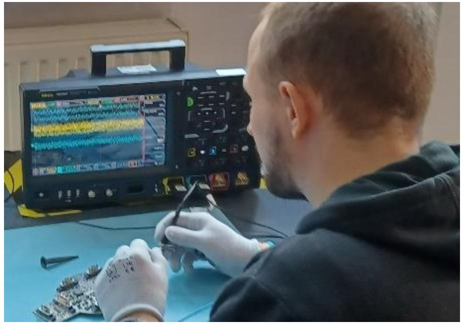
Development of Modular Robotic System for Servicing and Deorbiting Missions

Clean Space Industry Days (CSID)
ESA-ESTEC, Noordwijk, The Netherlands
18 October 2023

PIAP SPACE IN NUMBERS



- Established in 2017
- Based in Warsaw, Poland
- First 100% government-owned company in Polish space sector:
  - Owners: Industrial Development Agency JSC, Łukasiewicz Research Network – Industrial Research Institute for Automation and Measurements PIAP
- 50 employees including 36 engineers
- ISO 9001:2015 certification in 2021


CENTRUM CERTYFIKACJI JAKOŚCI
QUALITY CERTIFICATION CENTER

CERTIFICATE

This is to certify that quality management system in

PIAP Space Sp. z o.o.

ul. Stefana Batorego 107, 87-100 Toruń – miejsce rejestracji
Al. Jerozolimskie 202, 02-486 Warszawa - miejsce prowadzenia działalności

complies with the requirements of

ISO 9001:2015

Scope of certification:

Design, development, manufacturing, assembly and tests in the scope of space technology and robotics.

Certificate No 1438/5/2021 is valid from 23.09.2021 to 22.09.2024, under condition of fulfillment of the requirements contained in the confirmation, which is an integral part of this certificate. Initial certificate issue: 23.09.2021. Information about the certificate is available at www.ccj.wat.edu.pl. Edition: A, date of issuing: 23.09.2021.

MILITARY UNIVERSITY OF TECHNOLOGY
QUALITY CERTIFICATION CENTER
gen. Sylwestra Kaliskiego 2 St., 00-908 Warsaw

Director of the QCC

IAF

PCA

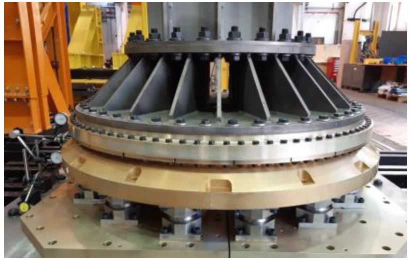
AC 057

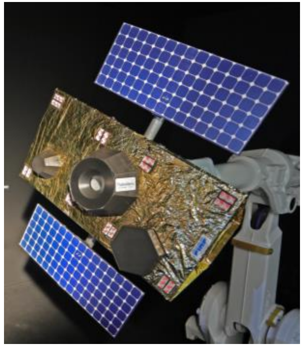
SPACE ROBOTICS

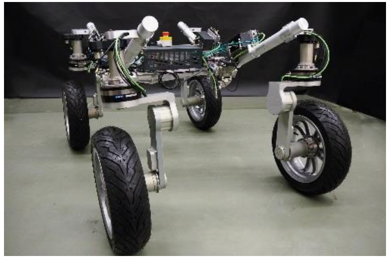
MGSE

(MECHANICAL GROUND SUPPORT EQUIPMENT)

I. MECHANICAL GROUND SUPPORT EQUIPMENT (MGSE)





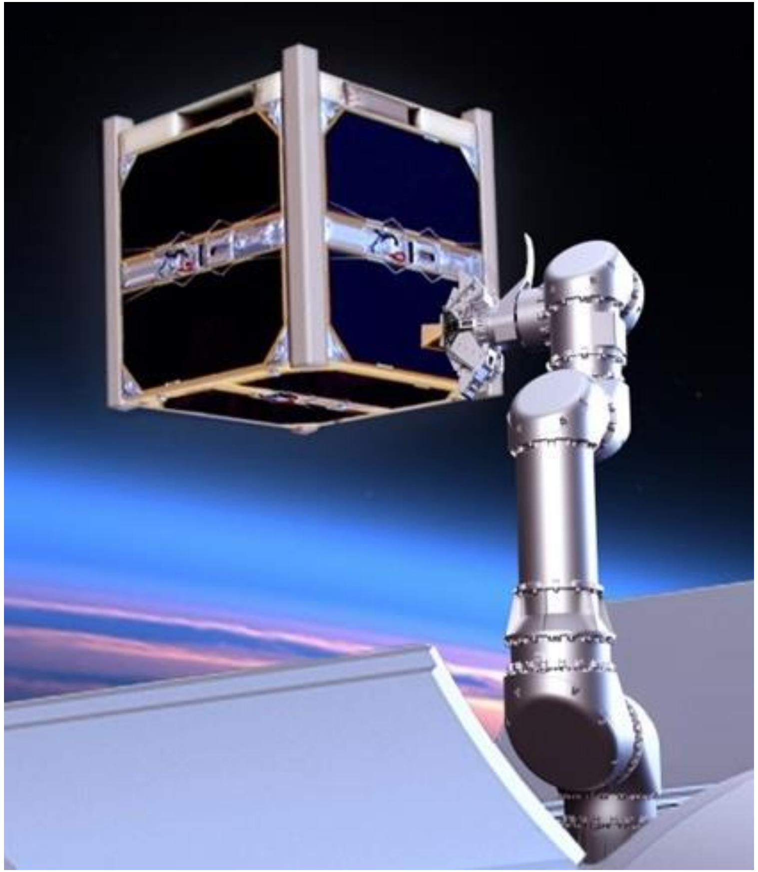


INTEGRATION STANDS (PIS, PIT)

ADAPTERS (GHA, VTA) AND CLAMP BANDS

TESTING DEVICES, MOCKUPS

II. ROBOTIC SYSTEMS



ROBOTIC ARM

END EFFECTORS

- LARIS GRIPPER
- MULTIPURPOSE GRIPPER

SENSORS FOR SPACE ROBOTICS

- FORCE / TORQUE SENSORS

ELECTRONICS & SOFTWARE

- BLDC DC CONTROLLERS
- ANALOG SIGNAL PROCESSING
- 3D IMAGING SENSORS SOFTWARE

TITAN MANIPULATOR

The project (ESA GSTP) focuses on the development and testing of a 7 DoF European robotic manipulator system for on-orbit servicing and small debris removal missions. This work focuses on increasing the readiness levels of technologies related to robotic manipulator systems for: uncooperative small debris removal and cooperative servicing.

Technical parameters:

- Range: 2 m
- Weight: 50-70 kg
- Redundancy:
  - Full redundancy of: F/T Sensor, thermal control subsystem independent power lines for each joint
  - Redundant data buses
  - Joint level redundancy by 7th joint

Targeted TRL 6 in Q4 2023 / Q1 2024.

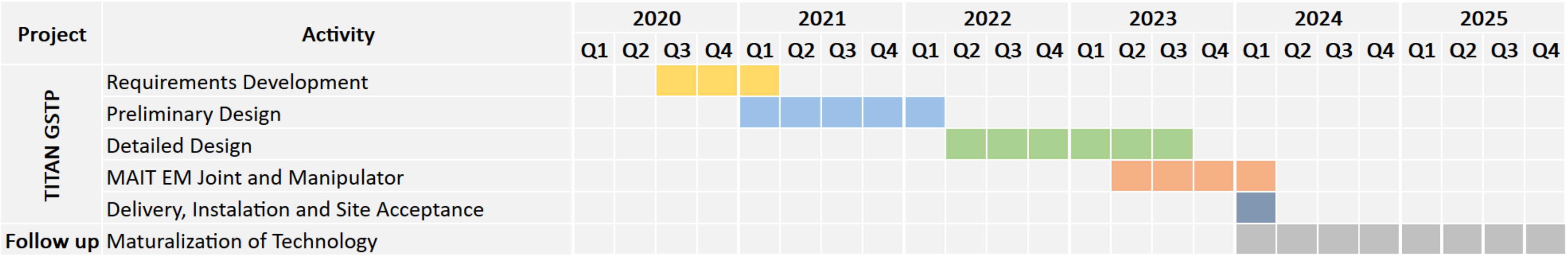
TITAN ROADMAP

Completed or ongoing activities:

- Joint development model tested,
- Critical design review for HW and preliminary design review for SW,
- Engineering model of joint and manipulator in during manufacturing.

Planned activities:

- Integration of joint and manipulator engineering models to be completed by early Q4 2023,
- Finalization of test campaign by the end of Q1 2024.



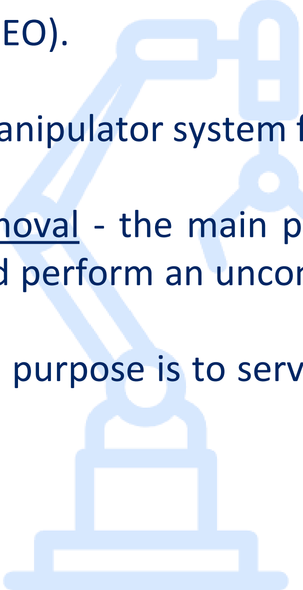
TITAN BACKGROUND

Different concepts of space tug and space servicing missions, using robotic manipulator systems for various purposes, have many other requirements.

The design of the TITAN arm is based on scalable joints and boom elements that will enable the specification of larger systems (e.g. for large ADR or missions to GEO).

This activity is focused on the development and testing robotic manipulator system for:

- <u>Uncooperative prepared and unprepared small debris removal</u> - the main purpose is to remove a megaconstellation satellite from the operational region and perform an uncontrolled re-entry of the satellite into orbit.
- <u>Cooperative prepared and unprepared servicing</u> - the main purpose is to service a future satellite in LEO or GEO (e.g. for refuelling).



TITAN PROJECT OBJECTIVES

DEVELOPMENT OF REQUIREMENT

Analyse the reference mission scenarios and extract relevant robotic system requirements.

DESIGN SCALABLE MANIPULATOR

Perform detailed design a family of manipulator joint subsystems: build and test DM of the joint subsystem, build and test EM of the joint subsystem, build EM of the manipulator.

TEST CAMPAIGN

Demonstrate the critical functions of the robotic manipulator system in relevant environments and reach TRL 6.

DEVELOP A PATH TO FLIGHT

The path to flight should include bringing the gap with respect to components, a test/verification approach and qualification to allow the system developed under this activity to be reused in an flight application.

TITAN PRIME AND SUBCONTRACTORS

PIAP SPACE (POLAND)

Development of requirements for the manipulator and reference missions, design of the manipulator and test stands, FEM simulations, manufacturing, integration and testing.

THE SPACE RESEARCH CENTRE OF THE POLISH ACADEMY OF SCIENCES CBK PAN (POLAND)

Simulations and analysis of manipulator kinematics and dynamics, free-floating control algorithm, development of BLDC motor controller, air bearing table tests.

SPACIVE (POLAND)

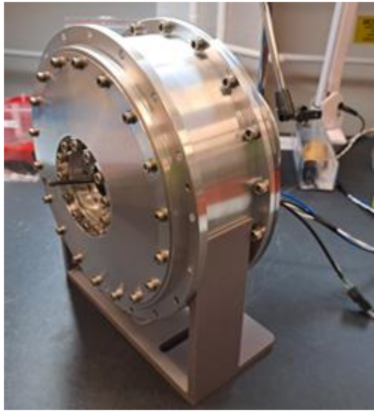
Thermal calculations, thermal system design and manufacturing, TVAC tests.

TITAN ESA INVOLVEMENT

- Support from an experienced technical officer and engineers in many fields (engineering, structural analysis, electronics).
- Possibility to use the ESA measuring system and software to evaluate the accuracy of the manipulator positioning and control system.
- Possible GSTP/TDE-related activities:
  - Six-axis force and torque sensor,
  - Universal BLDC controller.

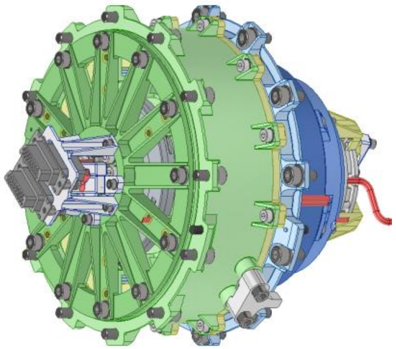
TITAN FACTS

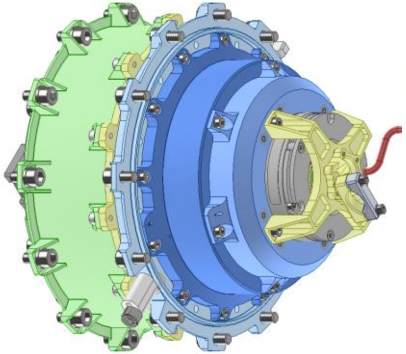
- TITAN manipulator makes an attractive addition to a servicing mission and one, which is of interest to future yet defined servicing missions or applications.
- The manipulator design consists of 7 joints, booms and FTS. Each joint consists of Joint Controller (with motor driver), Motor, Brake, Encoder, Thermal Sensors and Heaters.
- One of the distinguishing features of TITAN manipulator is a self-lifting capability, which significantly facilitates on ground testing.

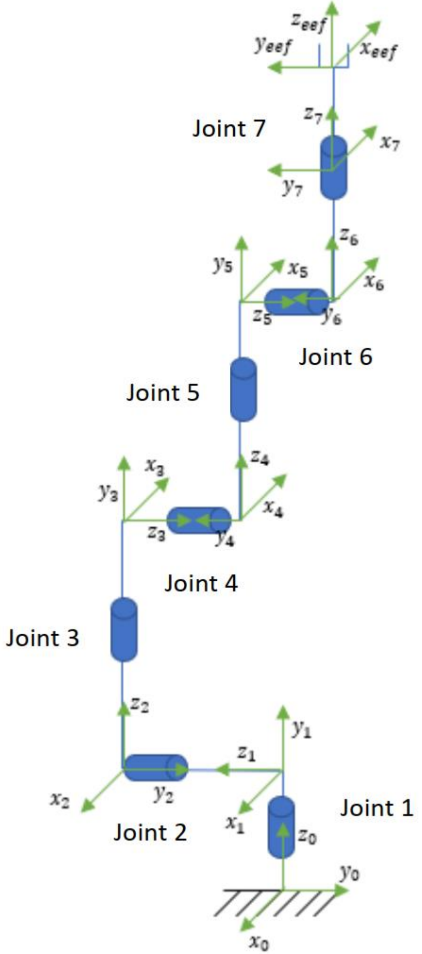


TITAN PARAMETERS

- Range of manipulator: up to 2 m.
- Manipulator mass: 65 kg.
- Positioning accuracy (at the tip): 0.5 mm, 0.1 deg.
- Maximum velocity (at the tip): 10 cm/s, 5 deg/s.
- Redundancy of thermal control subsystem.
- Redundancy of data buses.
- Joint level redundancy by 7th joint.
- Independent power lines for each joint.







TITAN THE BIGGEST CHALLENGES

- A highly complex system
- Management of a large number of requirements
- Subcontractor coordination

⇒ DOORS software implemented

- Large number of documentation and CAD model versions
- Data exchange between subcontractors

⇒ PDM and cloud software implemented

- Managing a large team and a high volume of tasks in multiple areas (hardware, electronics, software)

⇒ Kanban methodology implemented

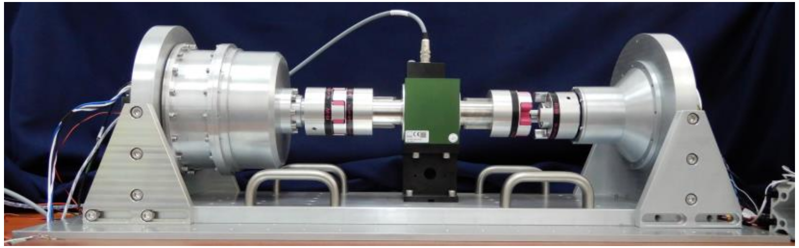
TITAN THE BIGGEST CHALLENGES

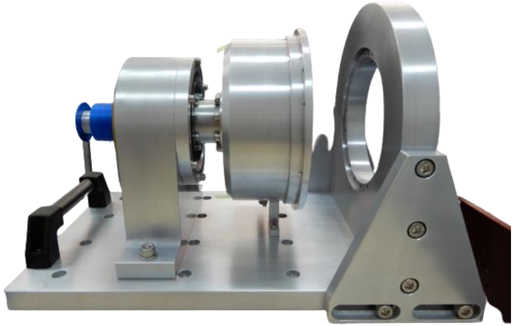
- Model Base Design
- Need to recode control algorithms to MCPUs

⇨ Automatic code generation software implemented

- FTS software of criticality category D
- Management and testing of software changes
- Synergy effects between SW in other projects

⇨ CI/CD framework and unit tests implemented

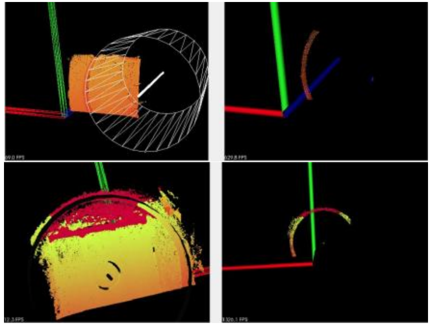




TITAN LESSON LEARNED

- All units shall be planned on preliminary design (volume model at least). Otherwise, it is difficult to implement.
- Starting design process - design drivers shall be identified.
- Units function shall be defined not later than PDR.
- Design factors (margins) approach shall be clearly defined.
- Try to keep dimensioning of mechanism by main functions not environment (e.g. launch vibrations).
- Clinging too tightly to self-defined requirements not confirmed in mission requirements.
- Safety factors on motorization are very high and it is worth starting the unit tests as soon as possible.

TITAN SYNERGY WITH OTHER PROJECTS



LARIS Gripper:

- Mass: 5 kg (including passive HOTDOCK)
- Max dimensions: 444 x 168 x 189 mm
- LAR compatibility: S3 LVA Ring 937, PAS_1666_S, PAS_1666_MVS, PAS_1194_VS
- Standard Interface: HOTDOCK (other interfaces integration possible)
- Current TRL 5, Targeted TRL 6 in Q4 2023 / Q1 2024, Targeted TRL 8 in 2026

Force Torque Sensor:

- 6 DOF (3 axial forces, 3 torque)
- Low mass 1.2 kg, high stiffens
- Measuring Range: ± 50 N, ±50 Nm
- Accuracy: 0.2 %
- Scalable and customizable design
- Current TRL 4, Targeted TRL 6 Q4 2023

Vison system:

- 6 DOF LAR pose estimation
- Based on ToF Camera
- Estimated Accuracy: ± 4 mm
- Current TRL 4

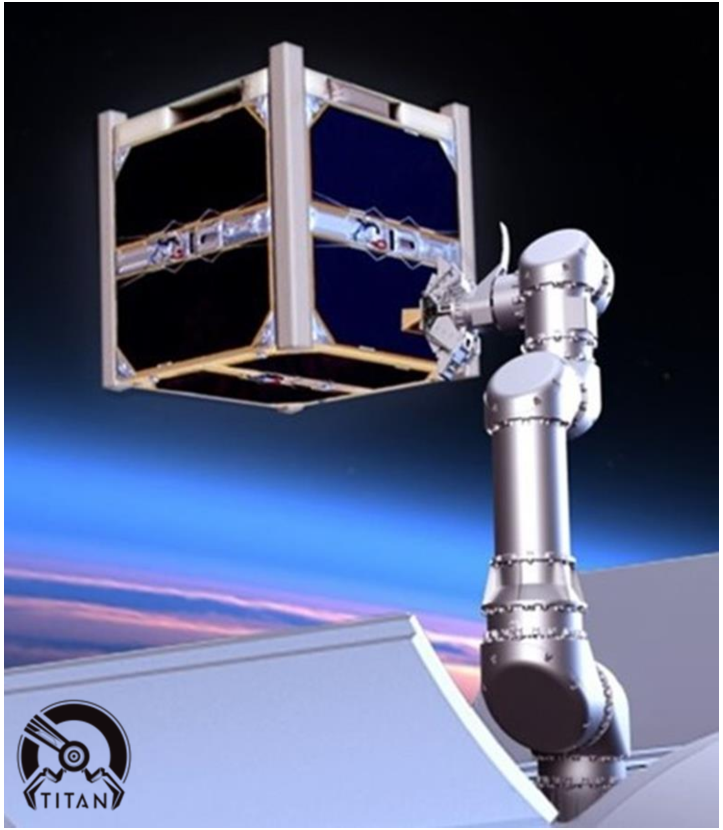
EROSS IOD HORIZON europe

Fundusze Europejskie Rzeczpospolita Polska Unia Europejska Europejskie Fundusze Strukturalne i Inwestycyjne

ORBITA

TITAN FURTHER DEVELOPMENT PLAN

	Feasibility studies Phase 0/A project	Been involved from the beginning in mission design
	Development of key technologies	Maturation and flight heritage Commercialization as a stand-alone product
	National and EU funding programmes	Development, optimalization and maturation of robotic arm
	Develop a commercial product	Reach TRL 8 of all of key technologies
	Commercialisation	In-orbit demonstration, flight mission
	Reaching new opportunities	Product modification to customer requirements



LAUNCH ADAPTER RING (LAR) GRIPPER

EROSS IOD European Robotic Orbital Support Services In-Orbit Demonstration

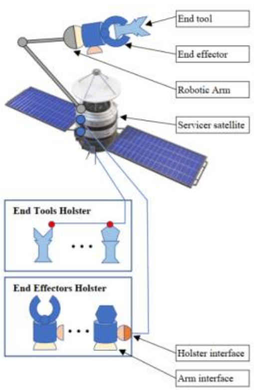
Technical parameters:

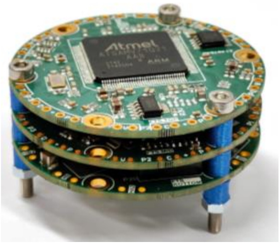
- Mass: 5 kg (including passive HOTDOCK)
- Max dimensions: 444 x 168 x 189 mm
- LAR compatibility:
  - S3 LVA Ring 937
  - PAS_1666_S
  - PAS_1666_MVS
  - PAS_1194_VS
- Standard Interface: HOTDOCK
  (other interfaces integration possible)

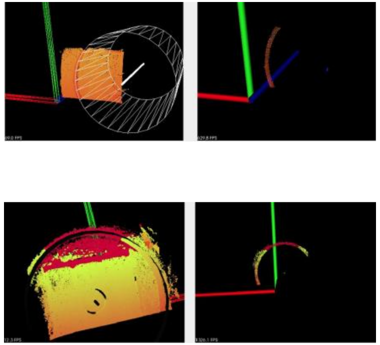
Current TRL 5. Targeted TRL 6 in Q4 2023 / Q1 2024. Targeted TRL 8 in 2026.

The project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101082464.

OTHER SPACE ROBOTICS SYSTEMS







Multipurpose Gripper:

- On-orbit Servicing, Refuelling and Assembling
- 2 DOF (unlimited rotation, grasp)
- Jaws compatible with dedicated tools
- Dimension: height 400 mm, ∅ 120 mm
- Mass: 5-6 kg
- Power supply: 28 VDC (50 W)
- Scalable and customizable design
- Current TRL 4, Targeted TRL 6 Q4 2023

Force Torque Sensor:

- 6 DOF (3 axial forces, 3 torque)
- Low mass 1.2 Kg, high Stiffens
- Measuring Range: ± 50 N, ±50 Nm
- Accuracy: 0.2 %
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- Current TRL 4, Targeted TRL 6 Q4 2023

Vison system:

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- Based on ToF Camera
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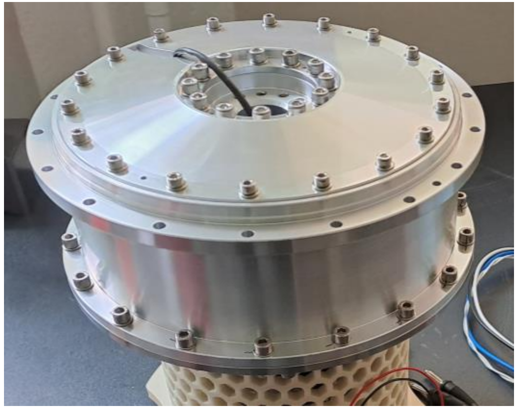
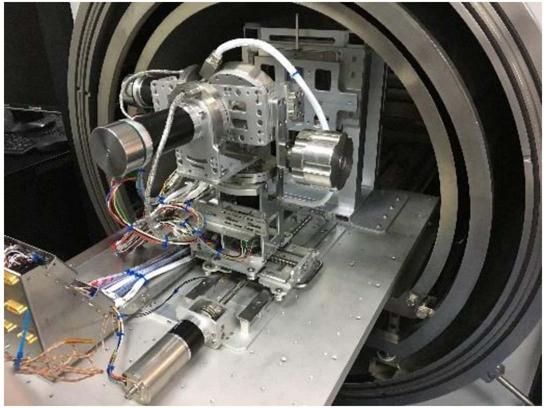
ACTUATORS & MECHANISM

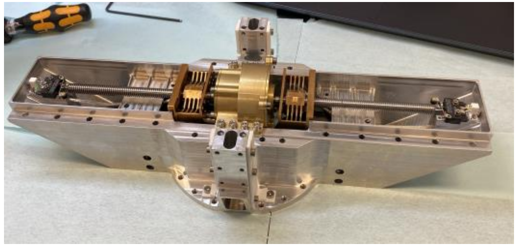
Rotary actuator



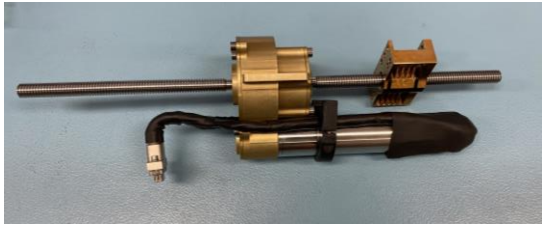
Mechanism for tests in TVAC



Clamping mechanism



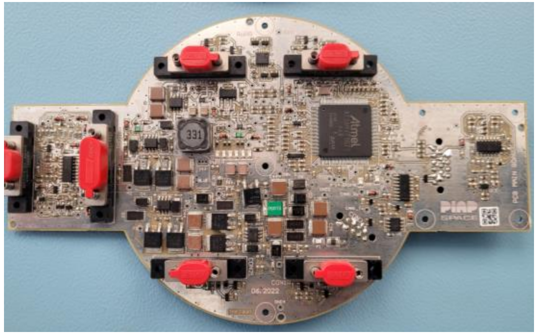
Screw actuators



ELECTRONIC CIRCUITS

BLDC motor controller:

- Power supply 28 VDC
- Maximum Power up to 60 W
- Hall sensor and Encoder support
- Scalable and customizable design
- CANbus communication

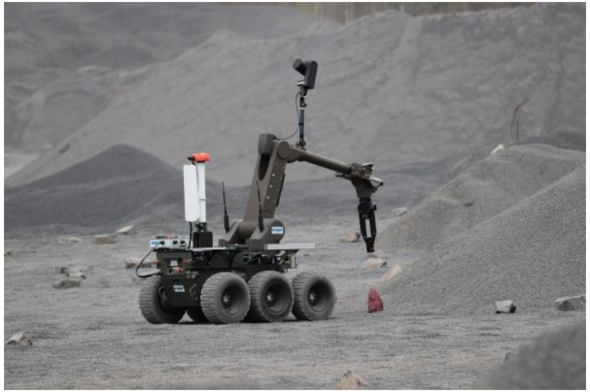


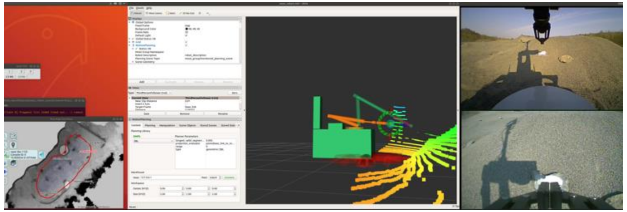
Signal processing circuit:

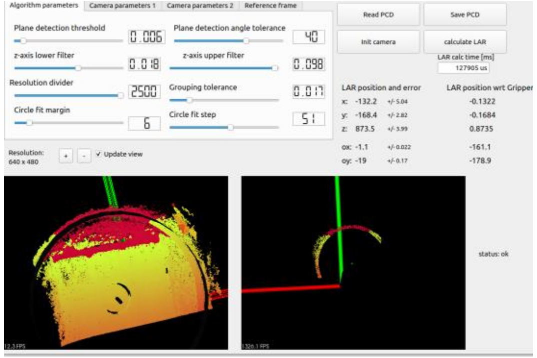
- Based on MCu
- For strain gauge sensor
- Hot redundancy supported
- Based on 32-bit converters
- CANbus communication

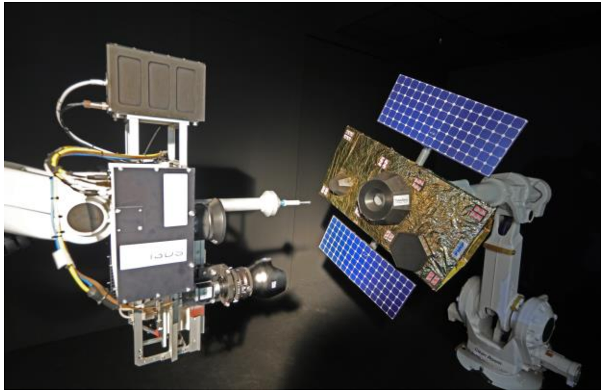
SOFTWARE

- Software Development for Embedded System
- Trajectory planning and control system for mobile robots and manipulators
- Algorithms for vision systems based on 3D imaging sensor

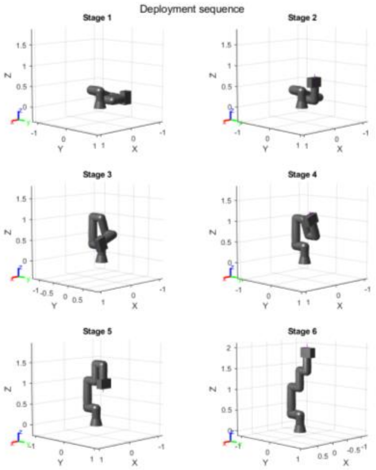


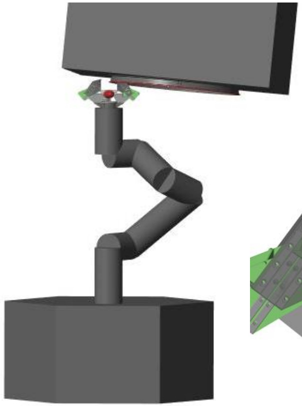


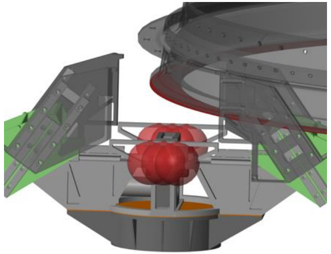


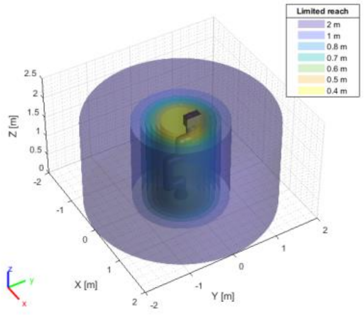


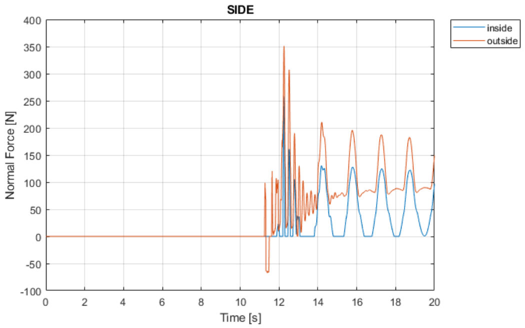
SIMULATIONS





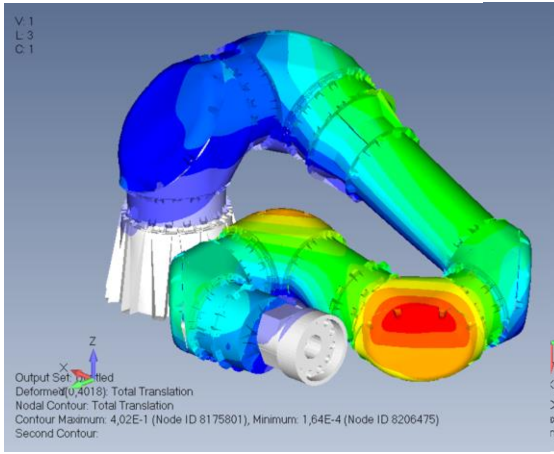


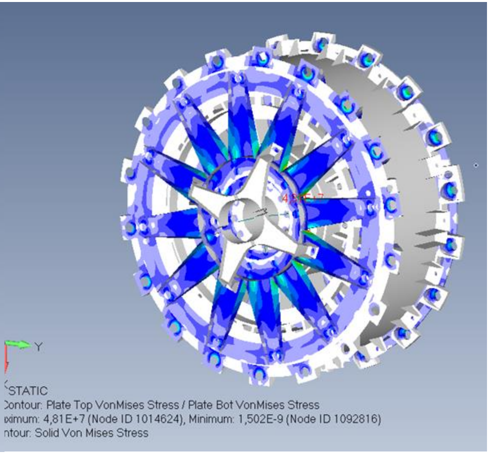




- Kinematic and dynamic simulation of multibody systems
- Dynamic simulations with friction and nonlinear contact
- Simulations and analysis of trajectory planning for multi-articulated manipulators
- Simulation and analysis of electronic control systems

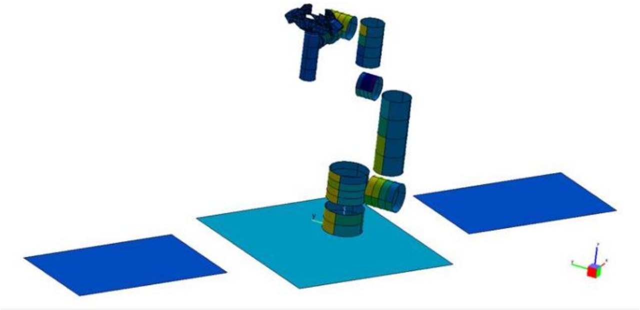
ANALYSIS

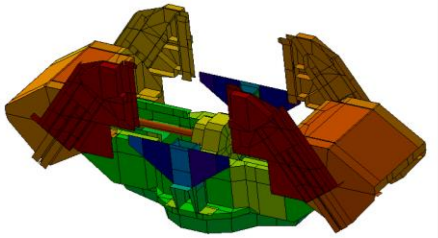




- **FEM** (NX Nastran)
- Static, modal, harmonic and random
- Thermoelastic (with thermal mapping)
- Non-linear (with contact), shock

- **Thermal** (ESATAN)
- Steady state, hot/cold case
- Transient
- Uncertainty
- On-orbit and internal thermal environments





R&D PROJECTS

TITAN (ESA) Robotic Arm Development for OOS Operations. End: Q1 2024.

European Robotic Orbital Support Services EROSS (H2020), EROSS+ (H2020), EROSS IOD (HEU). End: Q1 2025.

EROSS 2019 – 2021 TRL 4 → EROSS + 2021 - 2023 TRL 6 → EROSS IOD 2023 – 2025 TRL 7 → FLIGHT MODEL – 2026 TRL 8

ON-ORBIT SERVICING POC1 (ESA)

ORBITA (regional funds) Development of a family of modular grippers for orbital and planetary applications. End: Q1 2024.

CHABLIS (ESA) Prototype of a rover responsible for collecting and transporting the samples to a spacecraft that can carry them to Earth. End: Q4 2021.

I3DS (H2020) Integrated 3D Sensors suite (I3DS) for servicing satellites. End: Q1 2019.

PRO-ACT (H2020) Planetary Robots Deployed for Assembly and Construction Tasks. 1 January 2016 - 31 August 2019.

COMRADE (ESA) Development and tests of a robotic spacecraft control system. End: Q1 2020 (planned 2018).

ADREXP (ESA) Development and verification of a system for reliable, unattended visual recognition of the movement of an uncooperative in-orbit interceptor satellite. End: Q3 2016.

OUR VISION

Our vision is to be in the process of the ecosystem creation where enabling building blocks are the basis.

This brings space robotics solutions that fit together, making the whole industry competitive and also cooperative.

LET YOUR NEXT MISSION

BE OUR COMMON SUCCESS

We look forward to hearing from you

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