabilities has a particular interface?
  - Vocabulary
    - e.g. Coupling_State,
      - Coupled_State,
      - Decoupling_State,
      - Homing, Latching,
      - Ready_To_Capture,
    - Property_Of_SI
      - Capture_Range,
      - Envelope,
      - Technology_Readiness_Level,
    - Electronics_Capability,
      - Supply_Range,
      - Data_Transfer_Type,
      - Data_Transfer_Range,
      - Power_Transfer_Range.

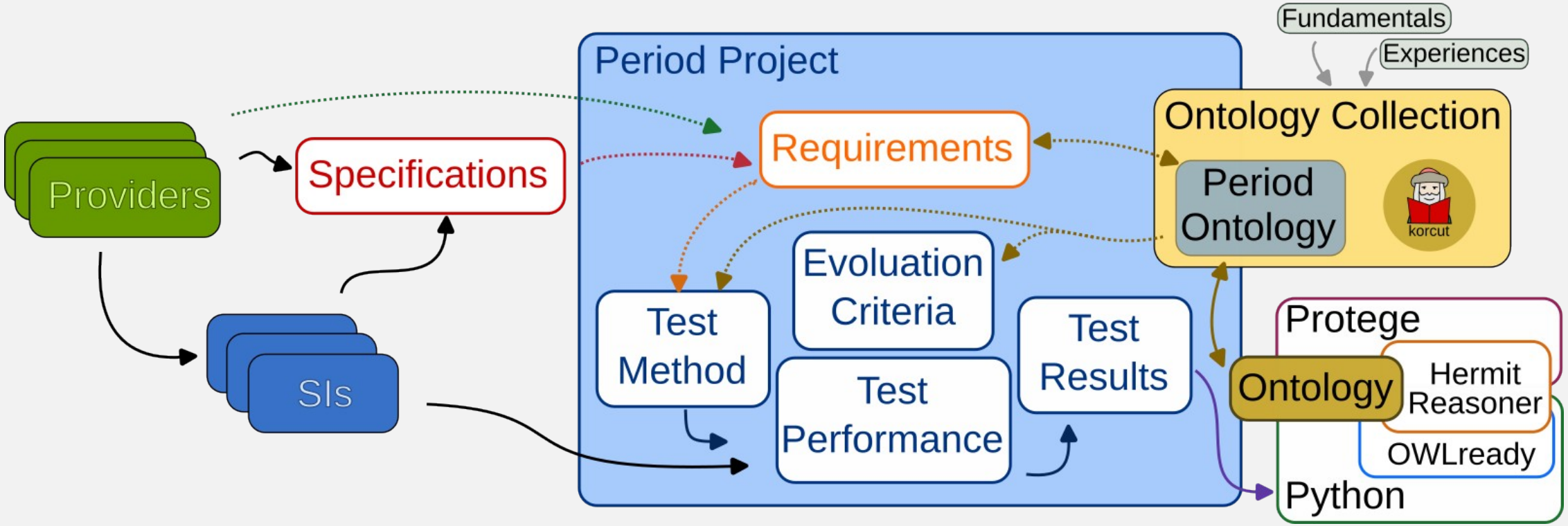


A look at PERIOD ontology in the Protégé environment for ontology development[1]

[1]In this example, due to confidentiality concerns, as test results fictitious test values (e.g. Ethernet speeds) are used to validate the functionality of the ontology and the resulting implicit knowledge.

Test results management and evolution

- PERIOD workflow



Test results management and evolution

Individual: test_interface_1

Types:
Test_Interface

Facts:
hasControlDataInterface control_data_interface_CAN,
hasTypeOfDataTransmission type_transmission_electrical,
hasCenterOfMass "0.0;0.0;0.5",
hasConsumptionTestStateOperationReady 5,
hasCouplingSymmetryRotational 30,
hasEthernetTransmissionSpeedMbitMax 99.0f,
hasEthernetTransmissionSpeedMbitMean 95.0f,
hasEthernetTransmissionSpeedMbitMin 90.0f,
hasFunctionPowerTransmission 10,
hasMass 1000,
hasOperatingVoltageMax 12,
hasOperatingVoltageMin 3,
hasOperatingVoltageNominal 5,
hasSizeX 1,
hasSizeY 2,
hasSizeZ 3,
hasTransmissionPowerCurrentMax 10,
hasTransmissionPowerVoltageMax 12,
isSITestedForCANSpeedMbits1 true,
isSITestedForCANSpeedkbits125 true,
isSITestedForCANSpeedkbits20 true,
isSITestedForCANSpeedkbits250 true,
isSITestedForCANSpeedkbits500 true,
isSITestedForCANSpeedkbits800 true

Individual: test_interface_2

Types:
Test_Interface

Facts:
hasControlDataInterface control_data_interface_CAN,
hasTypeOfDataTransmission type_transmission_optical,
hasConsumptionTestStateOperationReady 4,
hasDataTransmission 990.2f,
hasDiameter 3,
hasEthernetTransmission 990.2f,
hasEthernetTransmissionSpeedMbitMax 999.0,
hasEthernetTransmissionSpeedMbitMean 995.0f,
hasEthernetTransmissionSpeedMbitMin 990.0f,
hasHeight 2,
isVendorProvidingContolSoftware true

Test results management and evolution

Individual: test_interface_1

Types:
Test_Interface

Facts:
hasControlDataInterface control_data_interface_CAN,
hasTypeOfDataTransmission type_transmission_electrical,
hasCenterOfMass "0.0;0.0;0.5",
hasConsumptionTestStateOperationReady 5,
hasCouplingSymmetryRotational 30,
hasEthernetTransmissionSpeedMbitMax 99.0f,
hasEthernetTransmissionSpeedMbitMean 95.0f,
hasEthernetTransmissionSpeedMbitMin 90.0f,
hasFunctionPowerTransmission 10,
hasMass 1000,
hasOperatingVoltageMax 12,
hasOperatingVoltageMin 3,
hasOperatingVoltageNominal 5,
hasSizeX 1,
hasSizeY 2,
hasSizeZ 3,
hasTransmissionPowerCurrentMax 10,
hasTransmissionPowerVoltageMax 12,
isSITestedForCANSpeedMbits1 true,
isSITestedForCANSpeedkbits125 true,
isSITestedForCANSpeedkbits20 true,
isSITestedForCANSpeedkbits250 true,
isSITestedForCANSpeedkbits500 true,
isSITestedForCANSpeedkbits800 true

Individual: test_interface_2

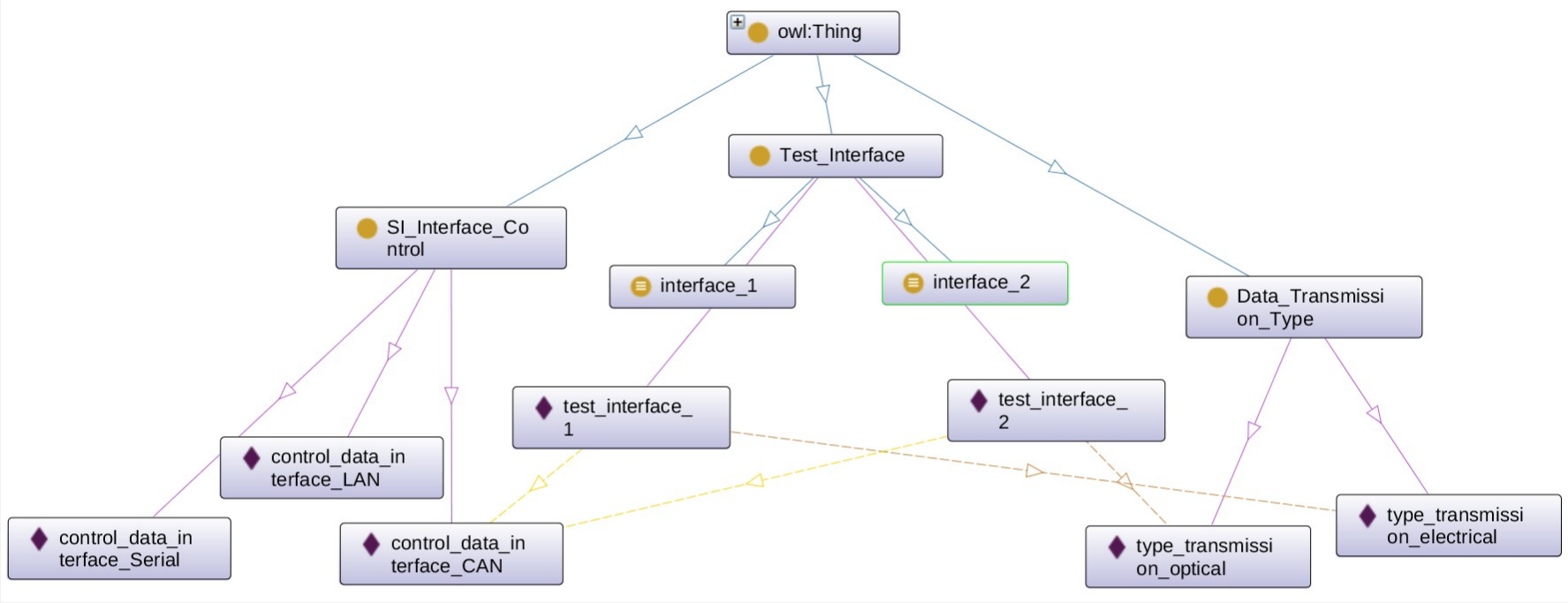
Types:
Test_Interface

Facts:
hasControlDataInterface control_data_interface_CAN,
hasTypeOfDataTransmission type_transmission_optical,
hasConsumptionTestStateOperationReady 4,
hasDataTransmission 990.2f,
hasDiameter 3,
hasEthernetTransmission 990.2f,
hasEthernetTransmissionSpeedMbitMax 999.0,
hasEthernetTransmissionSpeedMbitMean 995.0f,
hasEthernetTransmissionSpeedMbitMin 990.0f,
hasHeight 2,
isVendorProvidingContolSoftware true

Test results management and evolution

Axiom 1 as requirements criteria (interface_1):
Test_Interface and (hasCapabilityCAN value capabilty_CAN_kbits_125) and (hasCapabilityEthernet value capability_Ethernet_100Mbit)

Axiom 2 as requirements criteria (interface_2):
Test_Interface and (hasCapabilityEthernet value capability_Ethernet_1GB)



Discussion

- The development of a benchmark was necessary.
  - Technology Readyness Assesment cannot serve as a method for advancing technologies
  - The used method of SIs was not the same and the results were difficult to compare.
- The test method and performing of the tests:
  - Developed generic test cases in the electrical domain for the data and power transmission
  - Practical and repeatable test in the laboratory environment

Discussion

- Needs for ontology
  - Each interface has its own specific characteristics that are not directly comparable and can play an important role depending on the application.
  - These are also represented as a generic model for the mechatronic level of an interface in a unified ontology.
  - It was important to consider the test boundaries, which change depending on the characteristics of the interface.
  - The ontology was a way to model the interface, test steps, and test result in a unified and rich way, and to share them in a way that allowed comparing interfaces based on specific properties and tasks.
  - The general problem was to link the test method, test object, and result in the ontology and integrate them into a workflow in environment that automatically interacts
  - Thus, we have reached the point that this knowledge about the decision can be used for other purposes (e.g., controlling robots).

Discussion

- Using of PERIOD Ontology
  - The **offline** manual use of knowledge collection (**evolution criteria**) and the **online** integrated and automated use of the ontology for **generic model creation**, **storage and standardized data exchange** is verified in this work.
  - The use of korcut and its partial domain extension PERIOD ontology is tested in the area of space interfaces in the context of the real hardware task.

Conclusion

- PERIOD benchmark electrical test
  - Four-step electrical test process
  - To make a recommendation at the end for one of the three tested SI (HOTDOCK, iSSI® and SIROM) for use in the PERIOD demonstration scenario.
- Evolution
  - Application-oriented ontology based 12 criteria for electrical.
- PERIOD ontology as part of the korcut was created.
  - The meta-model of the generic interface
  - A method to distinguish SI
  - To share the test results of the SI

Outlook

- This method can be further developed and later applied as a standardized basis for selection procedures for multifunctional interconnects that can be used in orbital robotics.
- This method can be used for the development of standards within the European Operation Framework.
- PERIOD ontology as part of korcut will be further used for (space)robotic domain.

Questions?

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Thank you for your attention!

Acknowledgement:

This work has been carried out within the project PERIOD , which is funded by the European Union within the frame of the Horizon 2020 research and innovation programme under grant agreement No 101004151

European Commission