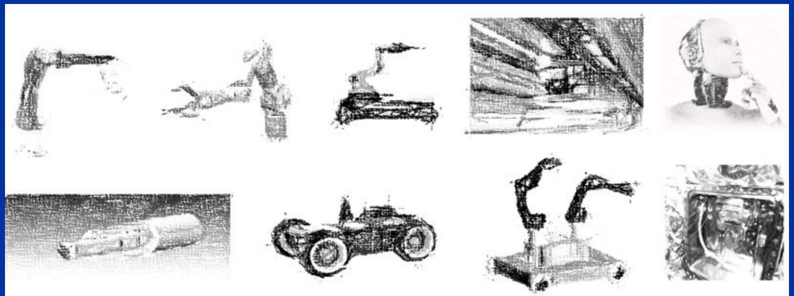
Robotic Solutions for Remote Maintenance and Quality Assurance

Mario DI CASTRO



Joint DESY and University of Hamburg Accelerator Physics Seminar, 10.5.2022

Disclaimer

This lecture will present a broader approach on how robotic solutions for remote maintenance and quality control are used at CERN by the BE-CEM group.

Design, controls, operation, maintenance aspects, tools and procedures around the use of robotic systems will be introduced, focusing on **requirements**, **challenges** and **operational constraints** present in CERN accelerator complex.

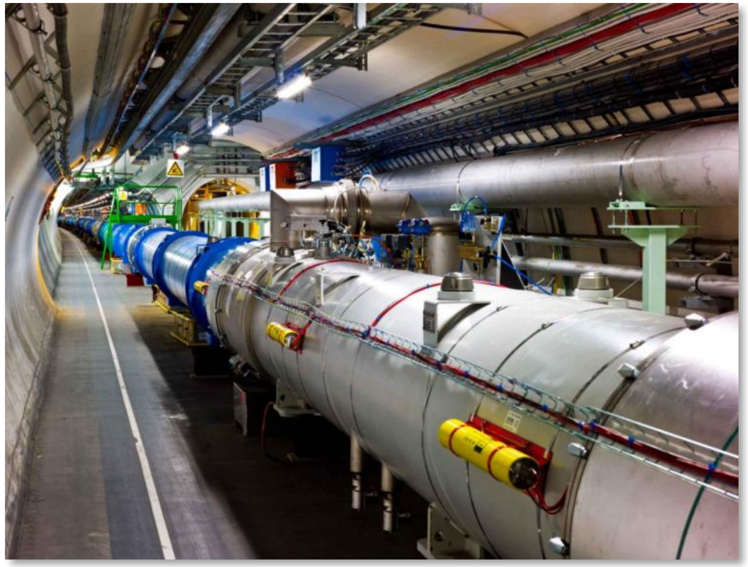
Detailed info could be found at the Academic Seminar lectures link → https://indico.cern.ch/event/1055745/

Content

- Needs and challenges for robotics at CERN
- The robotic service in BE-CEM
- Some challenging robotic missions
- Future objectives
- Conclusions

Main needs for robotics at CERN

- **Inspection, operation and maintenance of radioactive particle accelerators devices towards maintainability and availability increase**
  - ✓ **Experimental areas and objects not built to be remote handled/inspected**
    - ✓ Any intervention may lead to “**surprises**”
    - ✓ Risk of **contamination**



The LHC tunnel

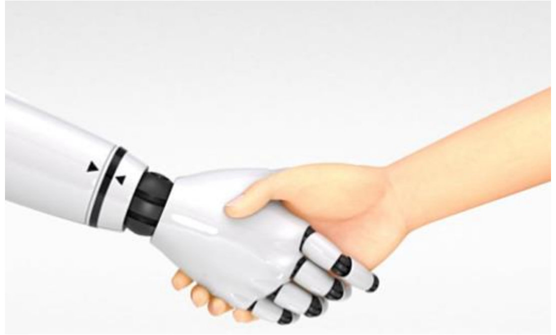
North Area experimental zone

Radioactive sample handled by a robot

Availability of Particle Accelerators

Reliability	Maintainability	Availability
Constant	Decreases	Decreases
Constant	Increases	Increases

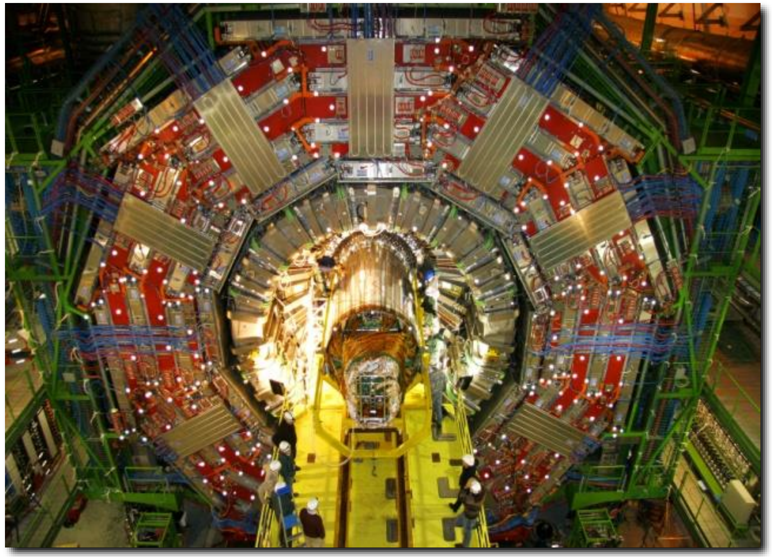
But before deploying robots, their reliability must be verified to be really high and recovery scenarios must be foreseen



Main difficulties for robotics at CERN

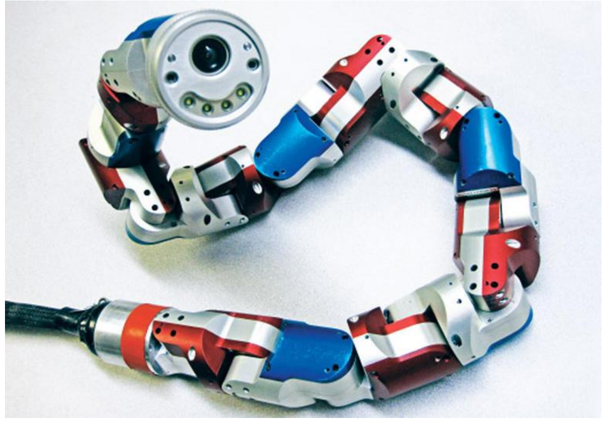
- Need for maintenance intervention and inspection in harsh and semi-structured environments
- **Radiation, magnetic disturbances**, delicate equipment not designed for robots, big distances, communication, time for the intervention, highly skilled technicians required (non robotic operators), etc.



Suitable robots for Big Science Facilities

- No single existing robotic solutions can fulfill the needs
- Mobility and manipulation capabilities are required
  - ✓ A “fusion” of several type of robot would be needed
  - ✓ **A modular robot could fulfill several needs**

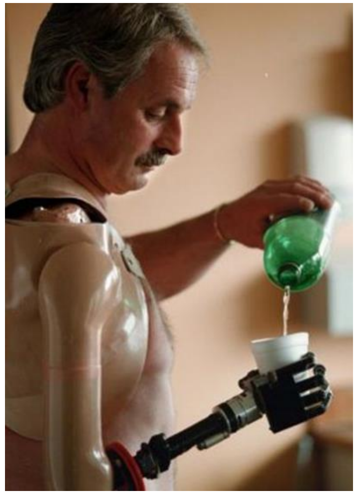


Robotics and Ethical aspects

- **Ethical aspects** [3] [4]
  - ✓ Will robots replace humans?
  - ✓ Will robots take our jobs?
  - ✓ Will robots make humans unnecessary?
  - ✓ Is humanity just a phase in a robotic evolution?

Robotics for us

- There is a lot of potential in this technology to be beneficial for people
- Ultimately, everything depends on how we decide to use the technology

Robots must improve the quality of work by taking over dangerous, tedious and dirty jobs that are not possible or safe for humans to perform.
<u>ALARA principle followed for each intervention</u>

Content

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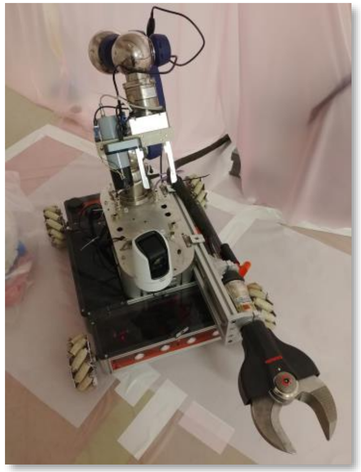
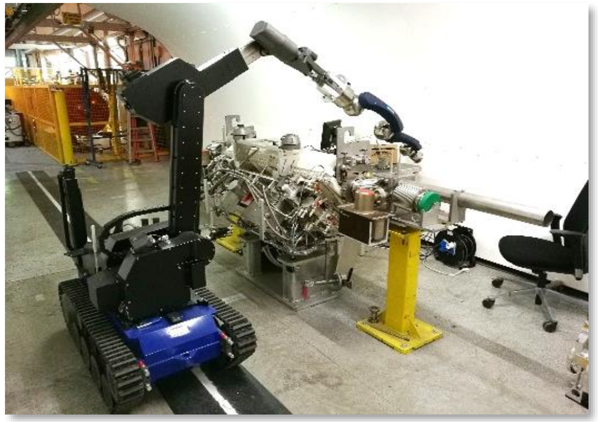
Robotic Support for CERN: Type of Robots Overview

Telemax robot

Train Inspection Monorail [10] (CERN made)

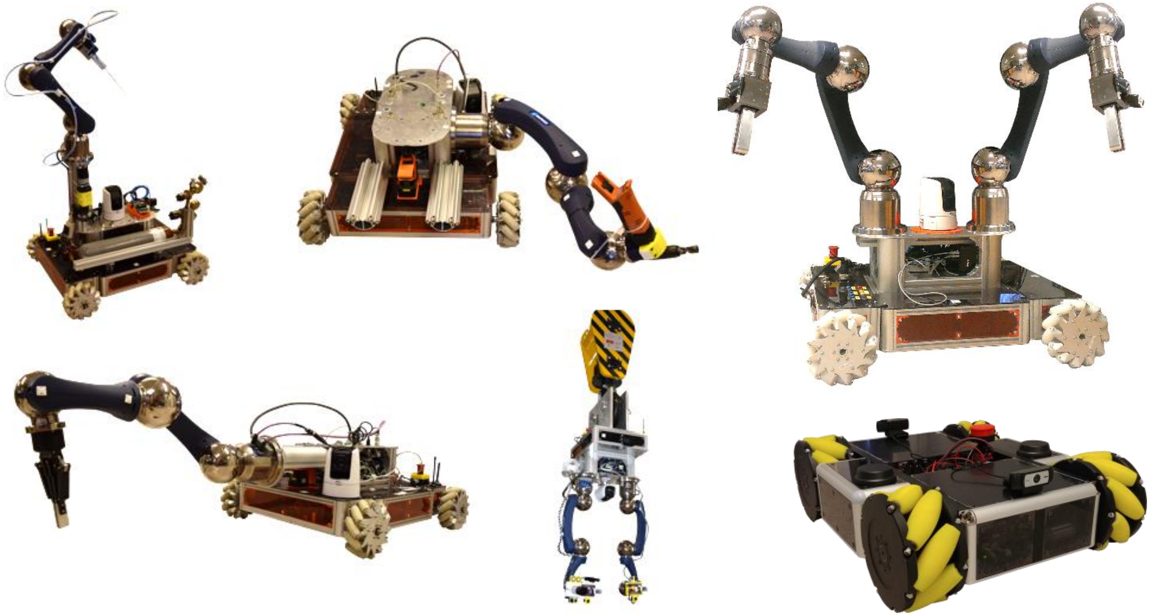




Teodor robot

EXTRM robot (CERN controls)

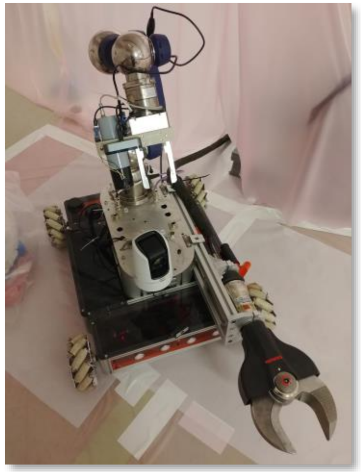
Drone for tele-
operation support



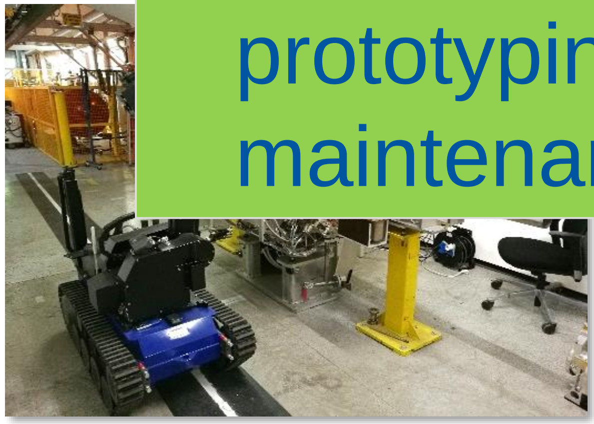
CERNBot [11-17] in different configurations (CERN made)

Robotic Support for CERN: Type of Robots Overview



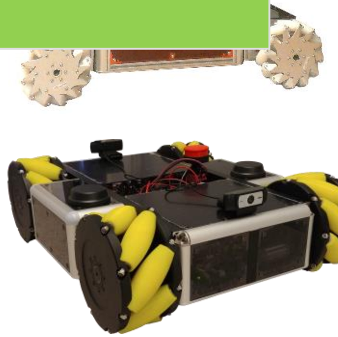
- ➢ Mechatronics conceptions, designs, proof of concepts, prototyping, series productions, <u>operations</u>, maintenance, tools and procedures



Teodor robot

EXTRM robot (CERN controls)



CERNBot [11-17] in different configurations (CERN made)

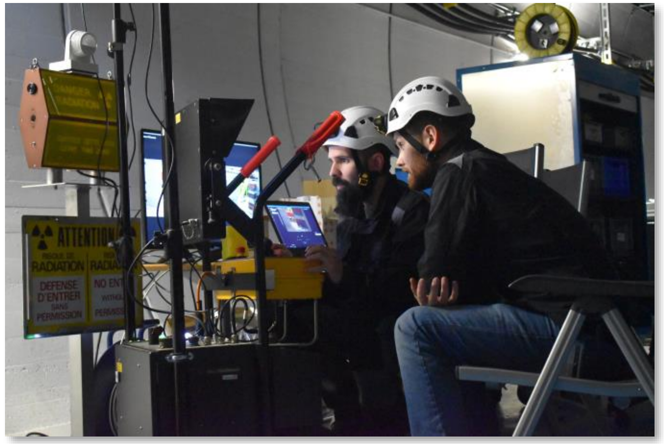
Drone for tele-operation support

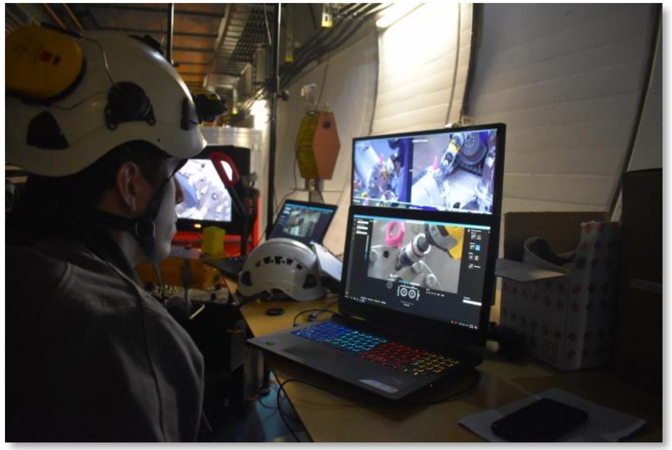
Robotics technologies are mainly used for:

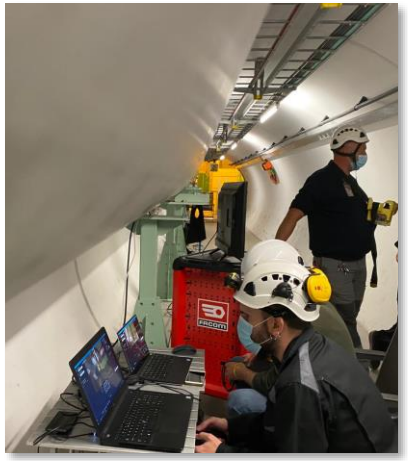
- Human intervention procedures preparation
- Environmental measurements, maintenance and inspection in radioactive areas
- Quality assurance
- Post-mortem analysis/inspection of radioactive devices
- Reconnaissance
- Search and rescue
- And others…

Robotic service for remote maintenance

- Remote inspection and teleoperation
  - ✓ Robotic controls (kinematics + feedbacks) and operation

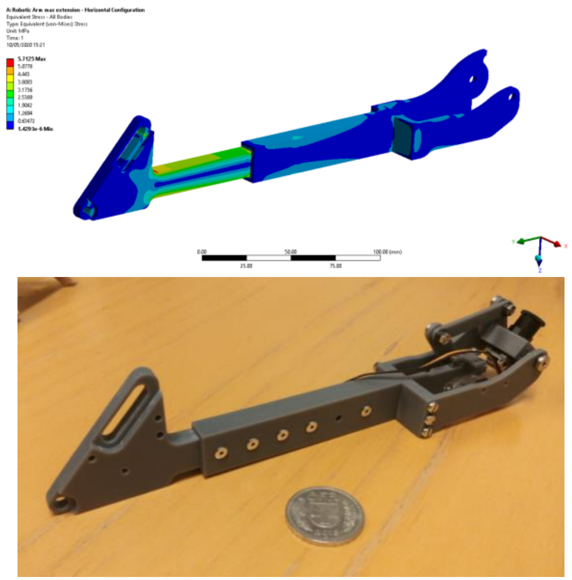






Robotic Lab #1, building 937

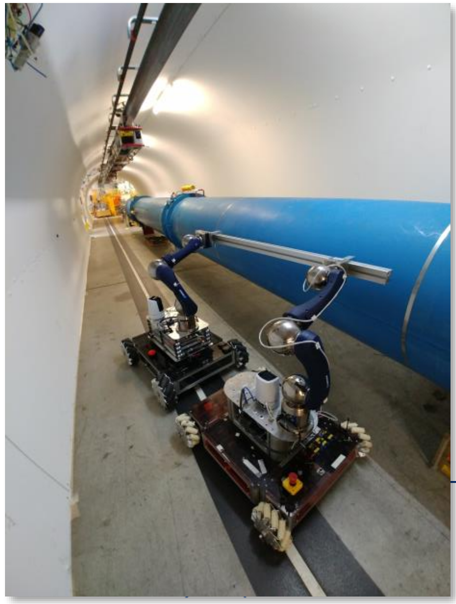
- Robotic prototyping
- 3D printing
- Robotic arm control, tools vision and algorithms testing (autonomy and teleoperation)
- Participation in the HSSIP and Italian teacher programs to host and mentor high-school students [42]

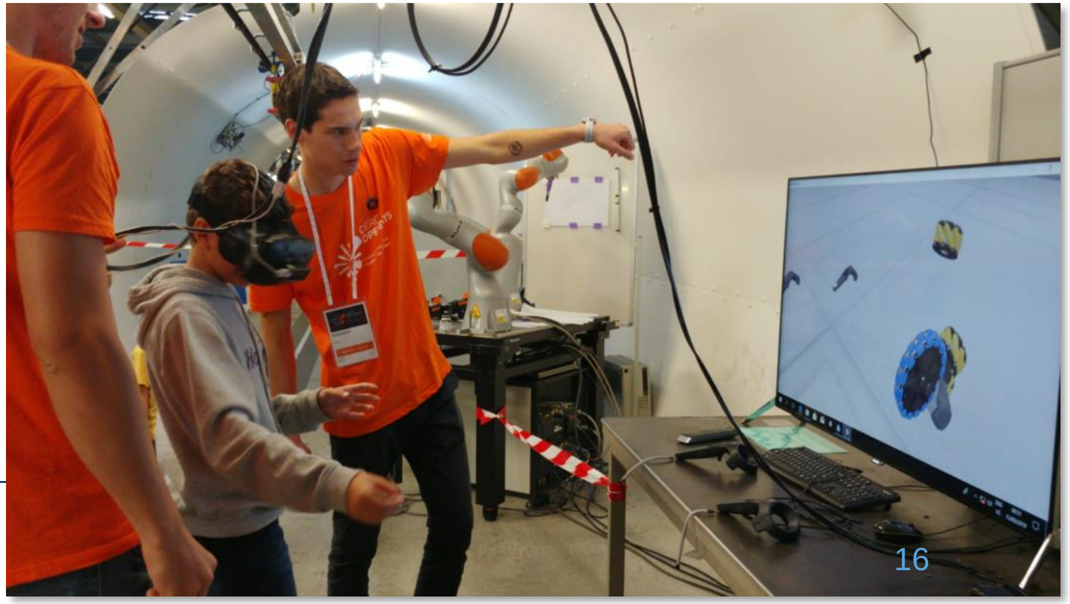


Desig and 3D printing prototype for the RF cavity inspection robot

Robotic Lab #2, building 927

- Robots testing and commissioning
- Intervention procedures and recovery scenarios commissioning (mockups)
- LHC Tunnel mockup (~ 30 meters)
- Virtual reality zone





Main Motivations for Custom Robotic Development #1

- CERN accelerator complex is vast with different type of machines
- Industrial solutions do not cover all CERN needs for remote maintenance and quality control
- Strong need to develop **a modular and adaptable robotic framework/system for** <u>semi-structured and harsh environments</u>

Main Motivations for Custom Robotic Development #2

- Industrial robot have **very complicated human-robot interfaces demanding intense operators training**, controls are not open to be integrated in our control system, communication channel is often via radio signal, not built to reduce contamination risks etc.

- Necessity of having the human, the machine and the interface working together adopting **user friendly interfaces**
  - ✓ Increase of **proprioception** reducing operators stress

PDM and PLM

- Pre-study
- Project planning
- Sizing and materials
- 3D Model
- Finite element analysis

- Study
- 3D model update
- Detail drawings
- Assembly drawings
- Prototype

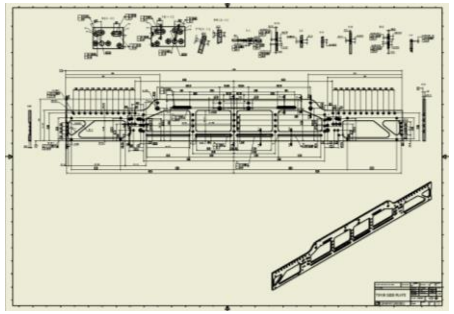
- Quality Assurance
- PDM
- PLM control loop
- ISO GPS specification
- Technical documentation

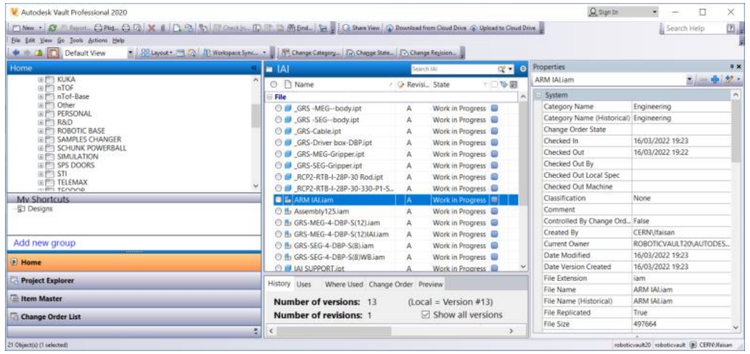
- Tender and quote
- Drawings
- DAI (equity balance)
- Manufacturing
- Follow-ups

- Delivery and Receipt
- Dimensional Control
- Assembly
- Follow-ups
- CAD updates

(Product Data Management)

(Product Life cycle Management)





CERNTAURO framework [7]

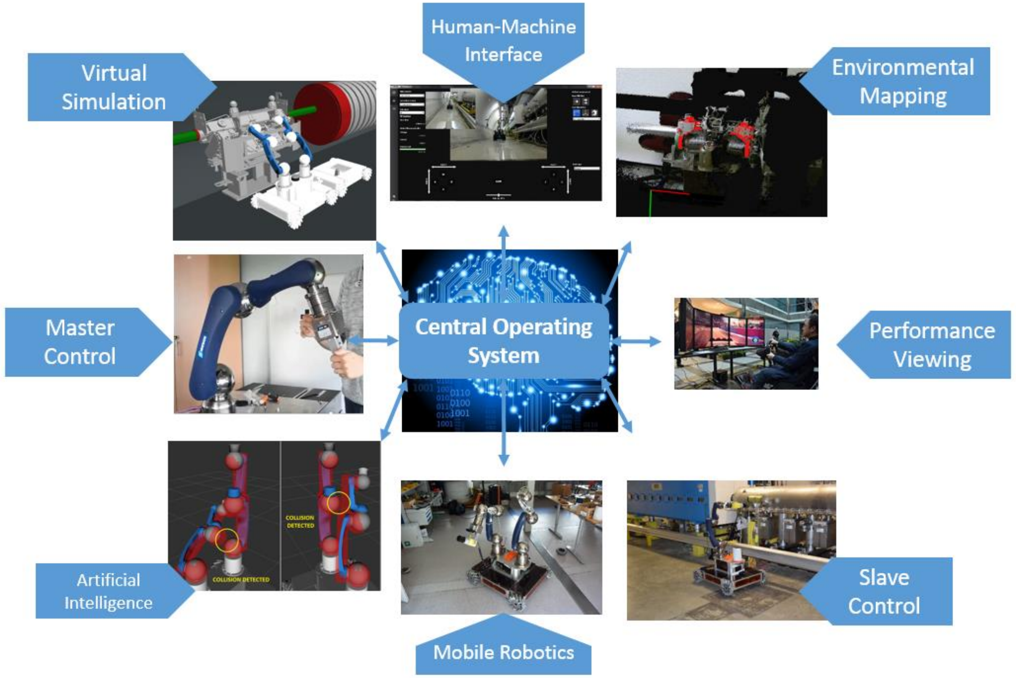
CERN Telemanipulation semi-**A**utonomous **U**nit for **R**obot **O**perations

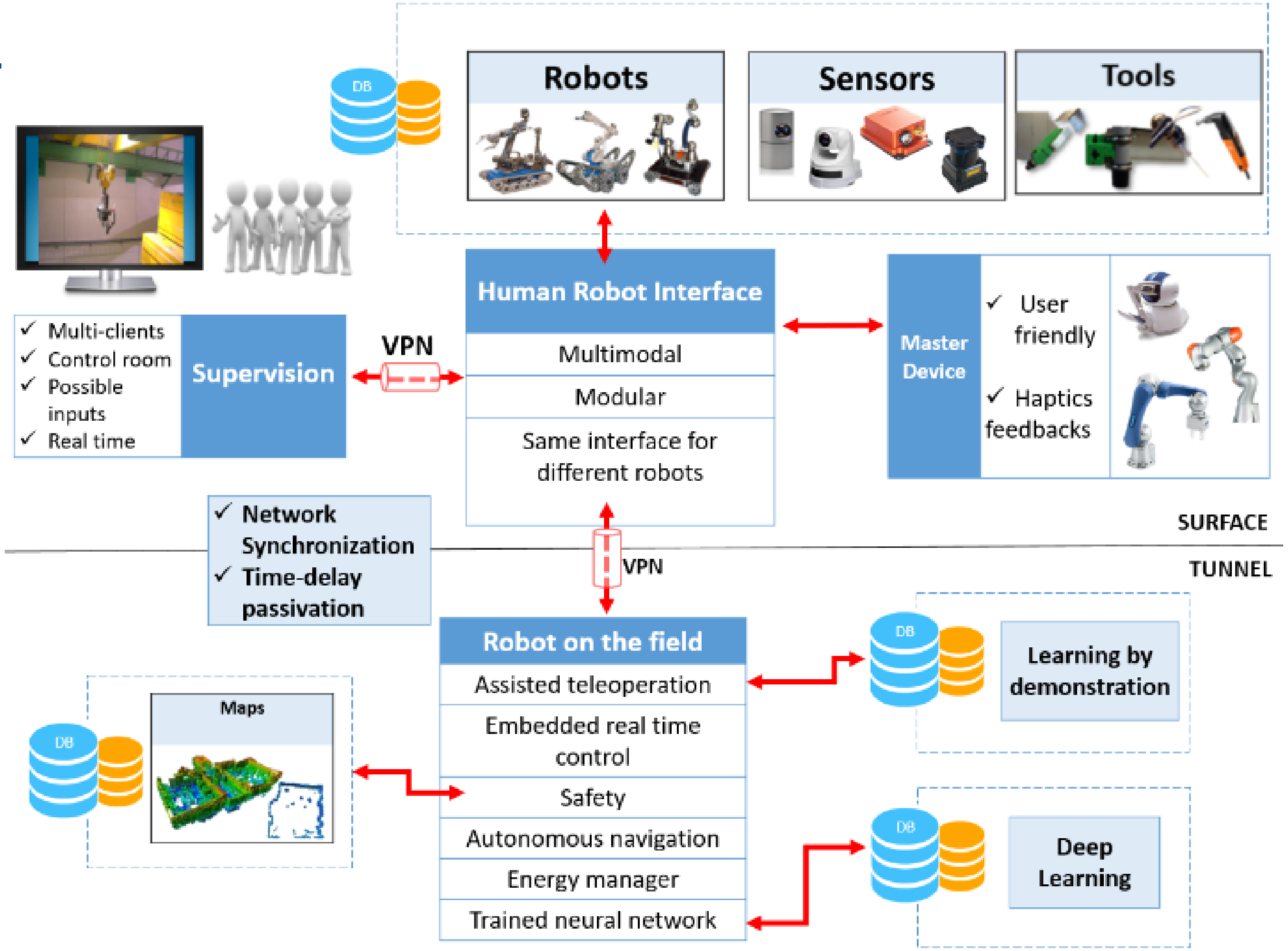
Mechatronic System

- **New robot and robotic control developed** [9-39]
  - ✓ Human robot interface
- **New user-friendly bilateral tele-manipulation system**
  - ✓ Haptic feedback
  - ✓ Assisted teleoperation
- **Artificial intelligence [30-31-38-40]**
  - ✓ Perception and autonomy
  - ✓ Deep learning
- **Operator and robot training system [41]**
  - ✓ Virtual and augmented reality
  - ✓ Learning by demonstration

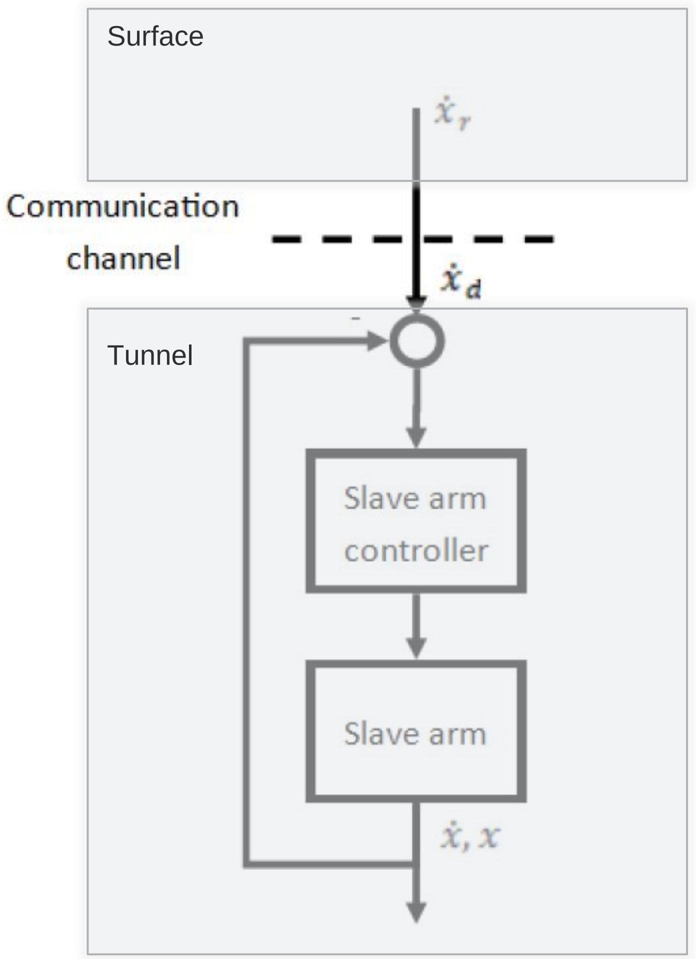
CERNTAURO framework

- In house robotic control system [7]
- No use of ROS [8]
- Sensor acquisition, fusion, measurements etc.



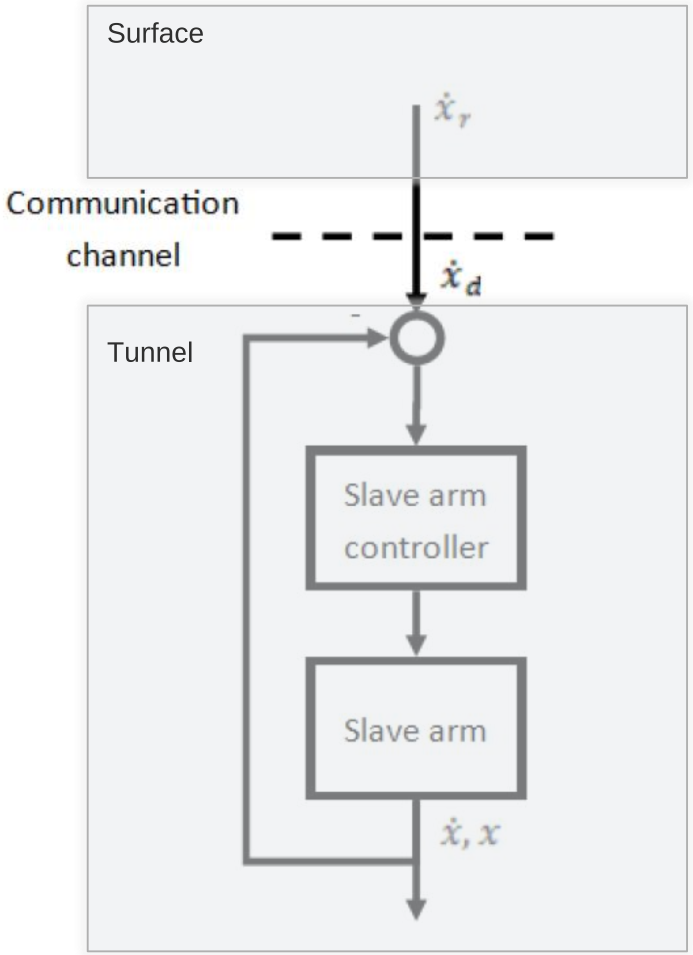


Unilateral vs Bilateral Controls



Unilateral control scheme of CERNTAURO

Unilateral vs Bilateral Controls



Unilateral control scheme of CERNTAURO

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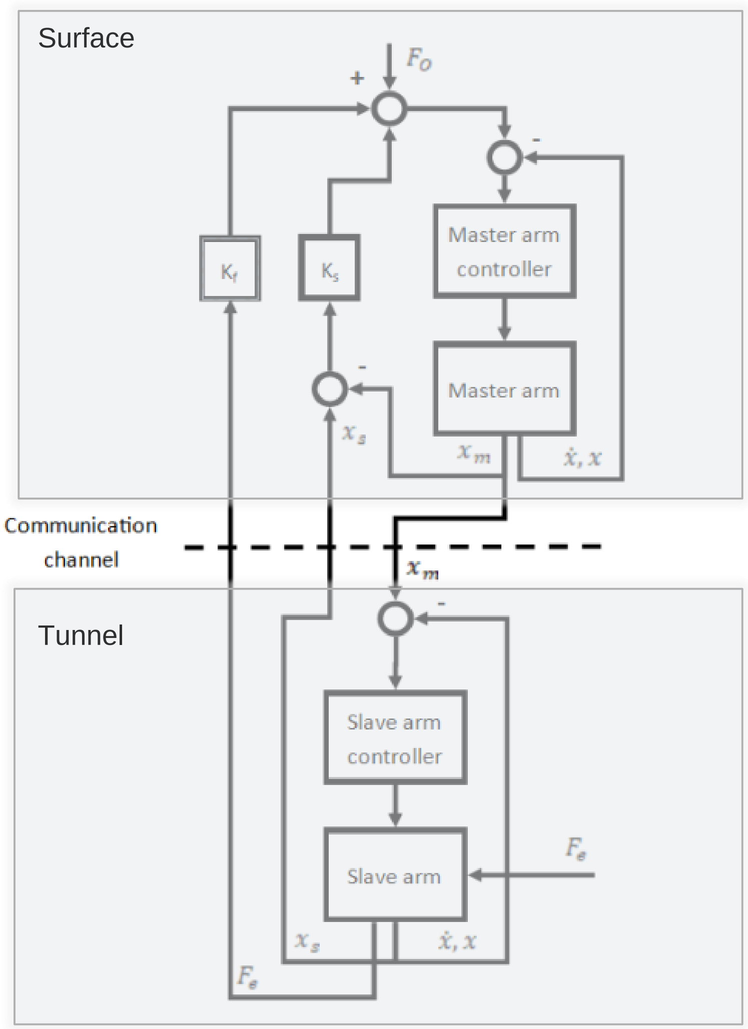
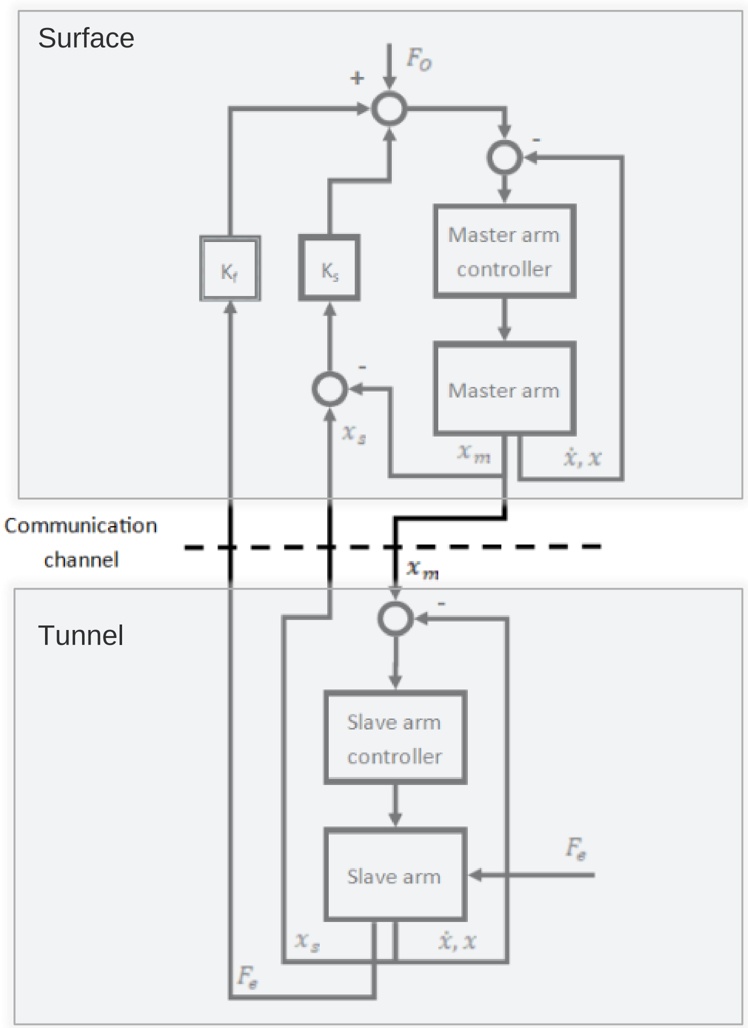
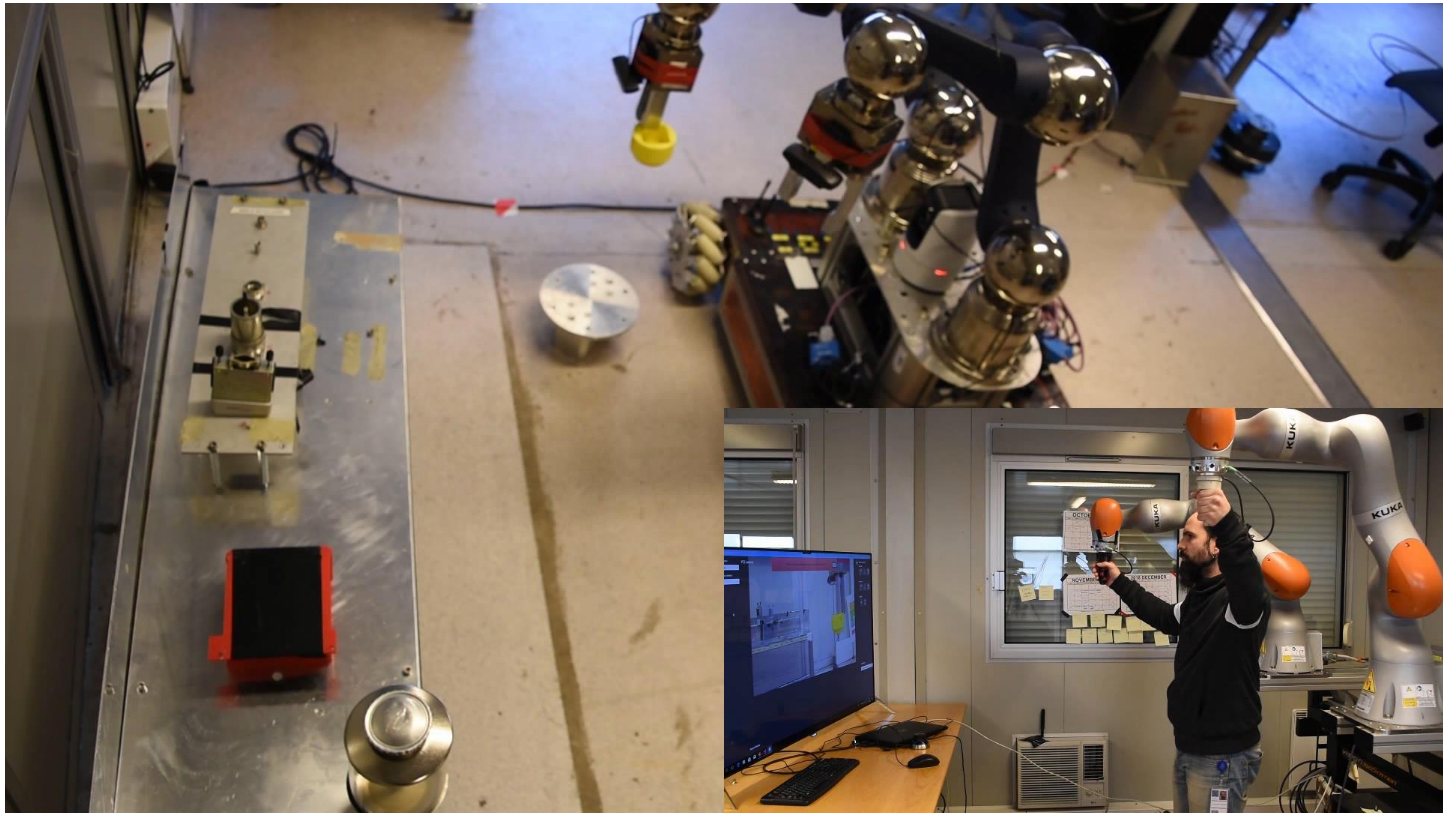


Bilateral control scheme of CERNTAURO. Experience of imitation

Unilateral vs Bilateral Controls





Bilateral control scheme of CERNTAURO. Experience of imitation

Haptics

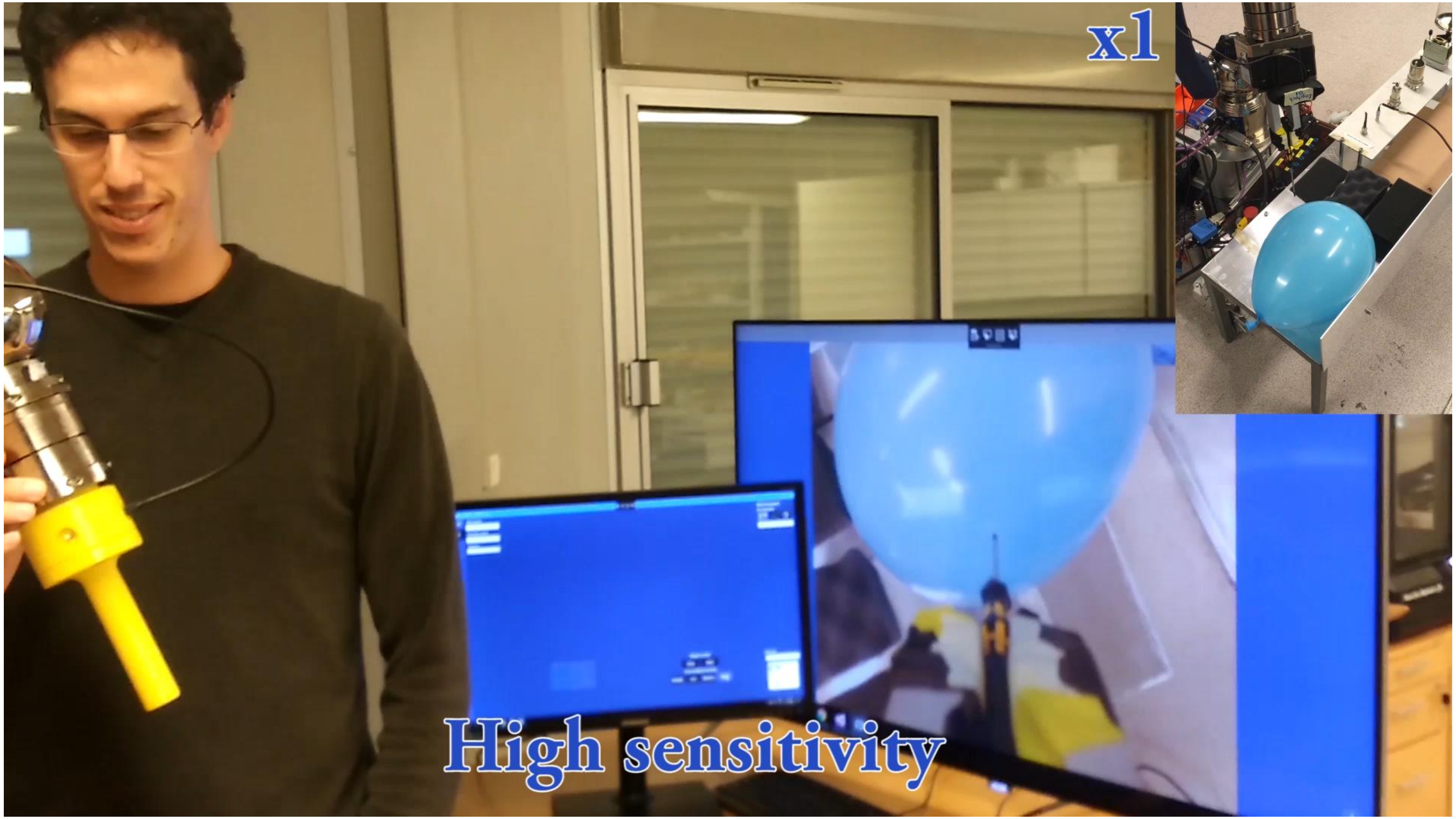
Unknown and unstructured environment:
How much does it weigh?
What happens if I touch it?
Does it break easily?
Haptics lets you understand your effect on the environment

How strong is the robot arm?
How fast can it move?
How much impulse does it have?
Haptics lets you understand the way the robot moves

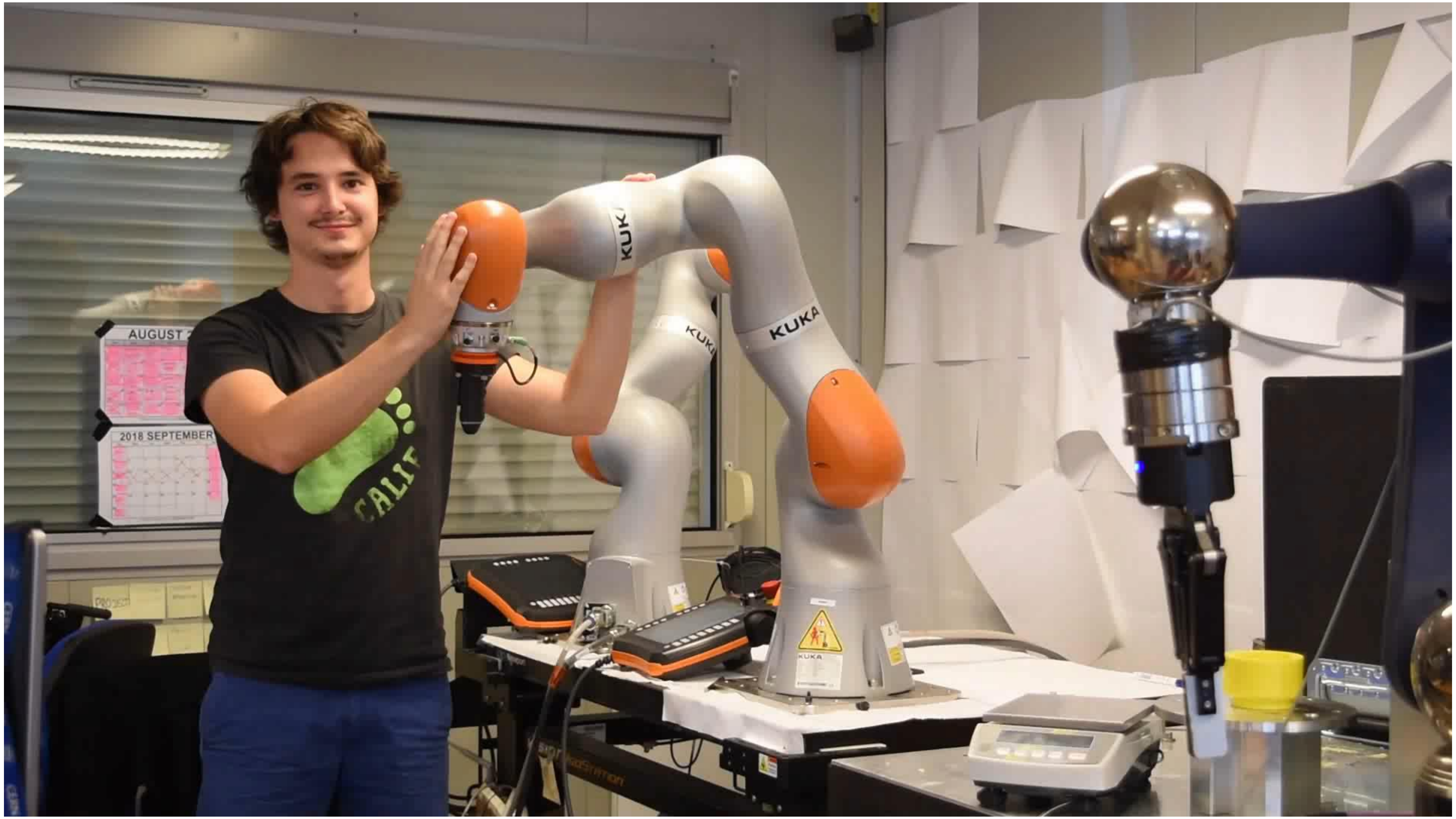
Be strong

Stay gentle

Bilateral Controls and Haptics

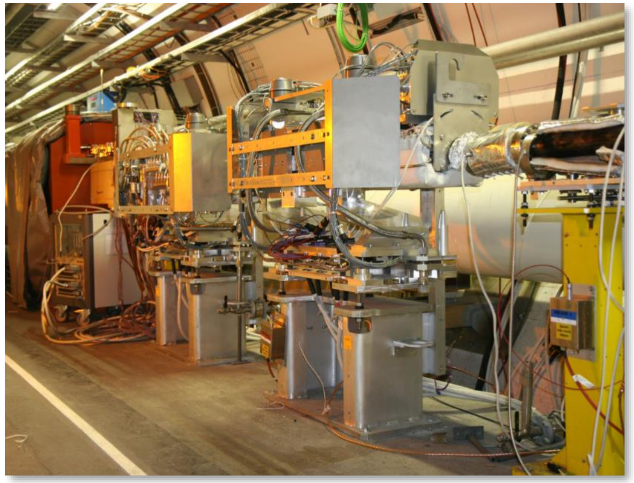


Impedance-Mode Control

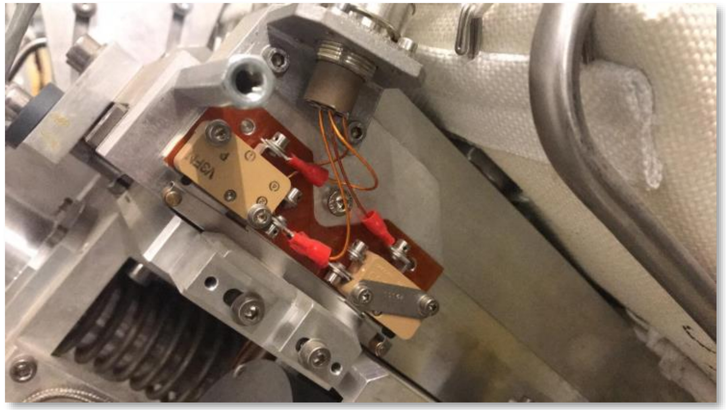


Environmental Perception: a use case

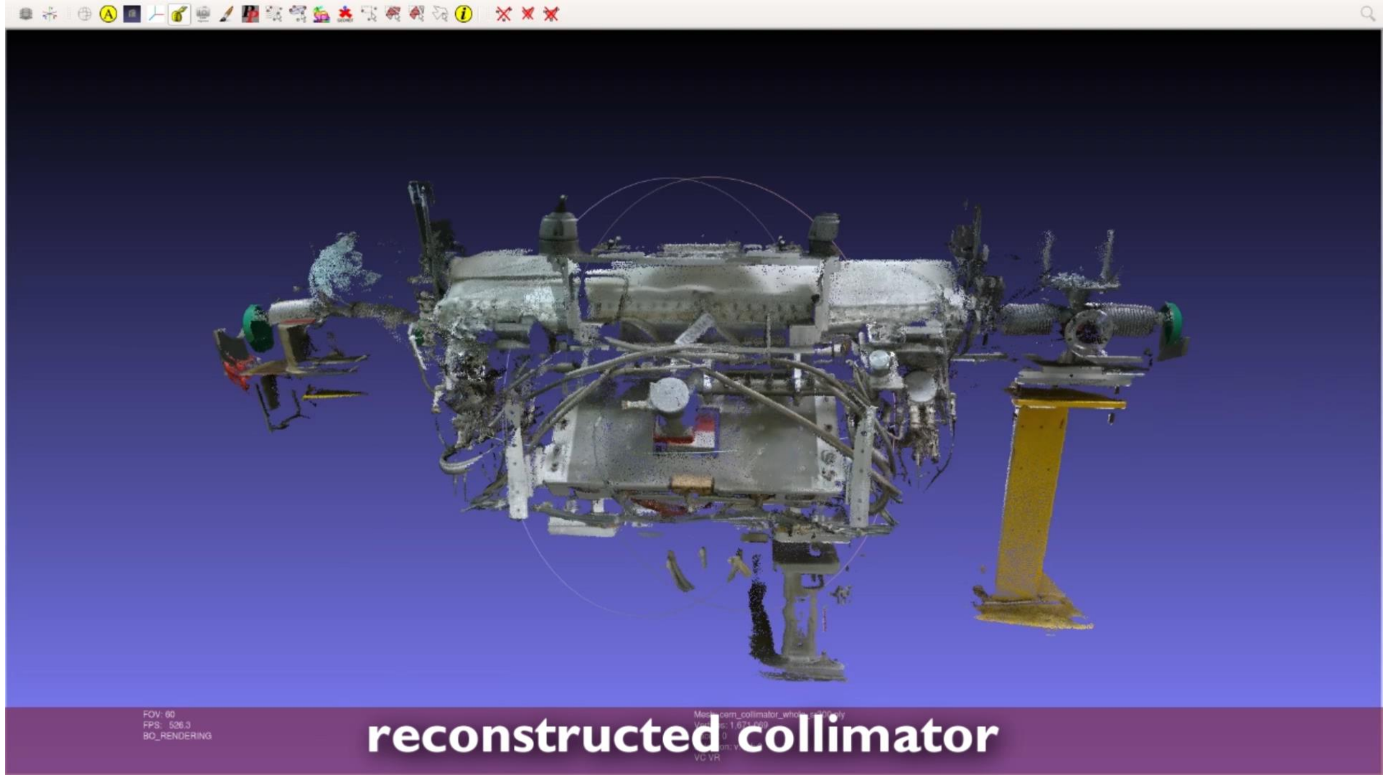
- Automatic recognition of collimator position switches and their actuation



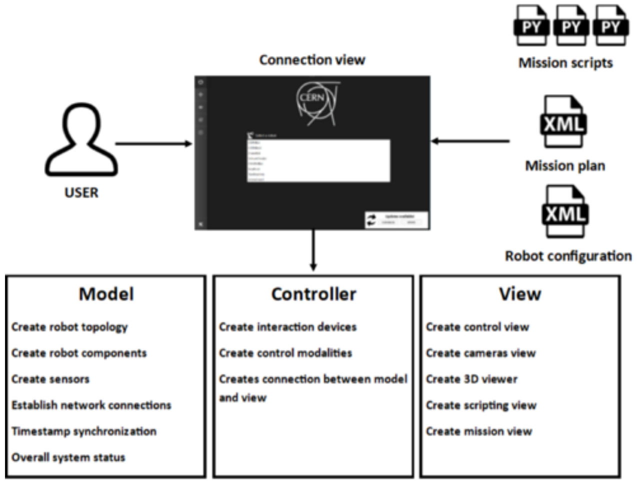
LHC Collimators



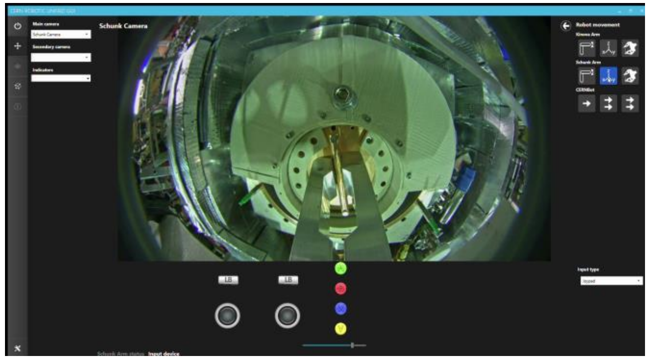
Close view of the LHC Collimators position switches

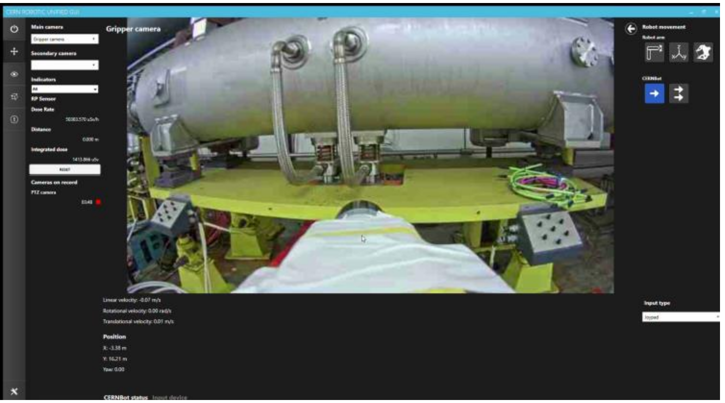


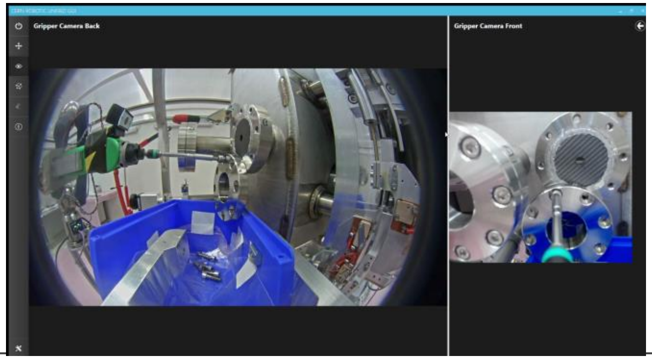
Human-Robot-Interface

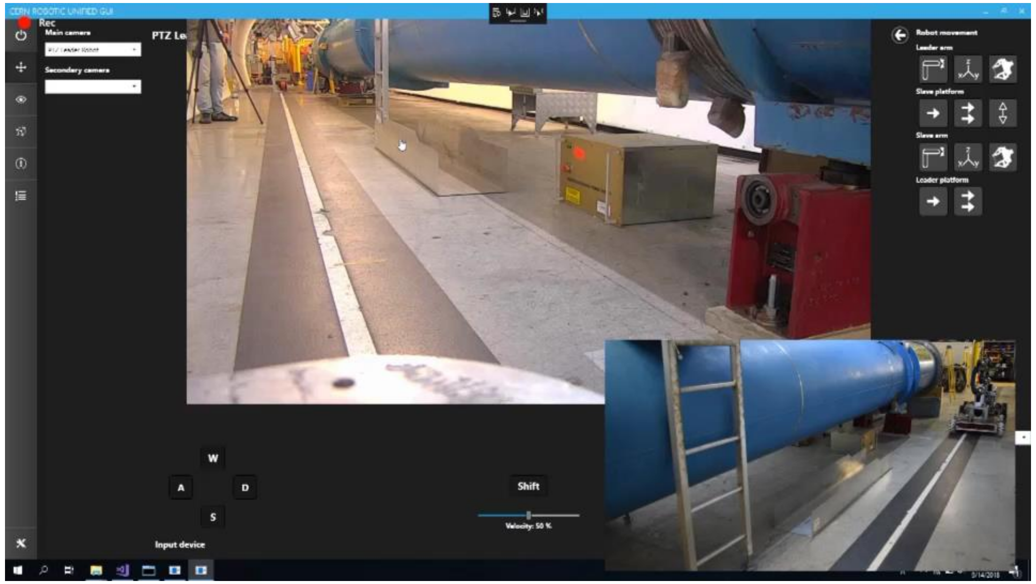


- ➢Controls all the BE-CEM robots
- ➢Includes enhanced reality modules
- ➢Different inputs device (keyboards, joystick, master arm etc.)
- ➢Operators training options
- ➢Multi screens capability
- ➢Time-delay passivation

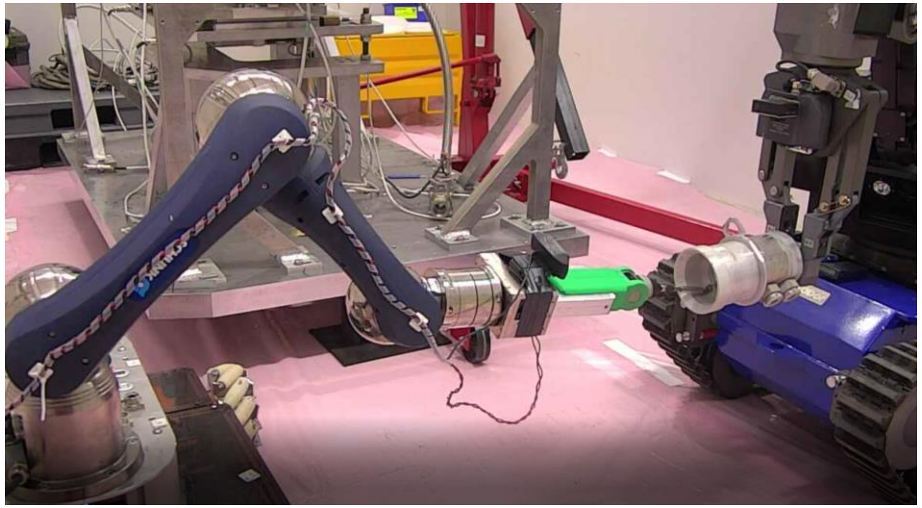


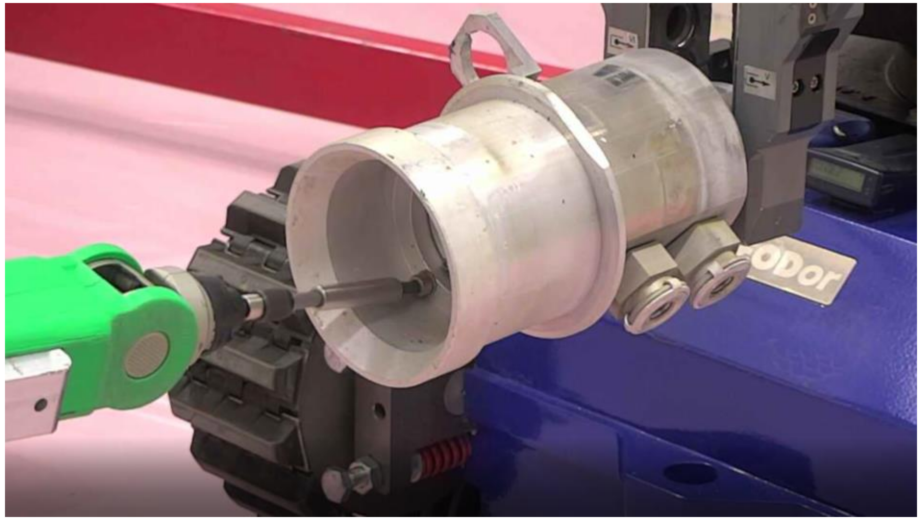




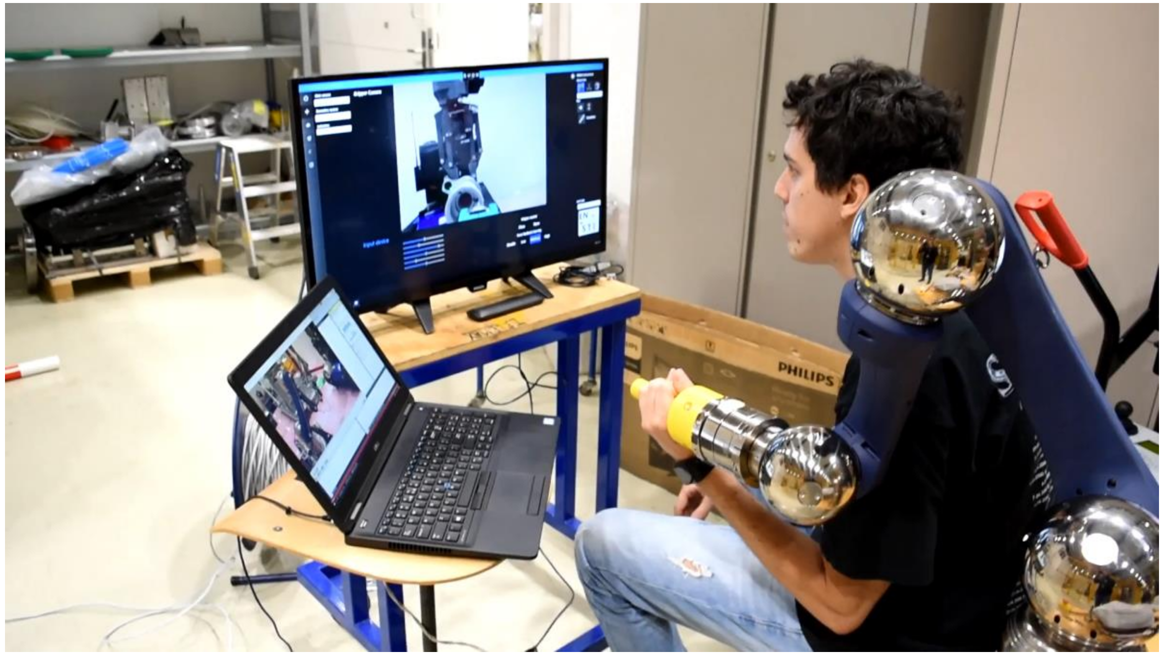


Operator Interface Performance



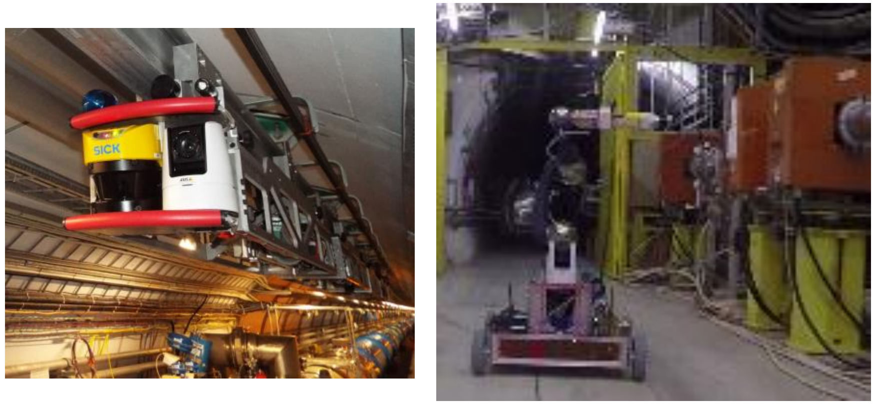


- Manipulation of radioactive targets
  - ✓ CERNTAURO intervention preparation, procedure, tooling and recovery scenarios
  - ✓ Force-feedback based bilateral control



Robotic preventive maintenance and inspection

SPS MKP oilers refill

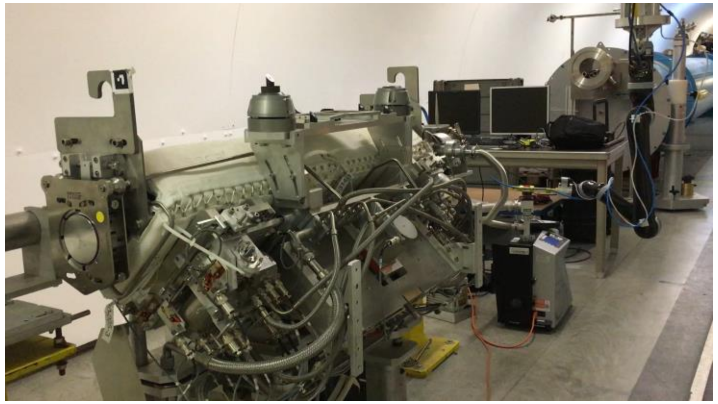


Remote radioprotection surveys

Cabling status inspection

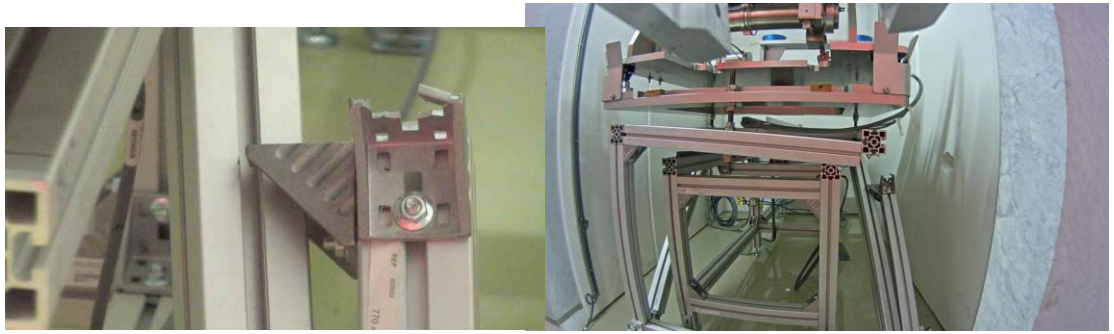
Temperature sensor installation on AD target

Tunnel structure monitoring



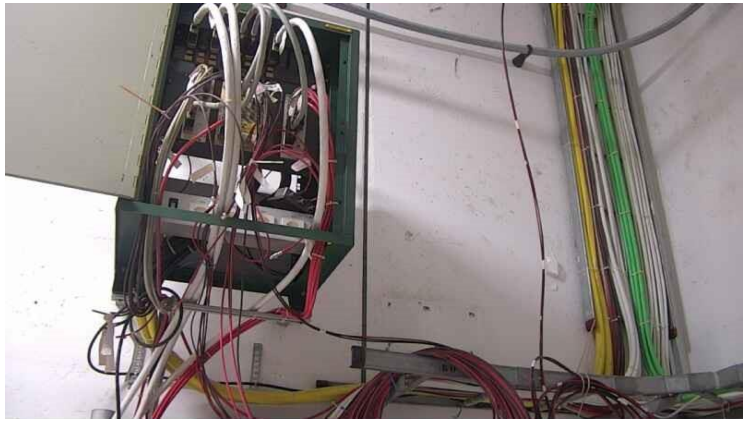
Remote Vacuum Leak detection

Fast reaction to equipment failures in radioactive areas

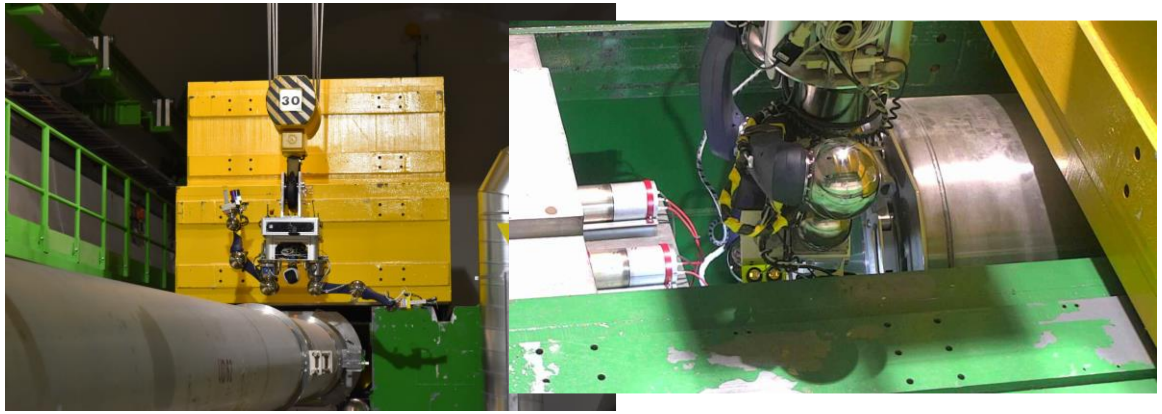


CHARM Target
In place 1 hour after the call

ISOLDE HRS Front-End
In place 2 hours after the call

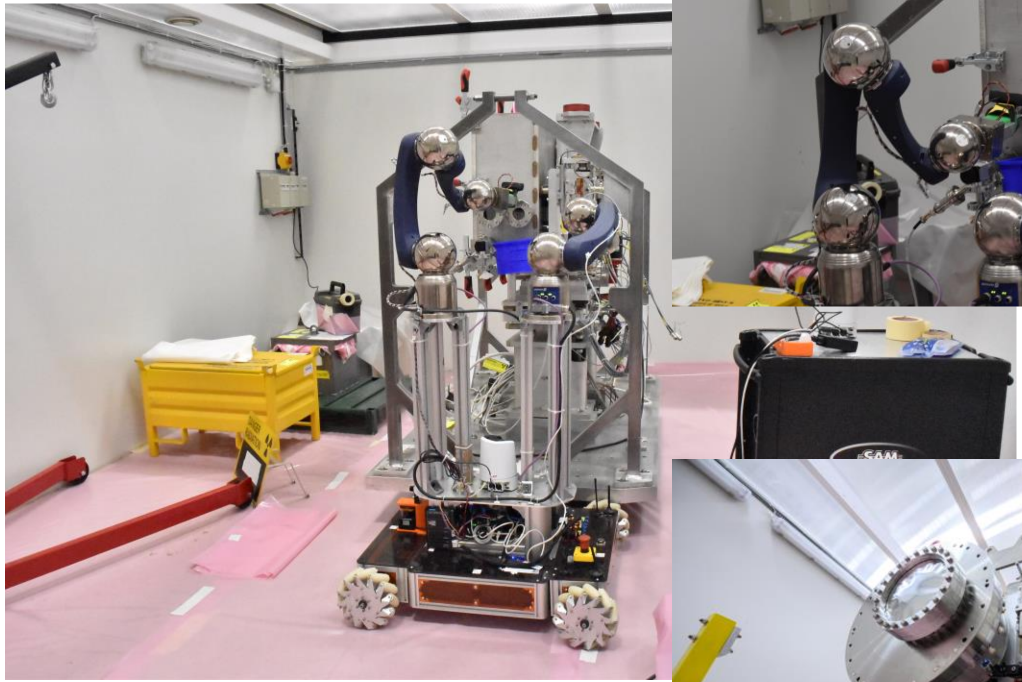


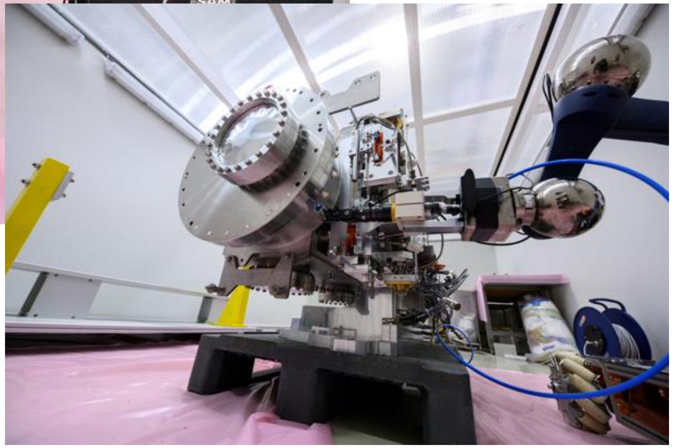
North Area BLM cables connection
In place 50 minutes after the call

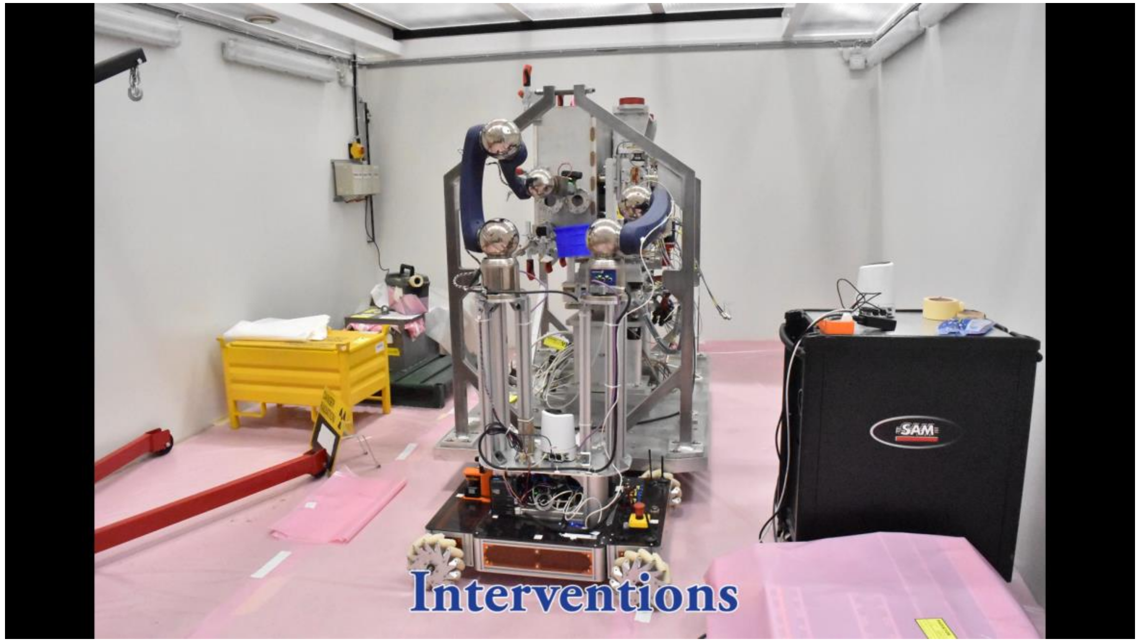


LHC TDE
New robot built in 3 days

Post-Mortem Analysis

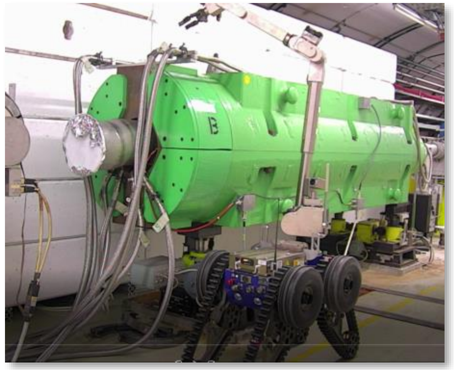
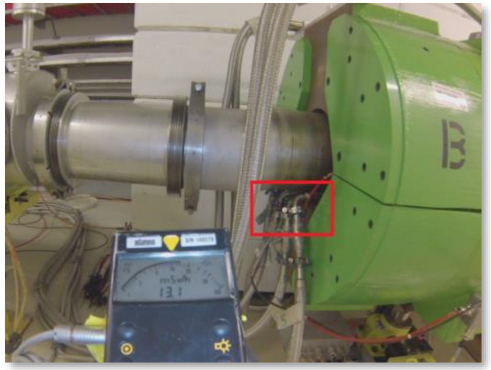




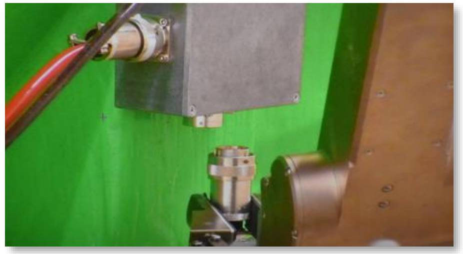


Importance of the design phase

- Designing machines that can be maintained by robots using appropriate and easily accessible interfaces will increase maintainability and decrease human exposure to hazards







Easier remote or hands-on manipulation than chain-type connection

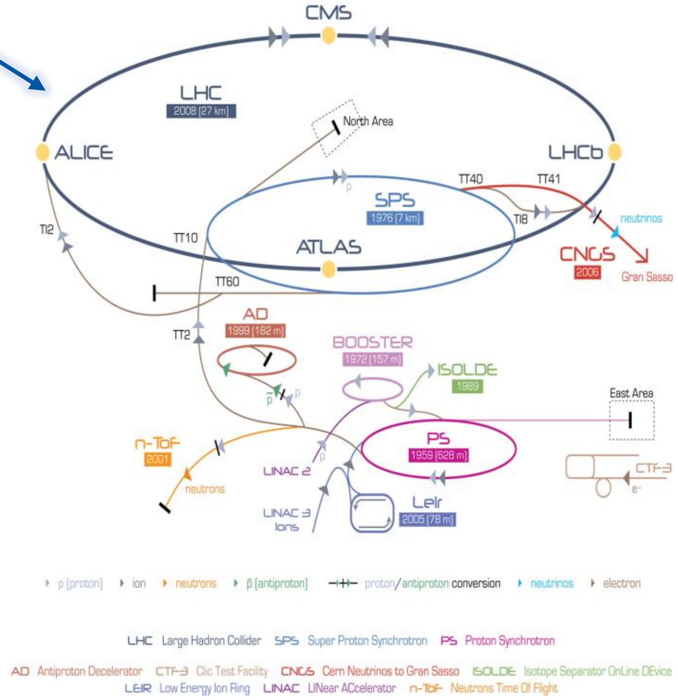
Procedures and Tools

- Several time consuming and costly tools, procedures and Mockups done for intervention on non-robotic friendly interfaces during the last years (several done also in emergency situations)
  - ✓ **Intervention procedures, recovery scenarios, tools and mock-ups are as important as the robot/device that does the remote intervention**
  - ✓ Standardization of interfaces → standardized tools and procedures, reduce costs and intervention time

More on L. Buonocore lecture

Main Robots integrated/controlled within facilities at CERN

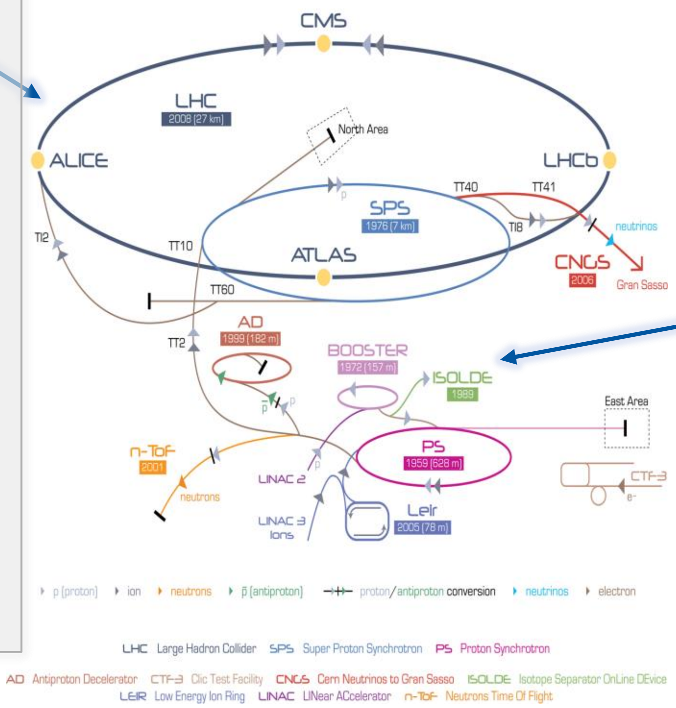
Train Inspection Monorail

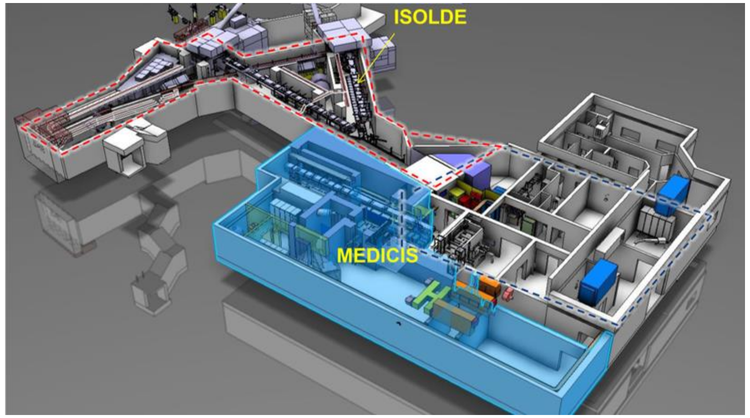


Main Robots integrated/controlled within facilities at CERN

Main Robots integrated/controlled within facilities at CERN

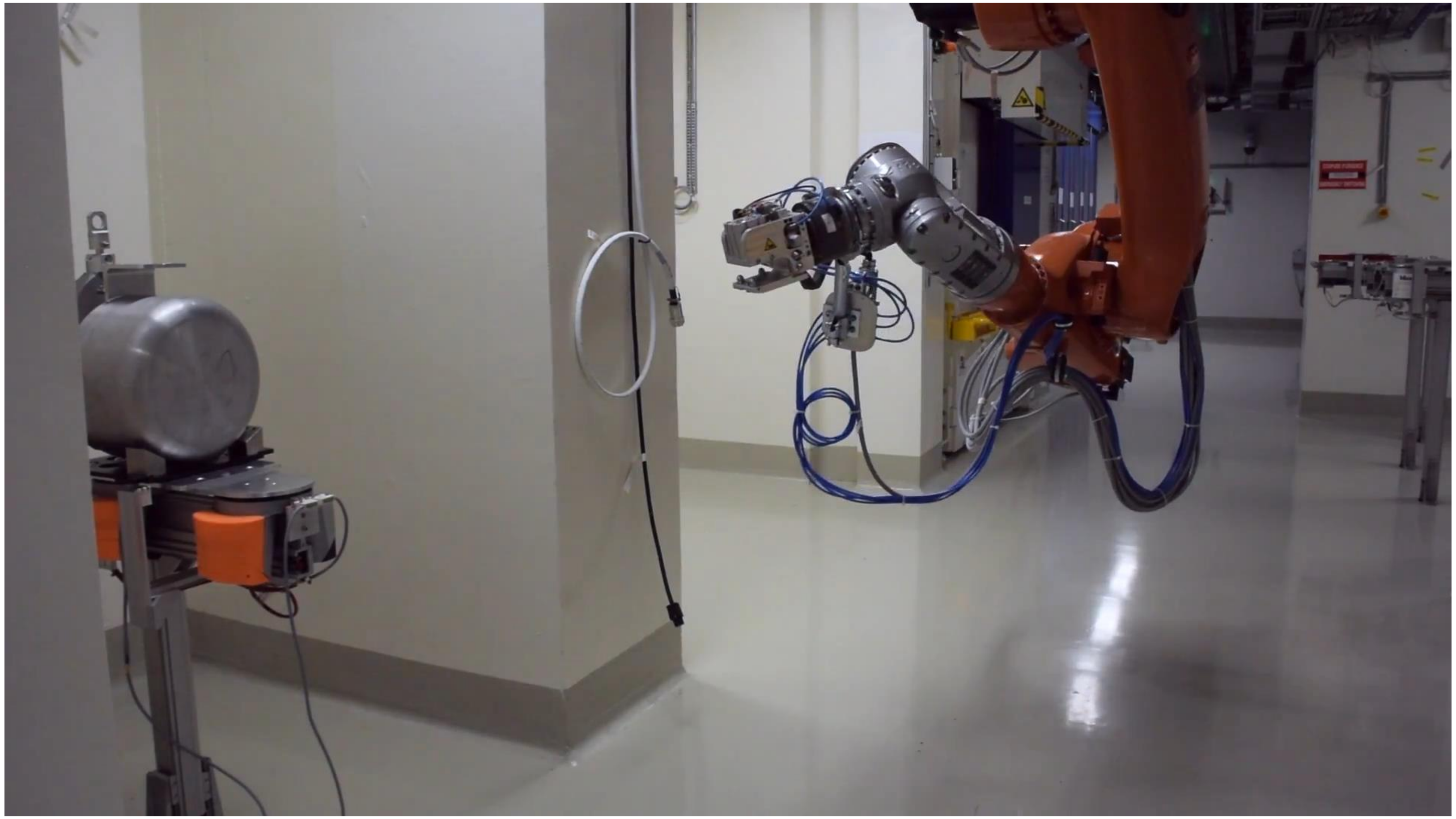
Train Inspection Monorail



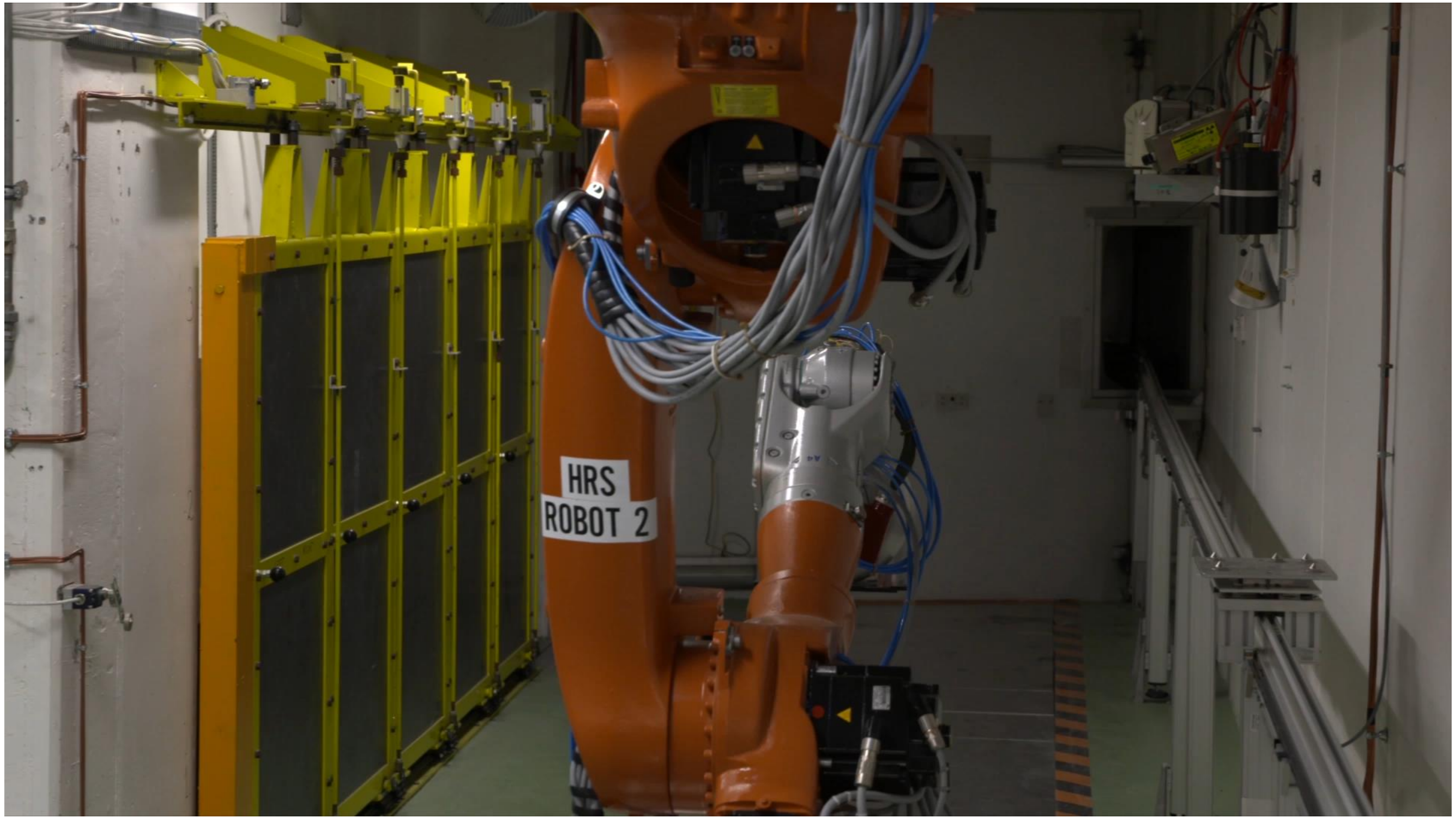


ISOLDE / MEDICIS Robots

Main Robots integrated/controlled within facilities at CERN

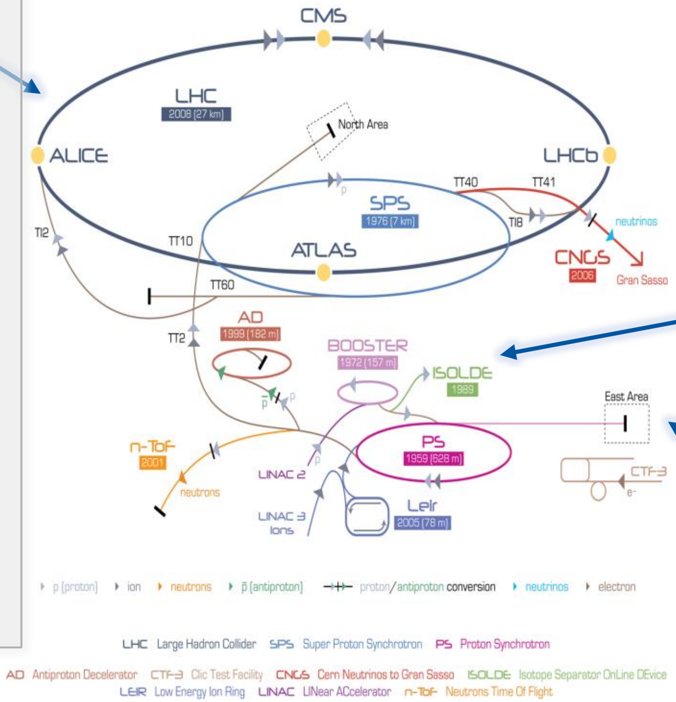


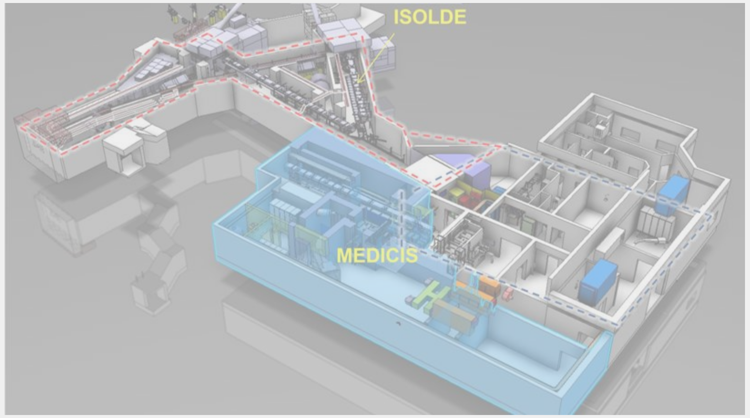
Main Robots integrated/controlled within facilities at CERN



Main Robots integrated/controlled within facilities at CERN

Train Inspection Monorail





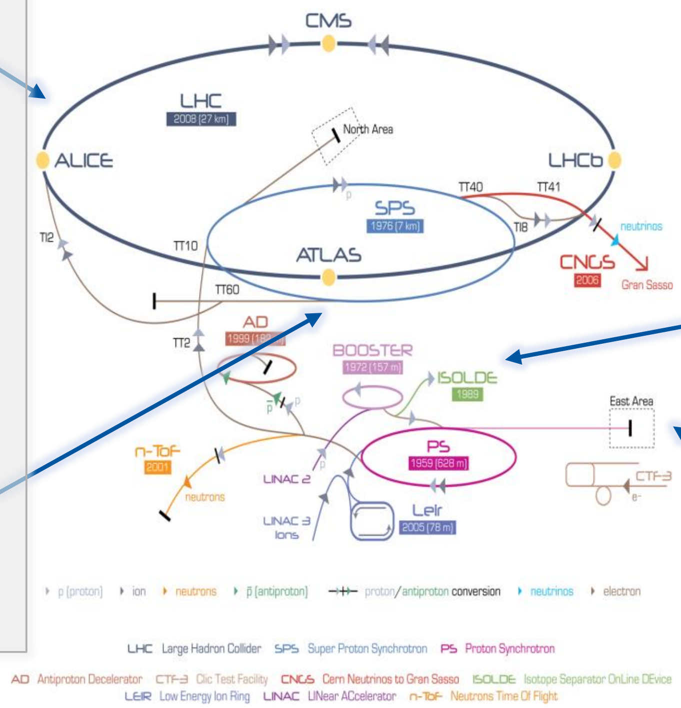
ISOLDE / MEDICIS Robots

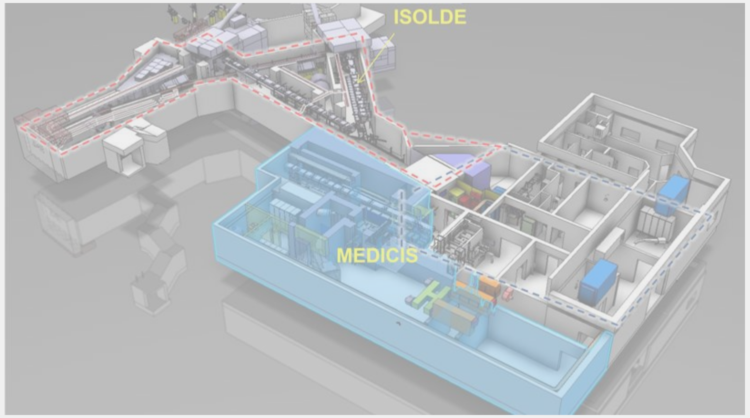
CHARMbot

Main Robots integrated/controlled within facilities at CERN

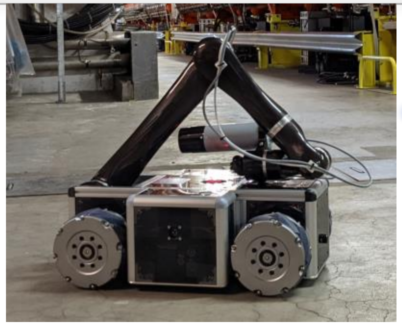
Main Robots integrated/controlled within facilities at CERN

Train Inspection Monorail

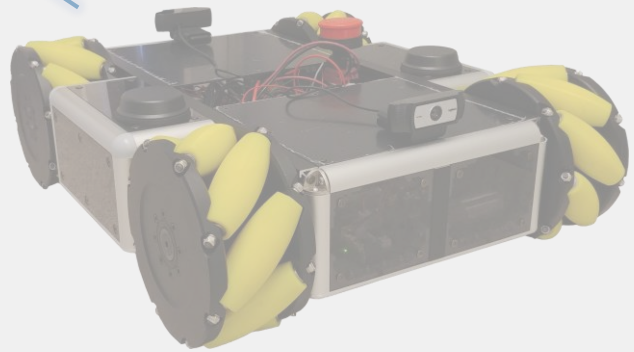




ISOLDE / MEDICIS Robots



SPS robot

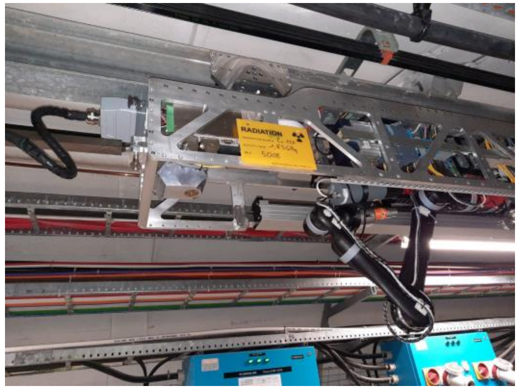


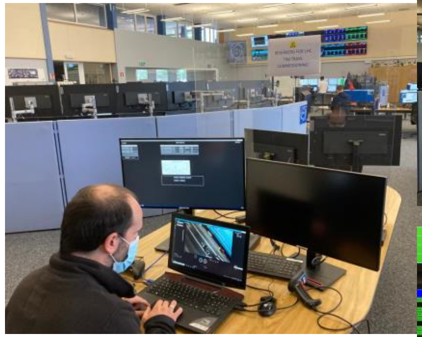
CHARMbot

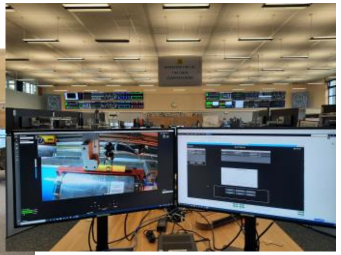
Main Robots integrated/controlled within facilities at CERN

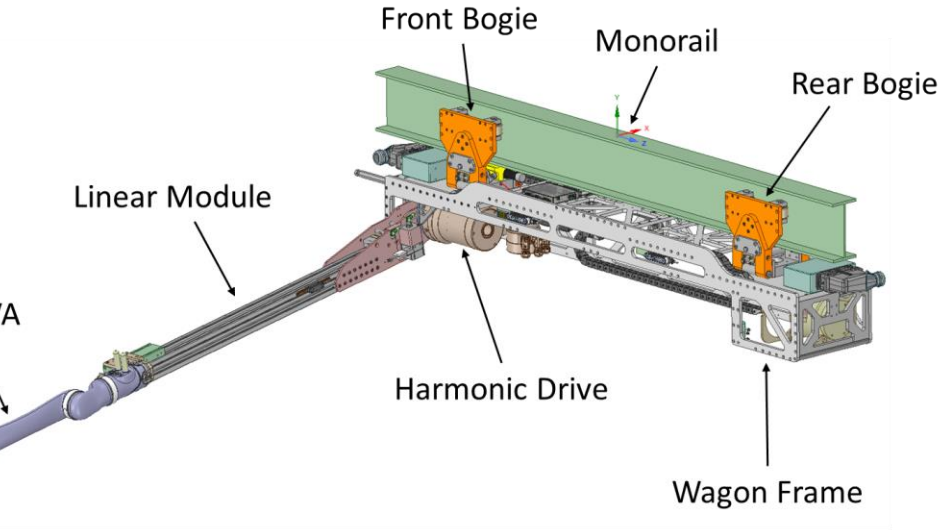
Novel TIM robotic wagon

- 6 DoF (rotational axis) + 1DoF (linear axis) for dexterity
- 2 DoF (harmonic drive, backlash-free) for transversal positioning
- 1 stabilization axis
- 5 cameras

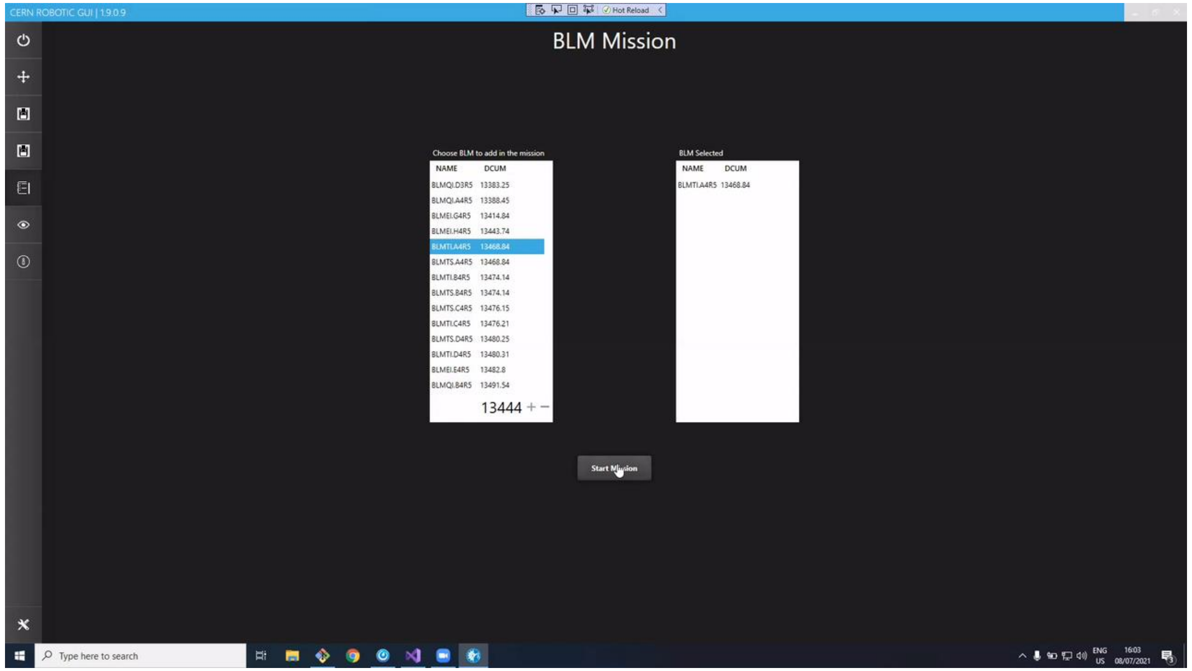




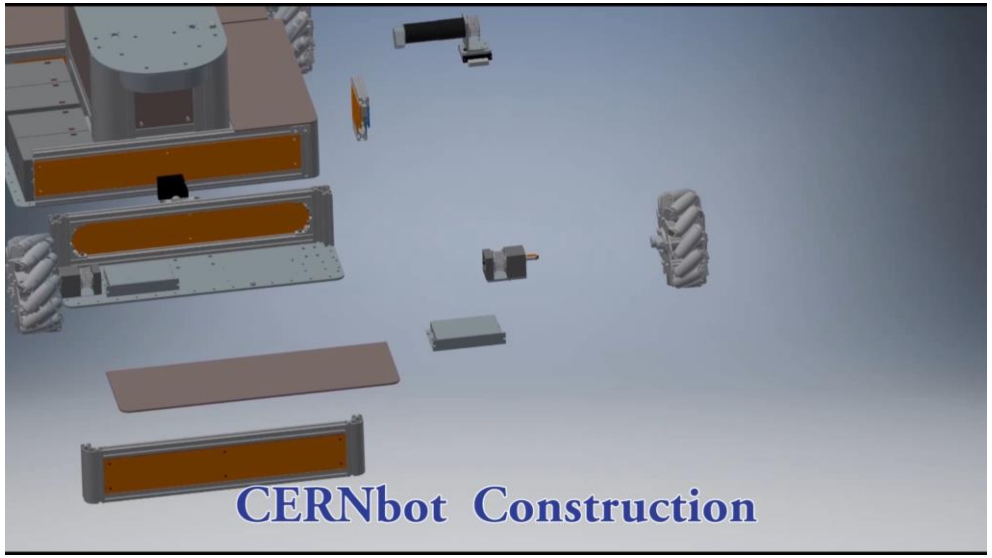


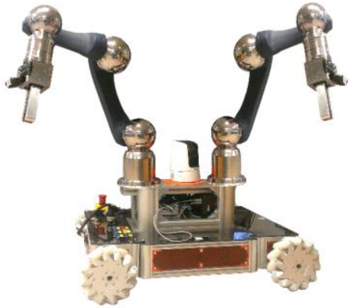


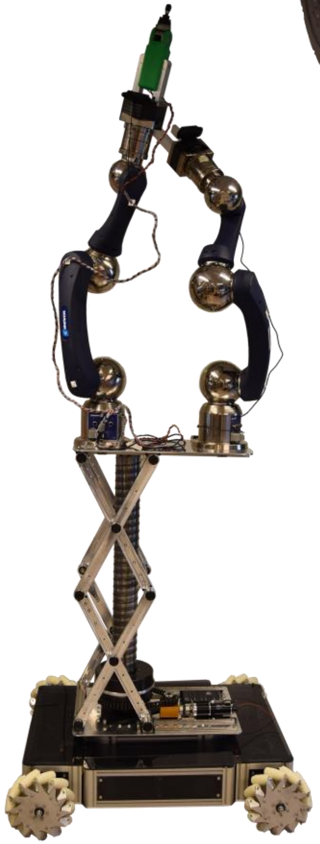
New TIM robotic wagon with extracted arm

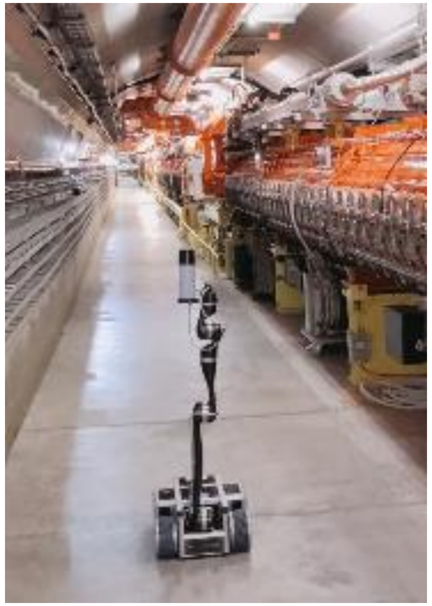


Modular Robot/Concept (CERNbot)





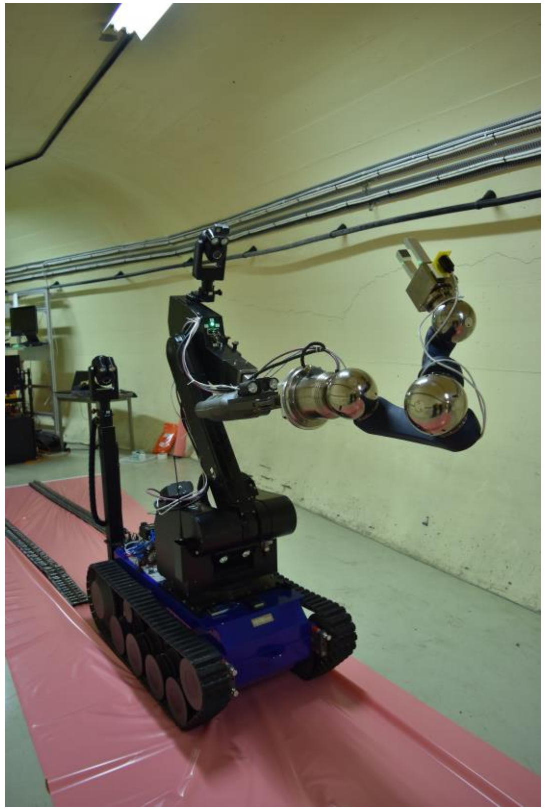


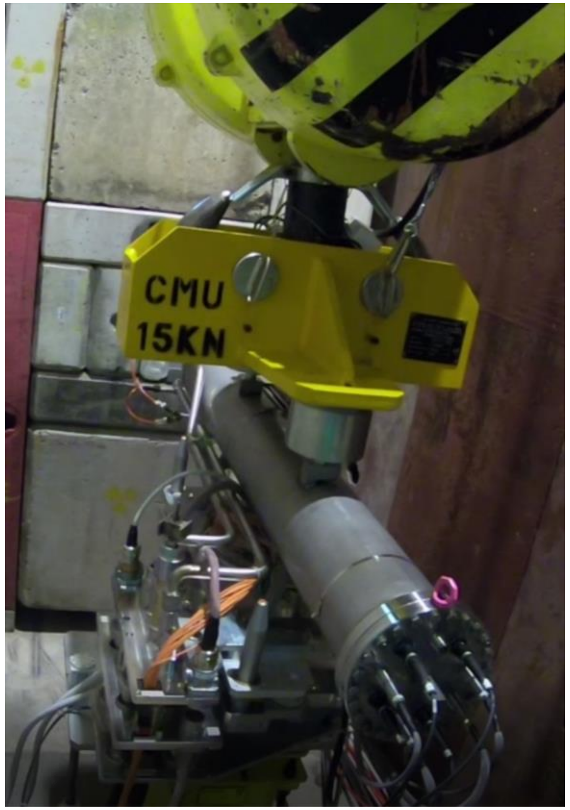


CERNbot, CERNbot2, CHARMbot, MIRA, CRANEbot

Modular Controls

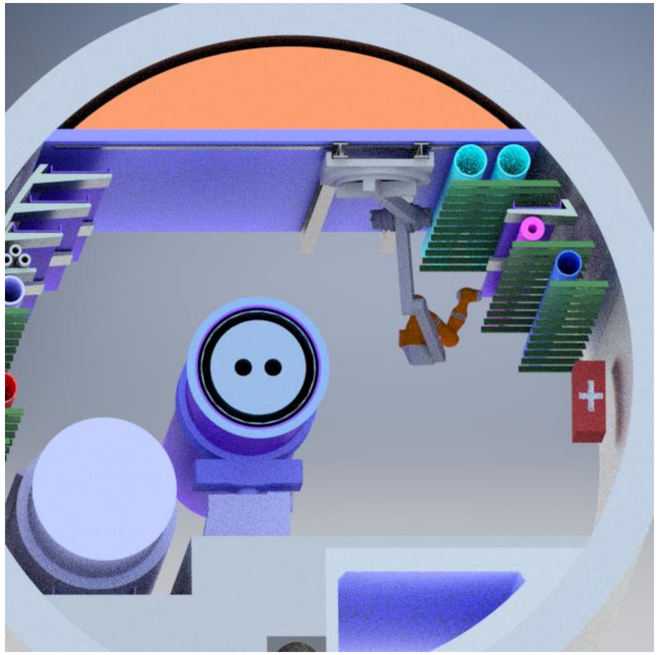
- Particle beam target maintenance, **integration of CERNTAURO on industrial robot**
  - ✓ **CERNTAURO adaptability → seamless control of multi-robots**
  - ✓ Manipulation from unstable support

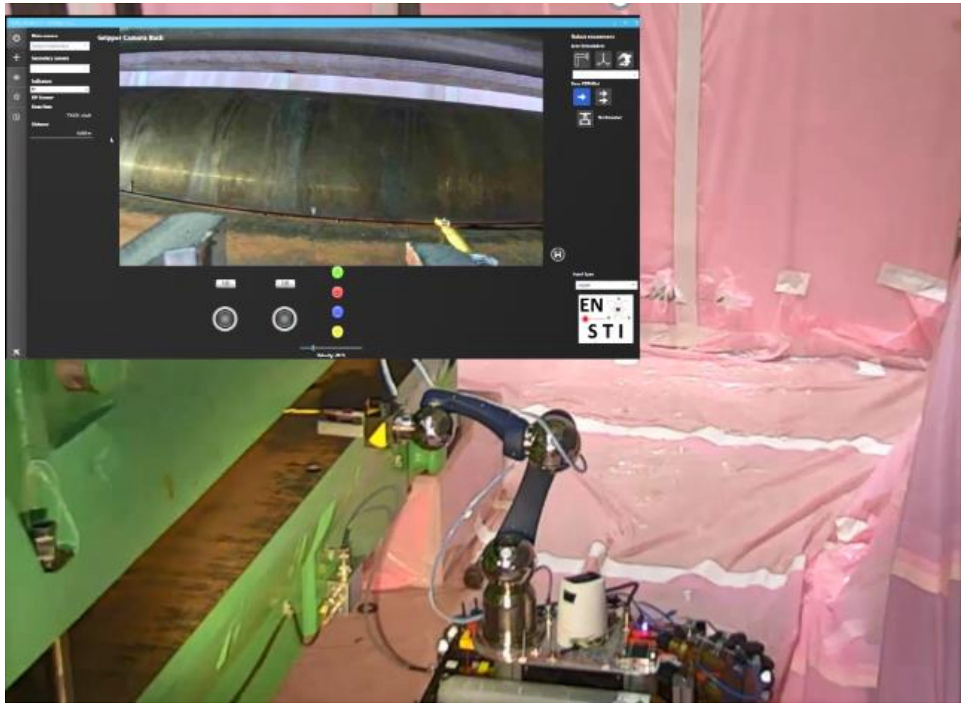




Some Considerations

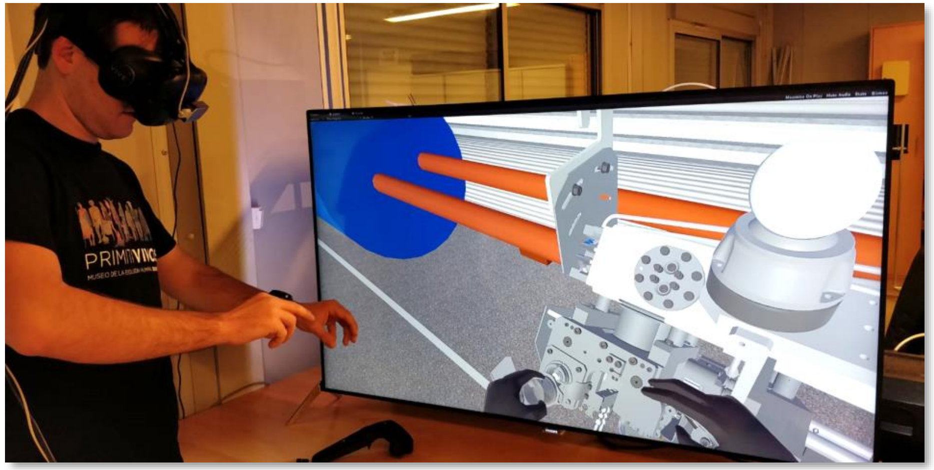
- Ideally Robots or any remote maintenance device should be “part” of the machine
- Preventive maintenance with regular inspection tasks reduces the risk of unavailability
- Post-mortem analysis and understandings of failure help in increasing future machine robustness

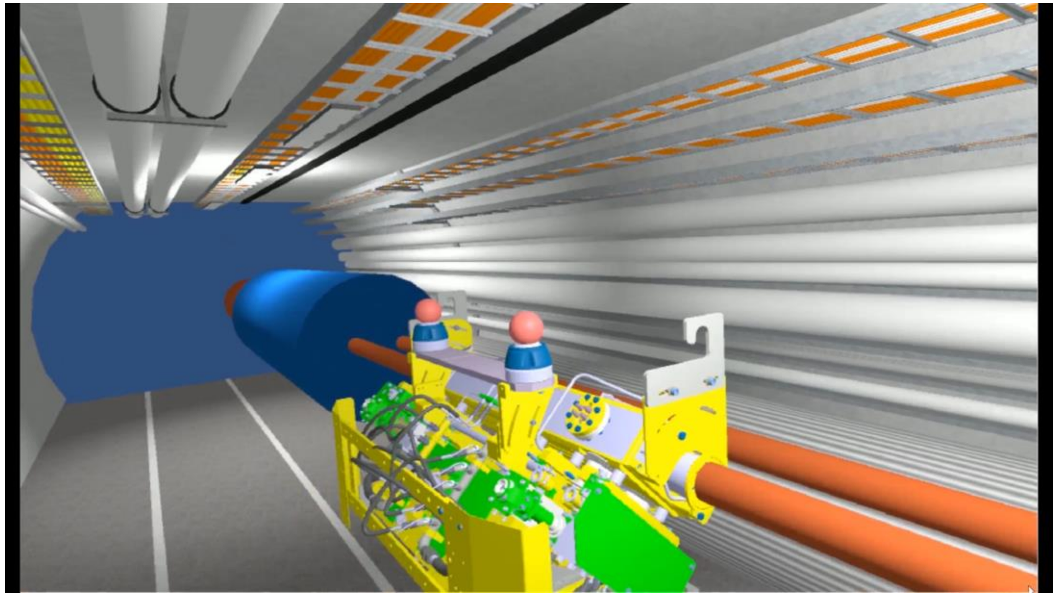




Current use of Enhanced Reality in BE-CEM- Digital Twins

- Simulation of robotic interventions
  - ✓ Integration of robots in the environment and choice of robots
  - ✓ Intervention procedures
  - ✓ Tools design and test
  - ✓ Machines risk assessment
  - ✓ Robots training by demonstration
  - ✓ Operators training and teleoperations
  - ✓ Risk analysis
  - ✓ Recovery procedures
- Simulation of human intervention
  - ✓ Human intervention procedures
  - ✓ Live radiation levels and cumulated dose while training in VR (Augmented reality in virtual reality)
  - ✓ Intervention training
  - ✓ Risk analysis
  - ✓ Feedbacks for future remote-handling-friendly machines



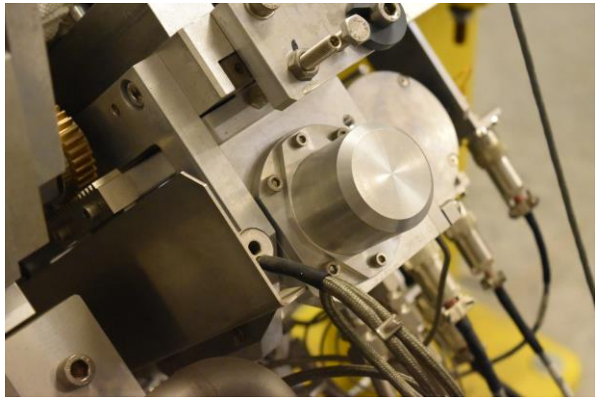


More on K. Szczurek lecture

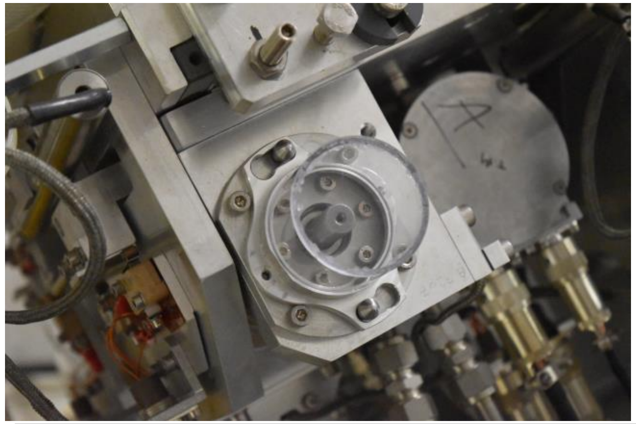
Steering New Machines Design

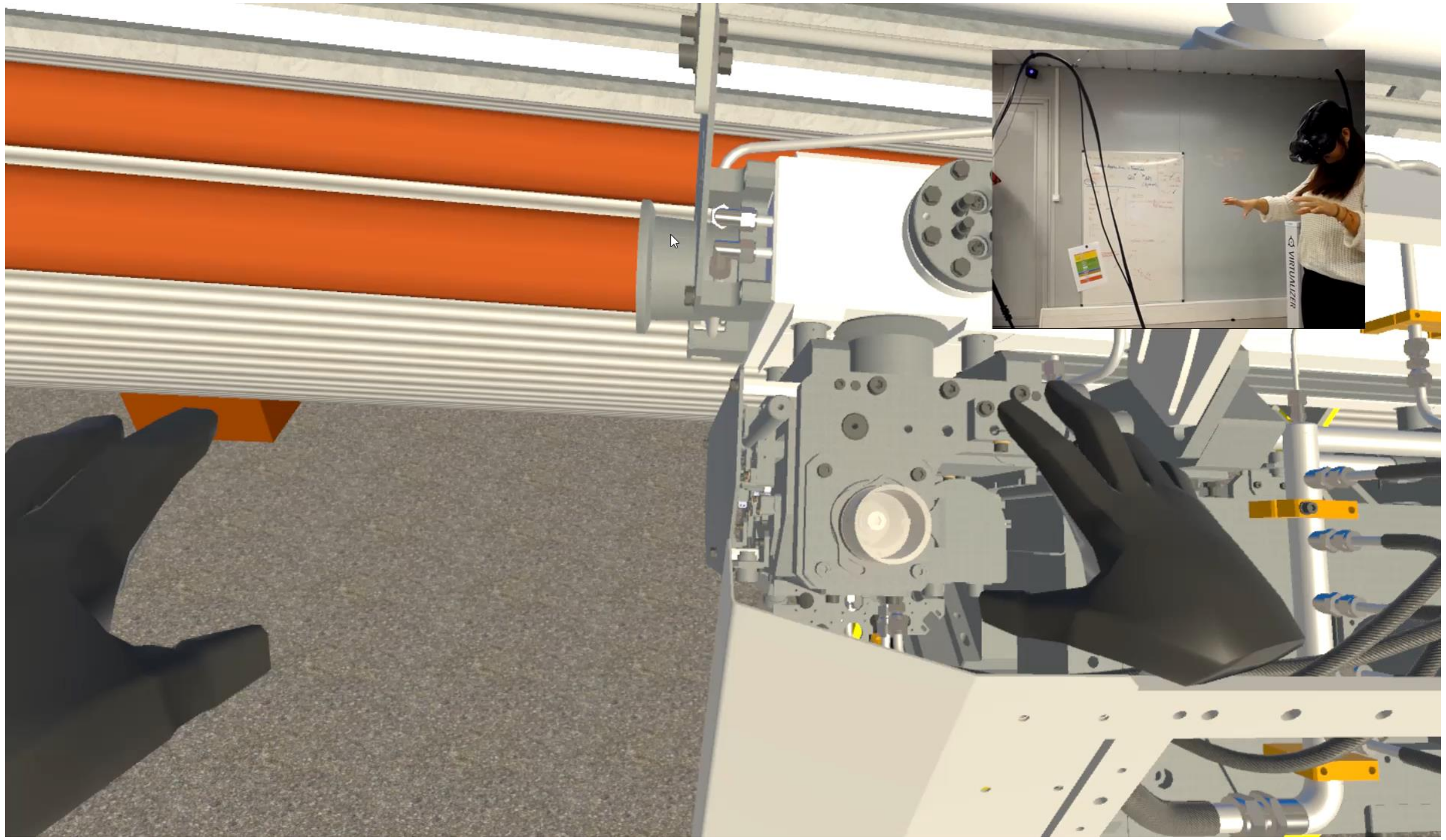
- For example, design of the new LHC Collimators motor screw cap
  - ✓ Simulation in VR to check hands on handling and "robot friendliness"

Current solution



New solution



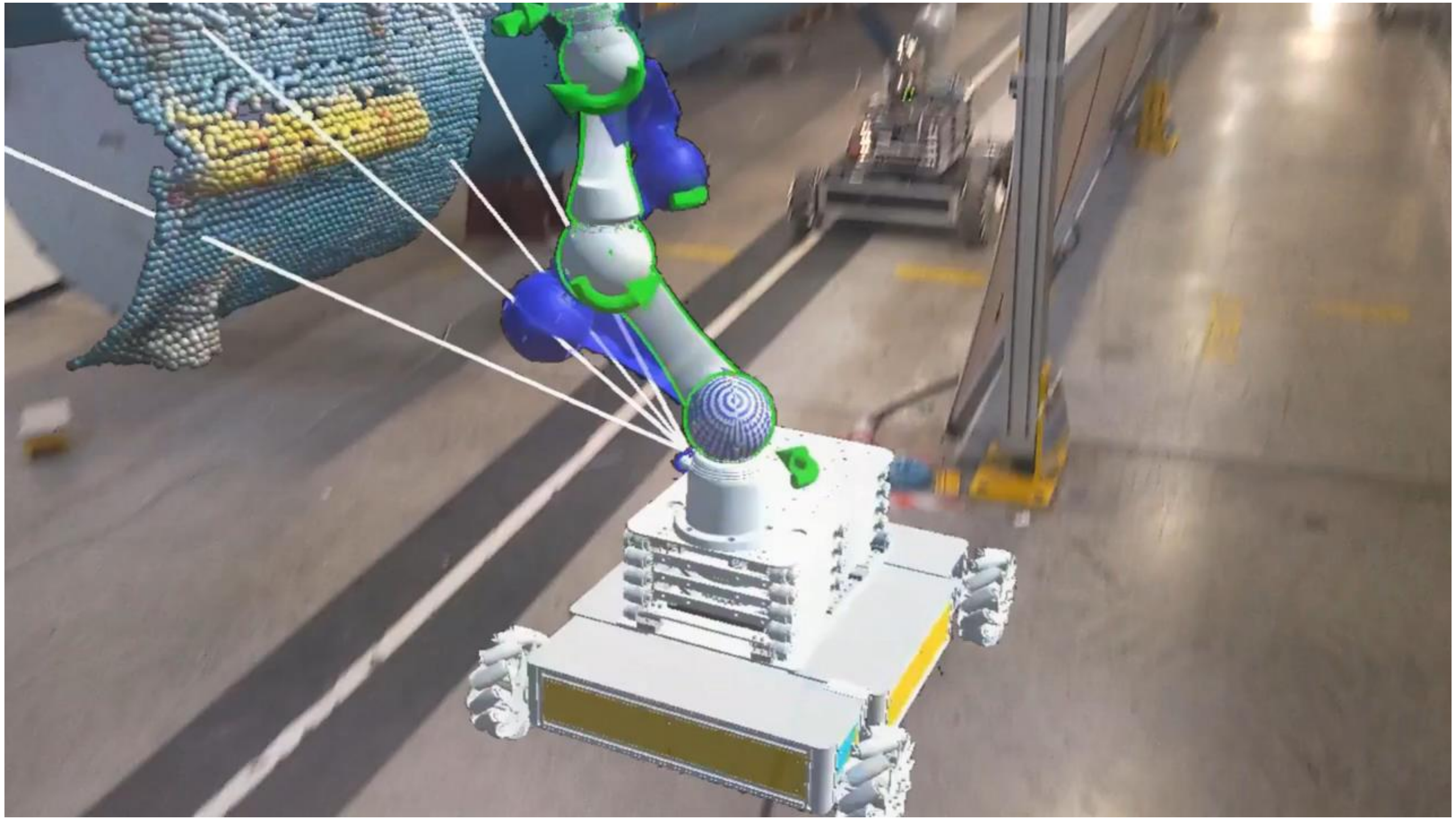


Mixed Reality Human-Robot Interface

- **Tunnel tests showed promising results for autonomous operations.**
  - ✓ Objects detection using ML.
  - ✓ Live environment reconstruction for obstacle avoidance using enhanced reality.
  - ✓ Trajectory planning.
  - ✓ Preview of motions to check for collisions.

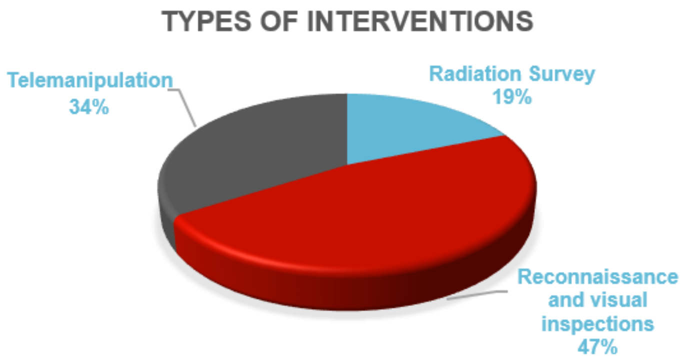
Mixed Reality Human-Robot Interface

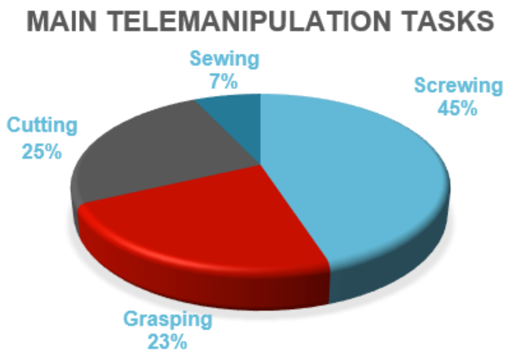
- Mixed reality will help to generate supervised autonomy



Robotics Interventions

Nr. of Interventions since 2014	Nr. of tasks performed	Robot operation time in harsh environment [h]
150	~500	~ 500



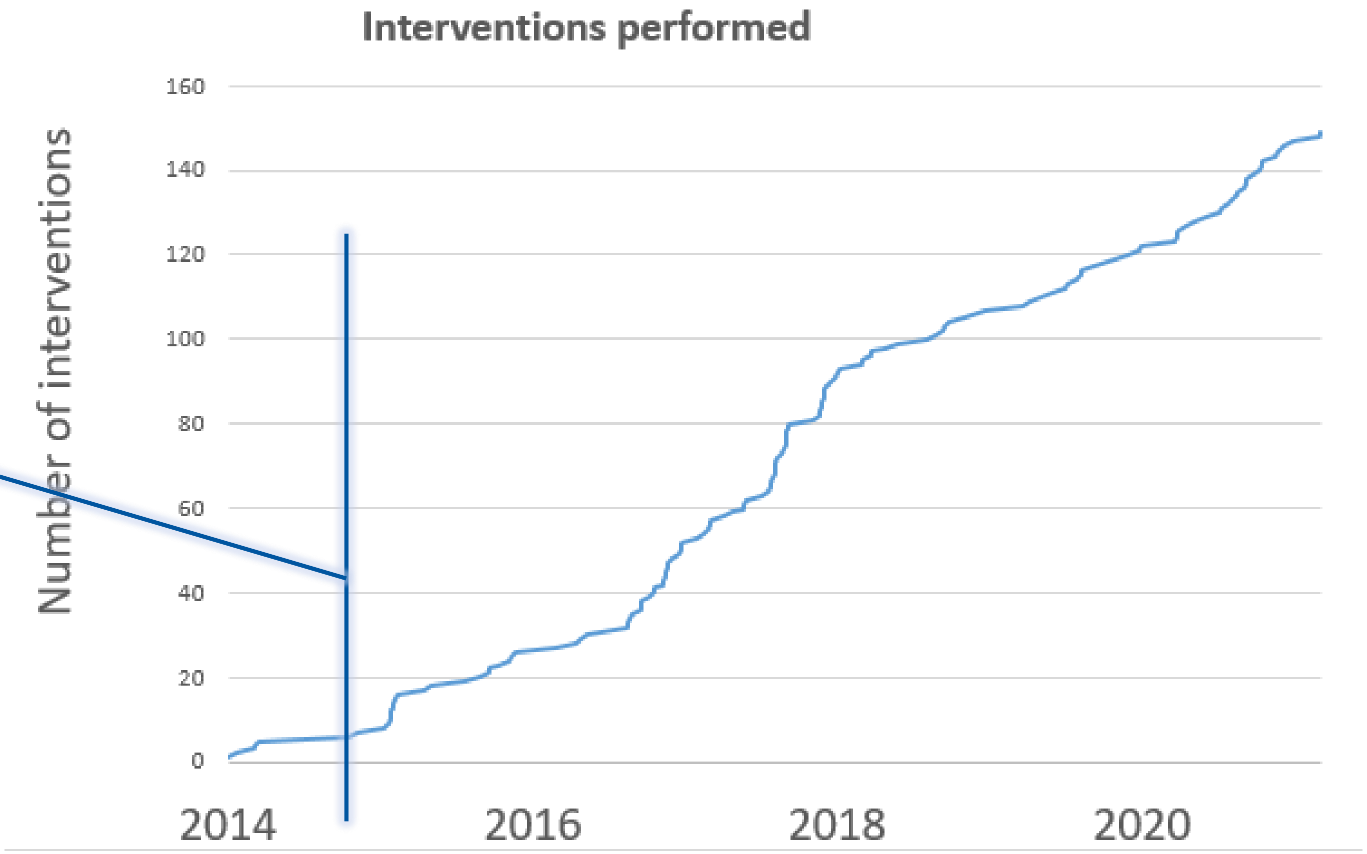


Remote maintenance test facility (b927)

Continuing developing best practice for equipment design and robotic intervention procedures and tools including recovery scenarios

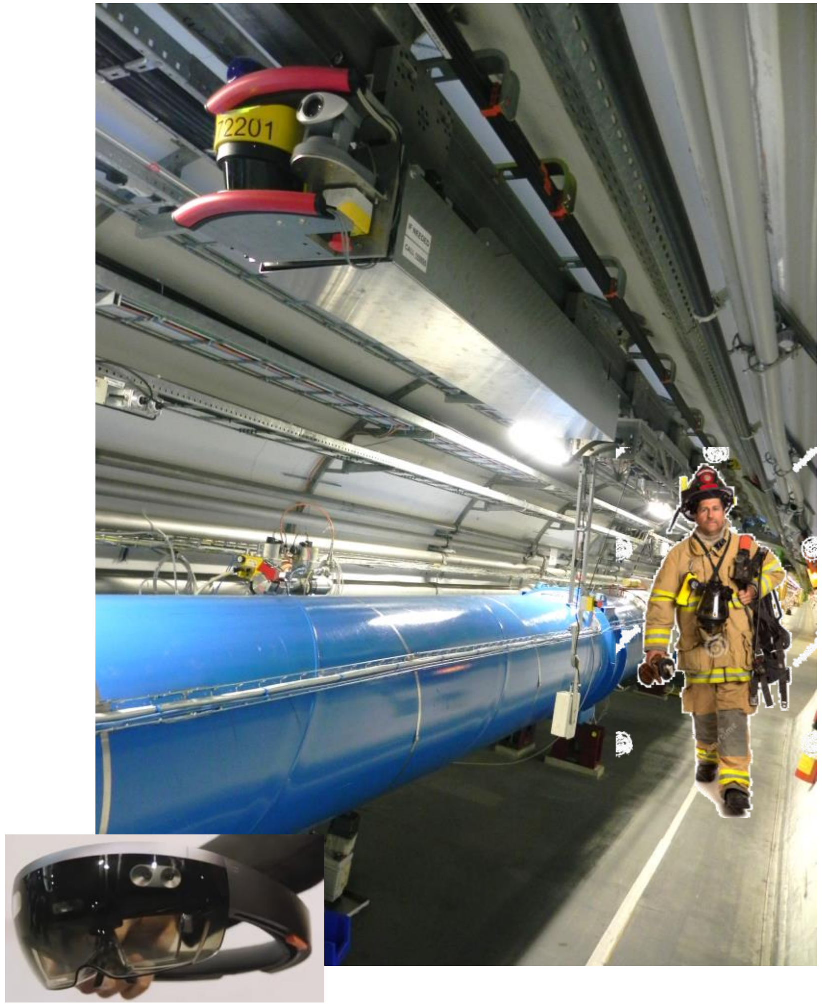
Robotic Support at CERN

Started to apply CERN custom made robotic solutions. Remote maintenance capabilities and modularity strongly increased!



Early intervention robots

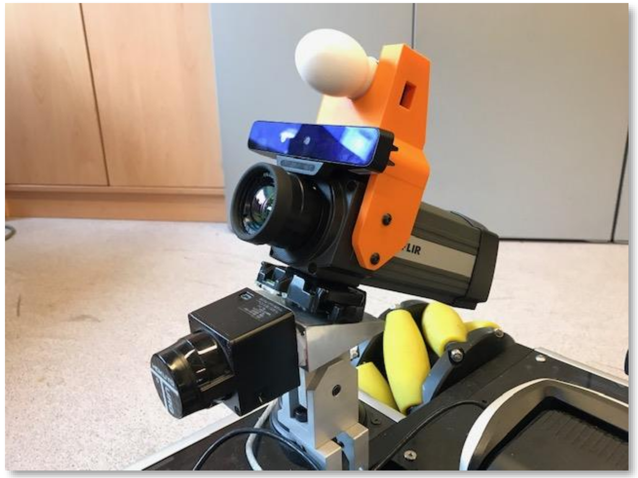
- **With such large distances, early intervention systems are necessary for example in case of accident or fire**
  - ✓ **Human fire response** (Fire Service) in accelerator facilities is judged **fundamental but not enough** due to response delay, personal risk assessment and reliability.
    - ❖ **Robotic** firefighting allows fire **inspection**, **victim** search and initial fire **suppression**.
    - ❖ **Robotic** firefighting could guide fire service giving environmental information
      - ❑ Augmented reality wearable systems
    - ❖ **Human** firefighting remains necessary for **rescue** operations and **final extinguishing.**



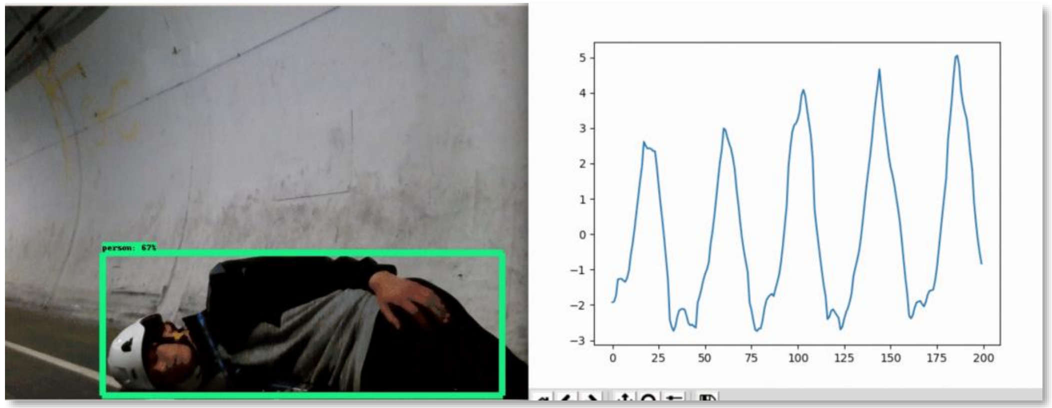
Collaboration with HSE-FRS

People recognition and vital monitoring

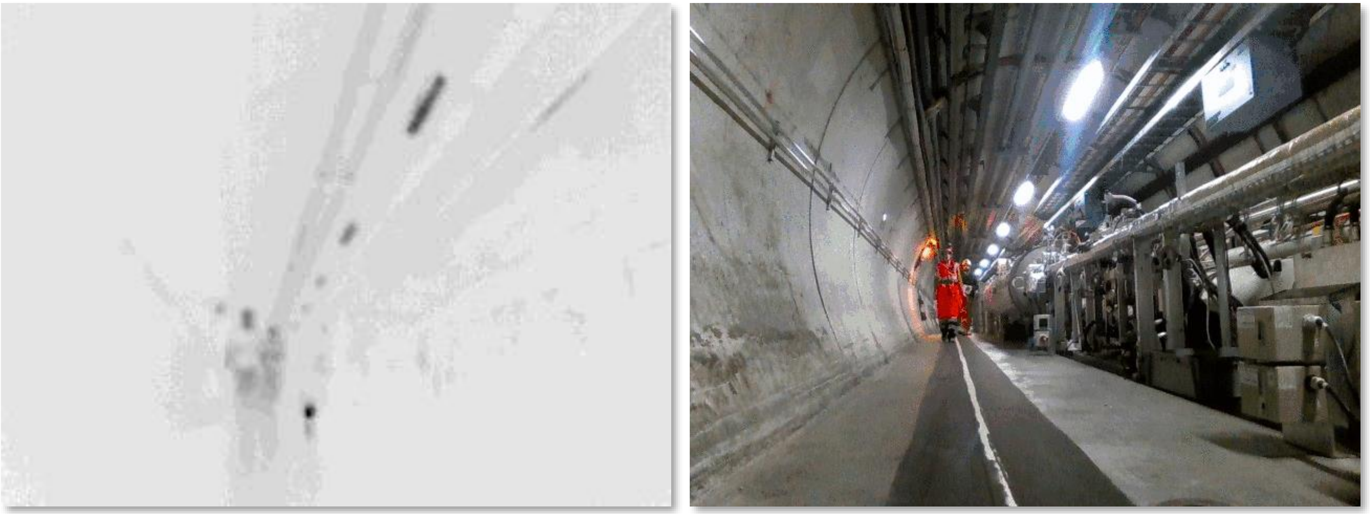
- Machine learning techniques enhance people detection and vital signals monitoring at distance
- People search and rescue is of primary interest in disaster scenarios
- People monitoring during rehabilitation



Vision system (2D Laser, radar, thermal and 2D-3D camera)

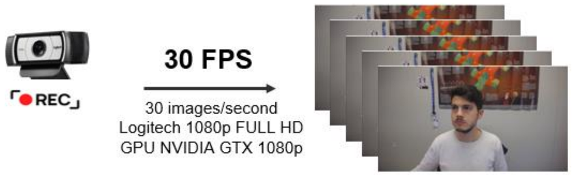


Online respiration monitoring

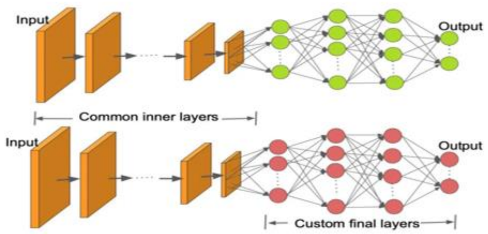


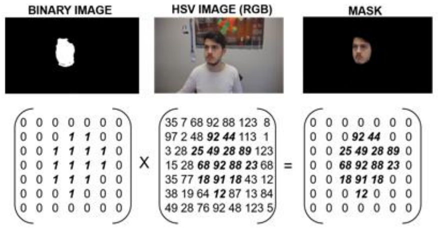
Online people recognition and tracking

MARCHESE project: Health Contactless Monitoring



Neural Network





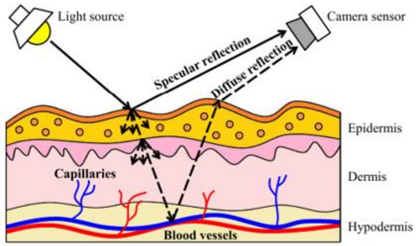
SKIN PIXELS
NO-SKIN PIXELS

$$\boxed{C_k(t) = I(t) \cdot [v_s(t) + v_d(t)] + v_n(t)}$$

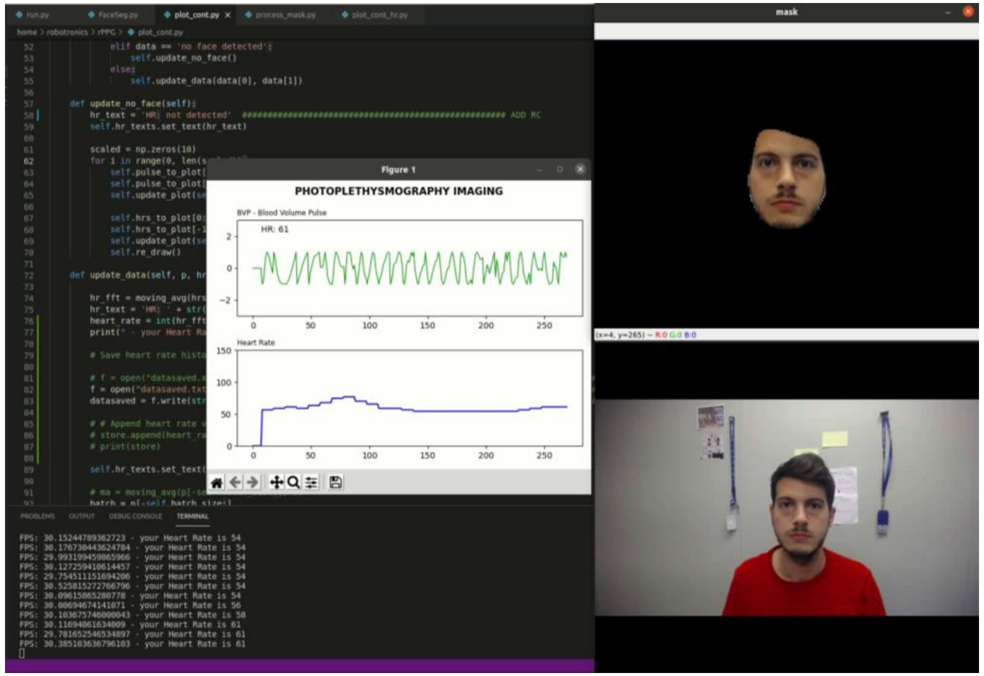
Reflection of each skin pixel in an image sequence in RGB channels

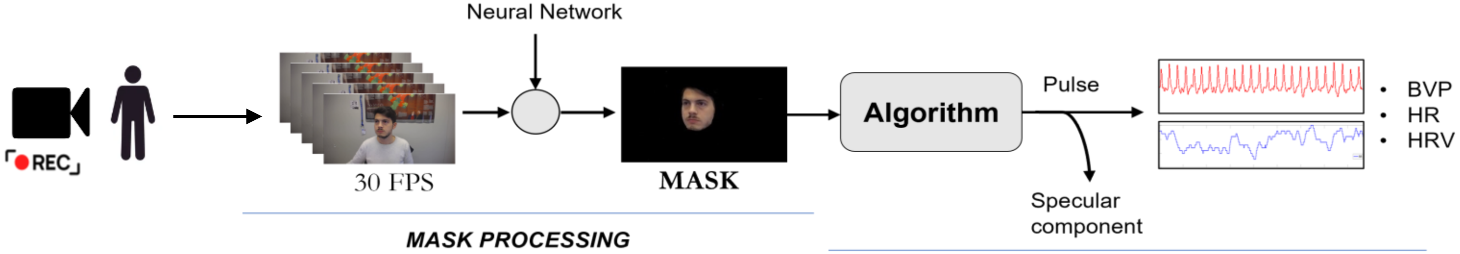
SPECULAR REFLECTION is a mirror-like light reflection from the skin surface (not contain any pulsatile information). Time dependent: body motion influence.

DIFFUSE REFLECTION is associated with the absorption of the light in skin tissues. The hemoglobin contents in skin tissues lead to a specific chromaticity.



DICHROMATIC MODEL $\rightarrow C_k(t) \sim I_0(1 + i(t)) \cdot [\underbrace{\cancel{u_c \cdot c_0}}_{\text{Constant}} + \underbrace{\cancel{u_s \cdot s(t)}}_{\text{Specular}} + \underbrace{u_p \cdot p(t)}_{\text{Pulse}}]$





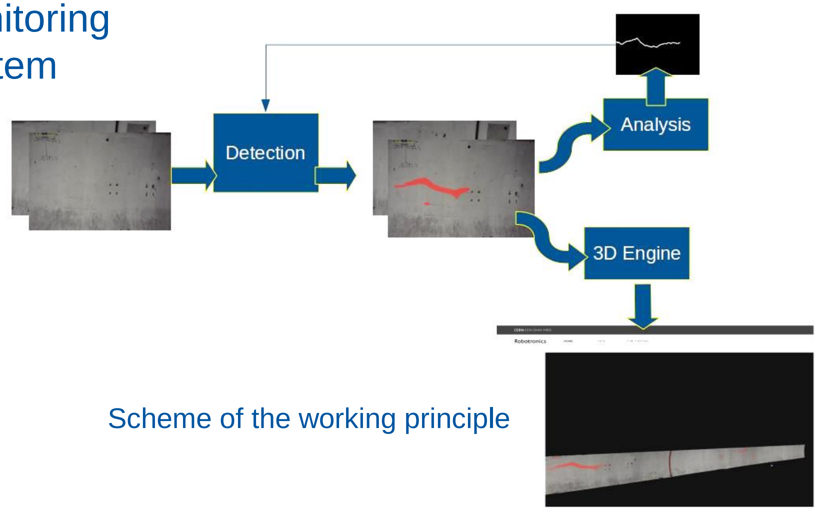
In collaboration and funded by KT group

Online Tunnel Structure Monitoring

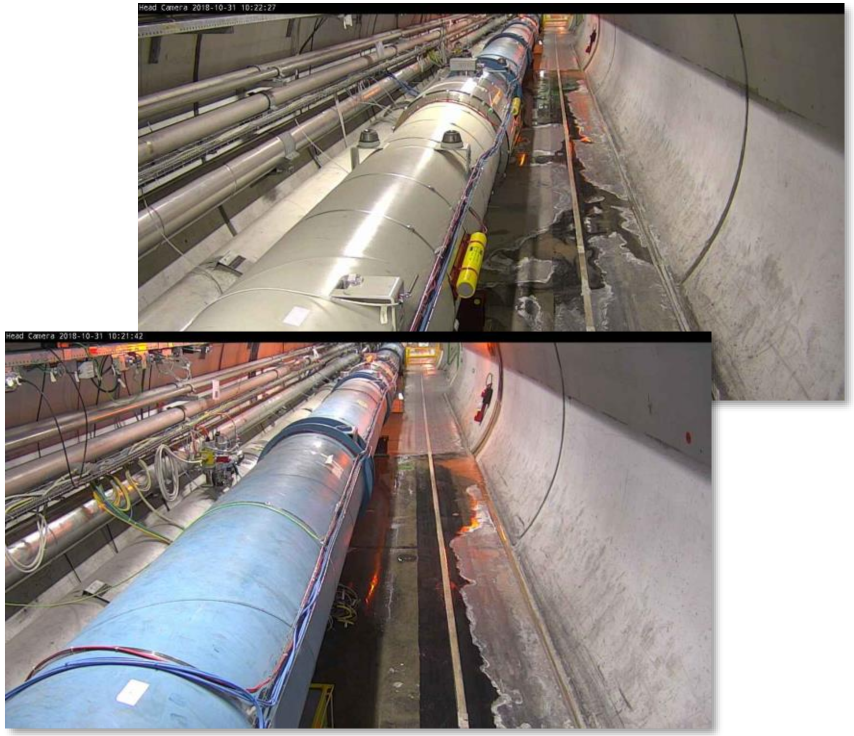
Collaboration with SCE-DOD

- Detects defects (cracks, water leaks, changes) using a Mask-RCNN network.
- High-definition picture collection using TIM and CERNBot
- 3D reconstruction of wall using Structure from Motion techniques to compare time evolution of defects (available on web browser or virtual reality headset)
- **HL-LHC condition survey of existing infrastructure carried out with TIM to monitor impact of new civil works**

Structural Health Monitoring System

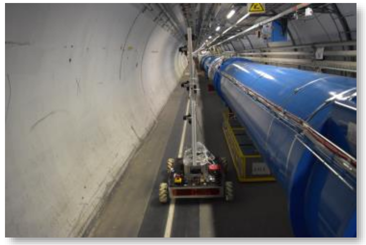


Scheme of the working principle

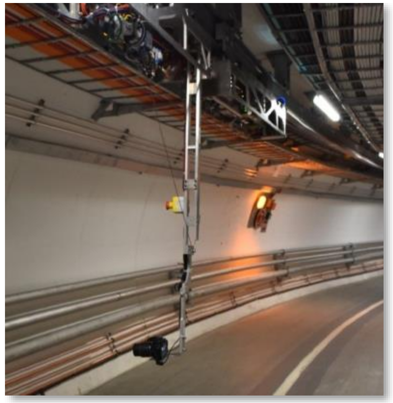


Example of water leak found by TIM2 during TS3 2018

HD camera system for tunnel dome view



System integrated also on other robots

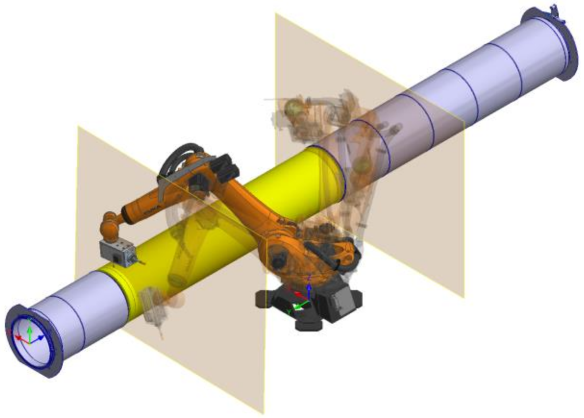


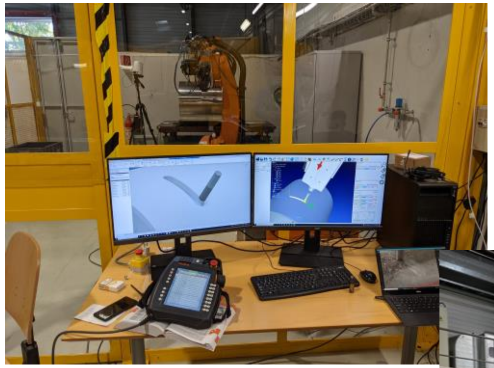
HD cameras mounted on TIM

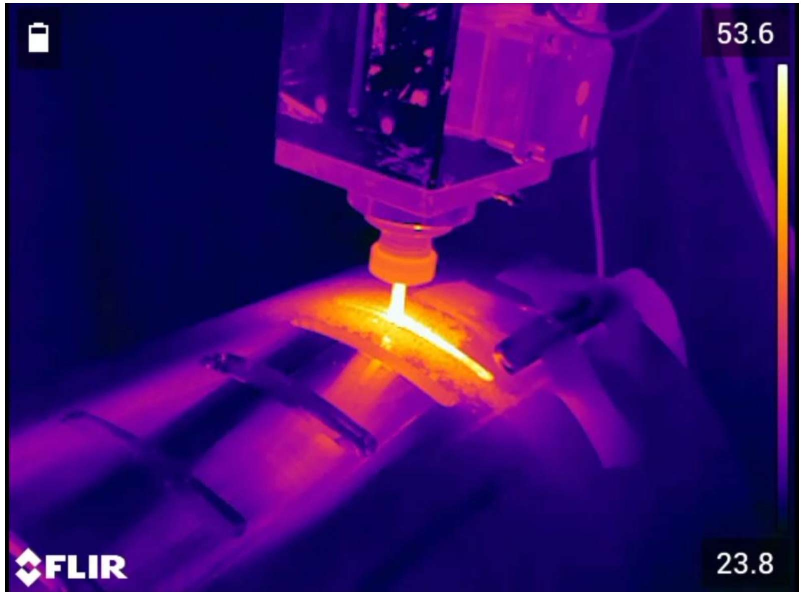
Example of crack found using vision based machine learning techniques

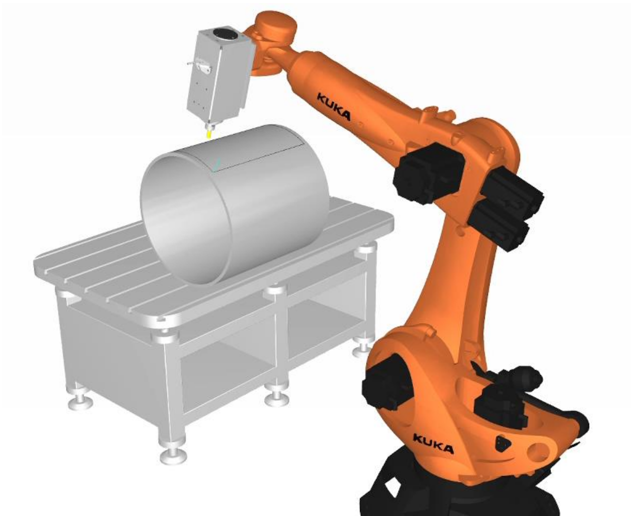
Robotics used for postmortem analysis

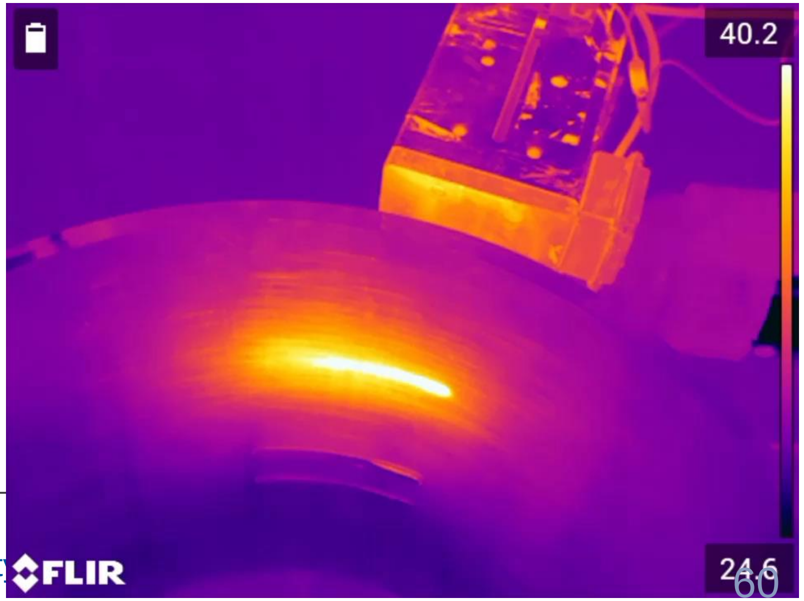
- Robotic milling to machine stainless steel, aluminum, iron etc.











Robot realized for Quality assurance: RF cavity visual inner inspection

- ✓ Automatic system
- ✓ 8-10h hours of scan per part
- ✓ ~19’000 photos per scan
- ✓ ~1.5 Tb data per scan
- ✓ Anti-collision system based on lasers
- ✓ High resolution camera and Liquid lens
- ✓ System unique in the world

- **Defintions**

Camera positions (end-effector): $\chi_{ee} = \begin{pmatrix} x_{ee} \\ y_{ee} \\ \psi_{ee} \end{pmatrix}$ $\psi_{ee} = \alpha + \beta$

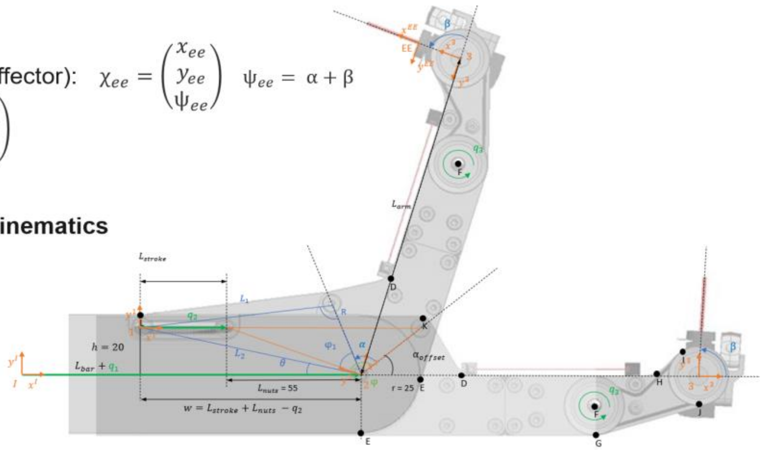
Joints Space: $q_{ee} = \begin{pmatrix} q_1 \\ q_2 \\ q_3 \end{pmatrix}$

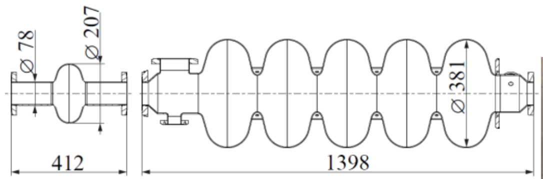
- **Forward & Inverse Kinematics**

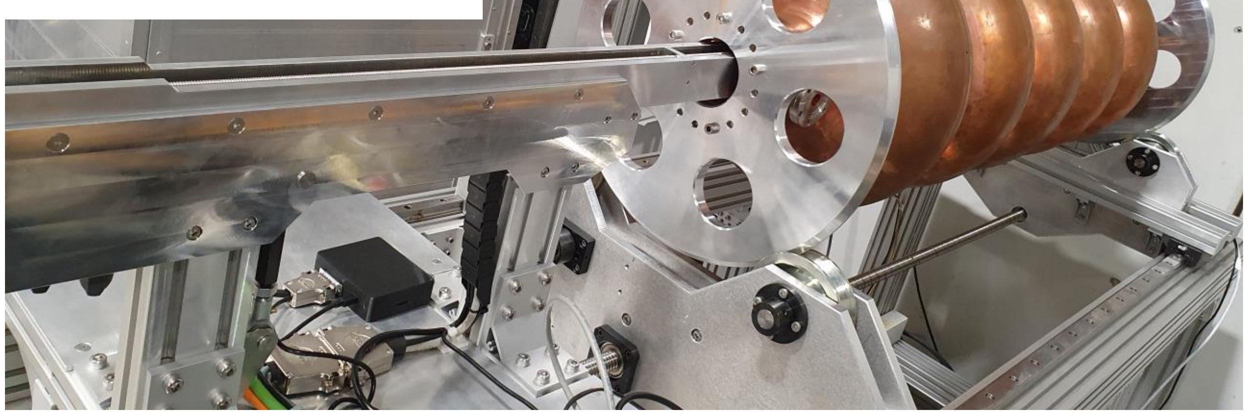
$\dot{\chi}_{ee} = J_A(q)\,\dot{q}$

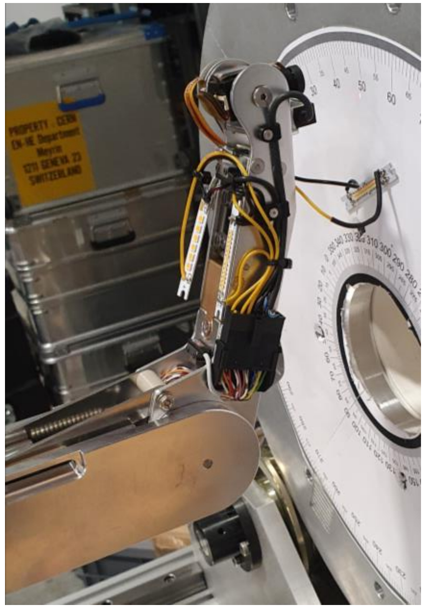
$\Delta q \cong J_A(q)^{-1}\Delta\chi_{ee}$

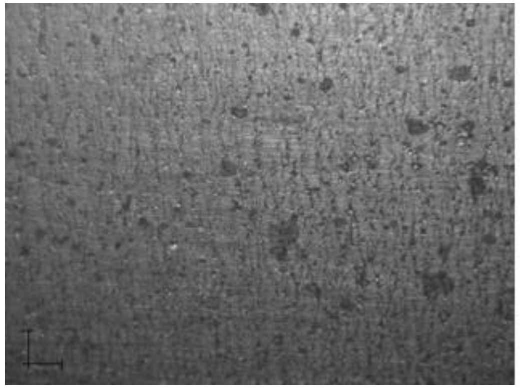
$qNext \cong qActual + \Delta q$







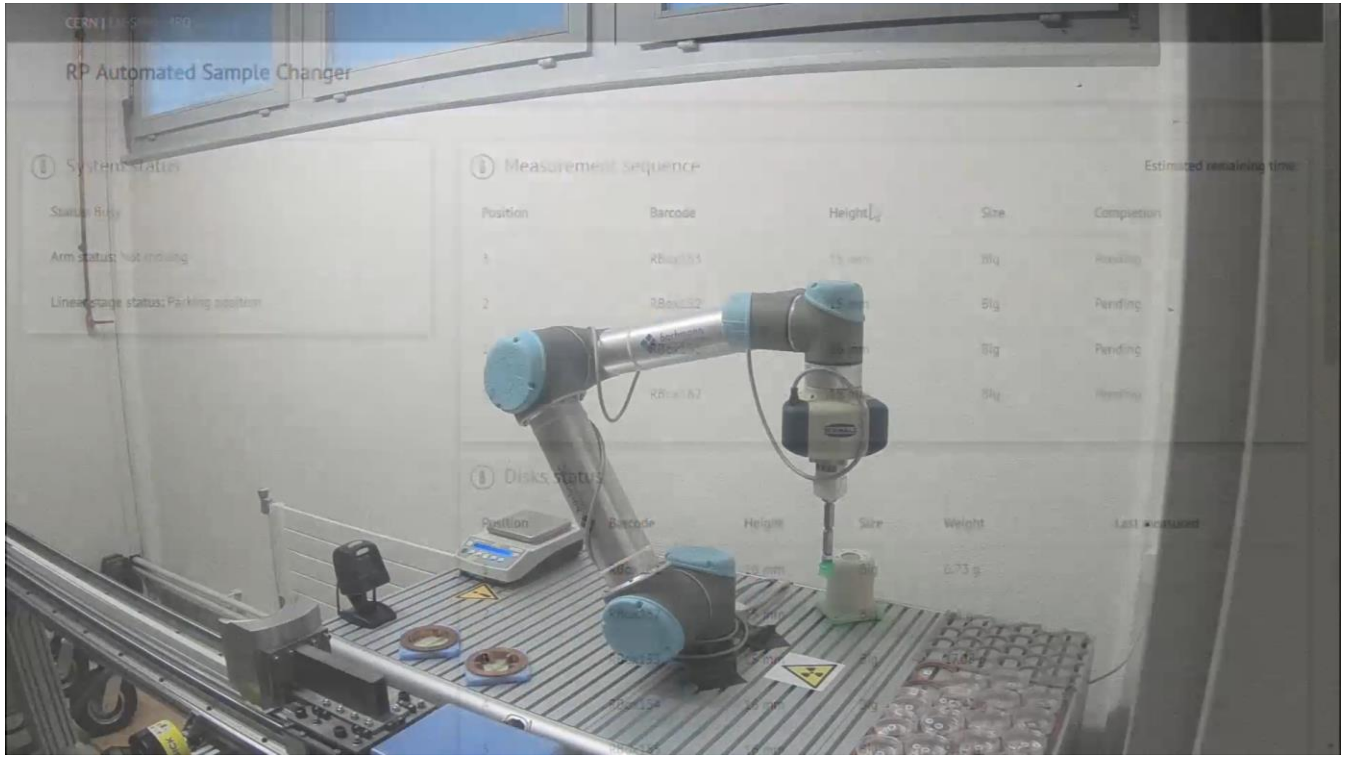


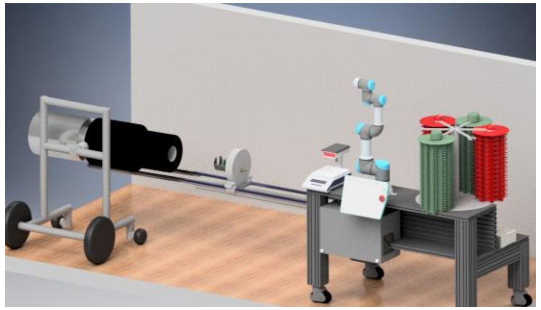


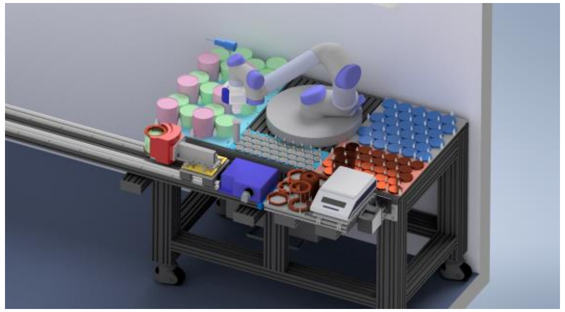
Images size: 1 x 1 cm taken at 23 mm distance

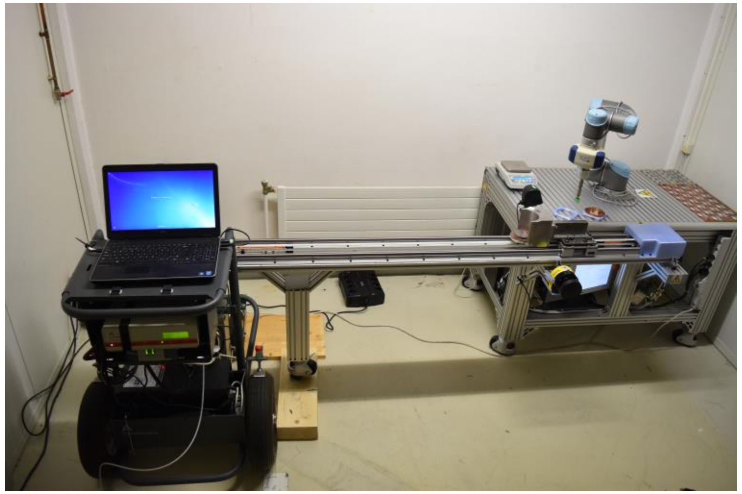
Quality control for RP sample positioning

- RP sample changer enhances throughput for spectrographic analysis of samples
- Supervised deep learning helps in ensuring heterogeneous sample position for measurement quality control





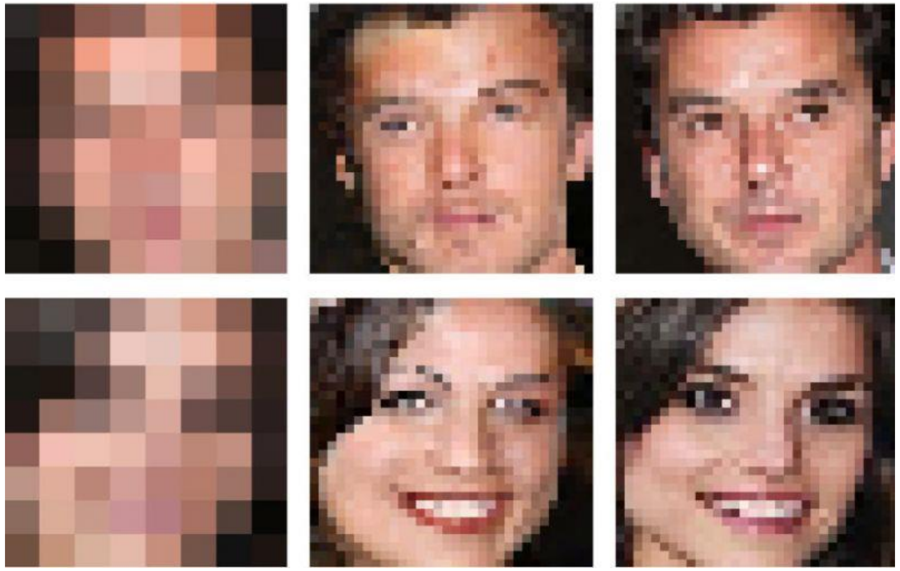


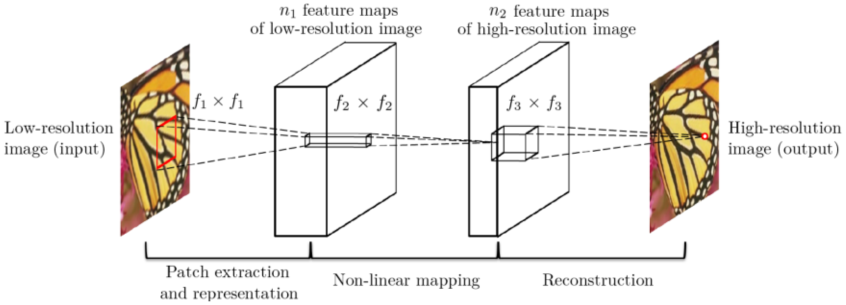


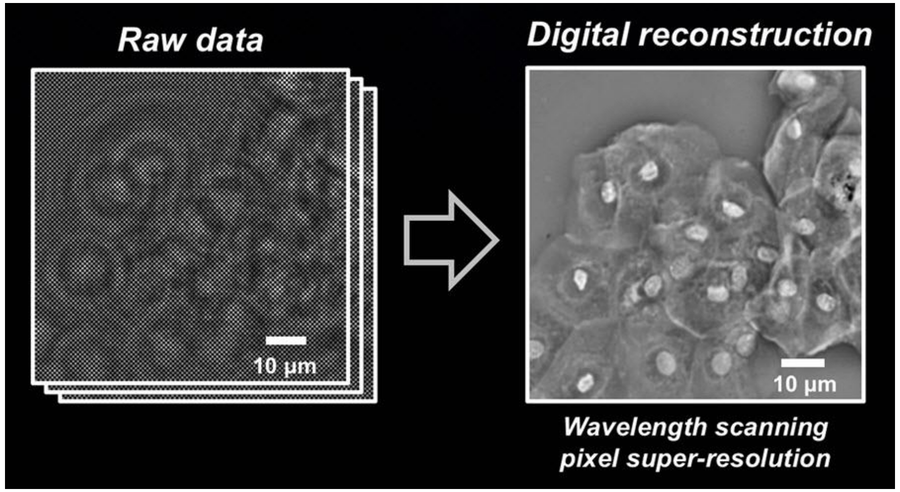
Collaboration with HSE-RP

Super resolution for visual online monitoring #1

- Generates higher resolution less noisy images from small resolution compressed images
- Two categories:
  - Single image super-resolution [7]
  - Multiple image super-resolution [8]
- State-of-the-art neural networks produce great results but are not suitable for real-time display

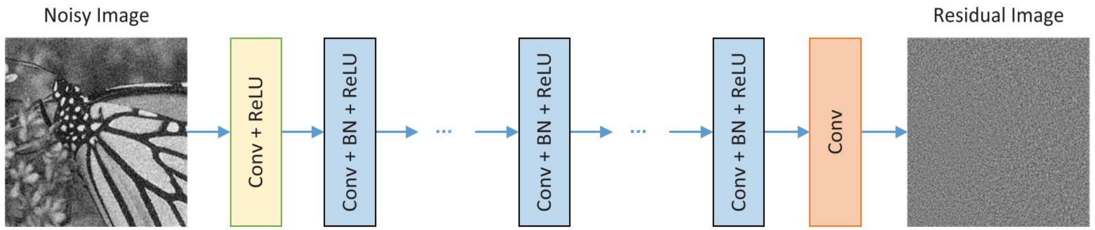


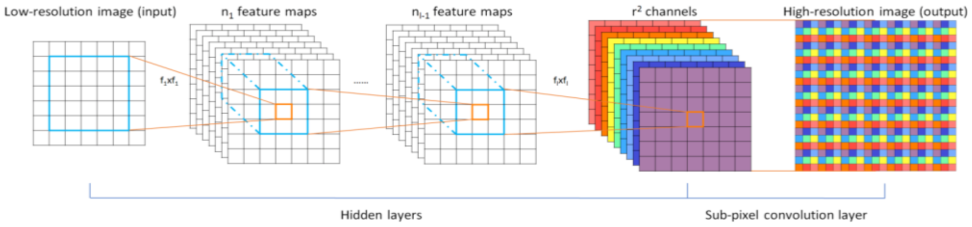




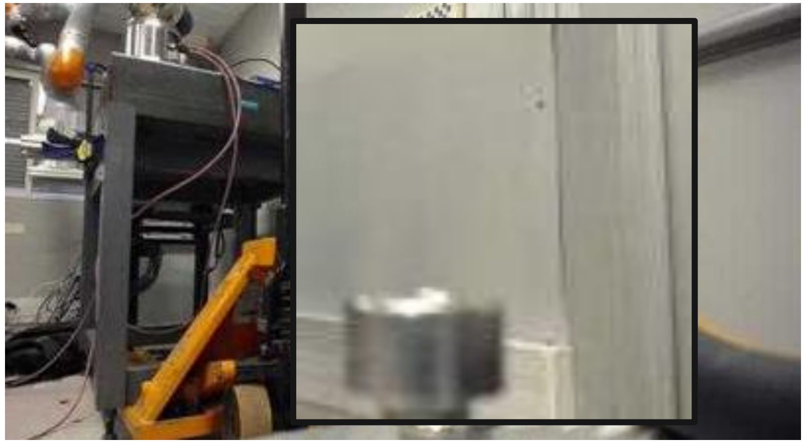
Super resolution for visual online monitoring #2

- We merged 2 neural networks : compression noise reduction and resolution enhancement [9]
- Reduce 4G bandwidth consumption for transmitting images
- Generates no lag thanks to real-time capabilities
- Little defects in some images are not critical as images are displayed to the operator at 15 fps
- Multiscale super resolution available (2x, 4x, 8x etc.)

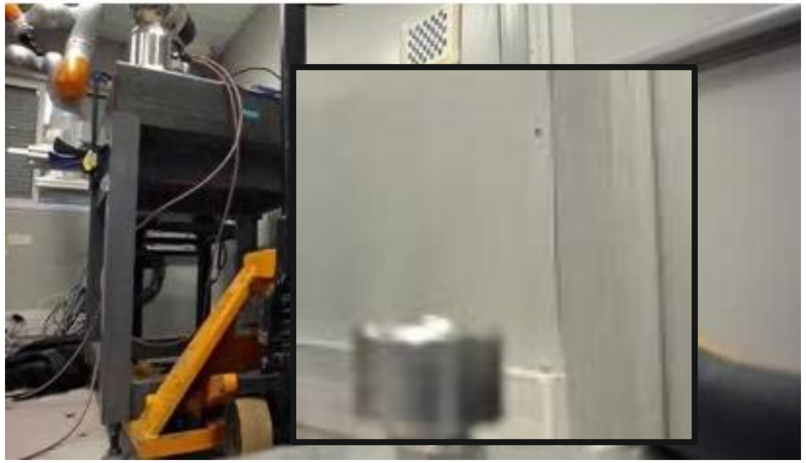




PYTORCH



50% jpeg compression; 14 kb

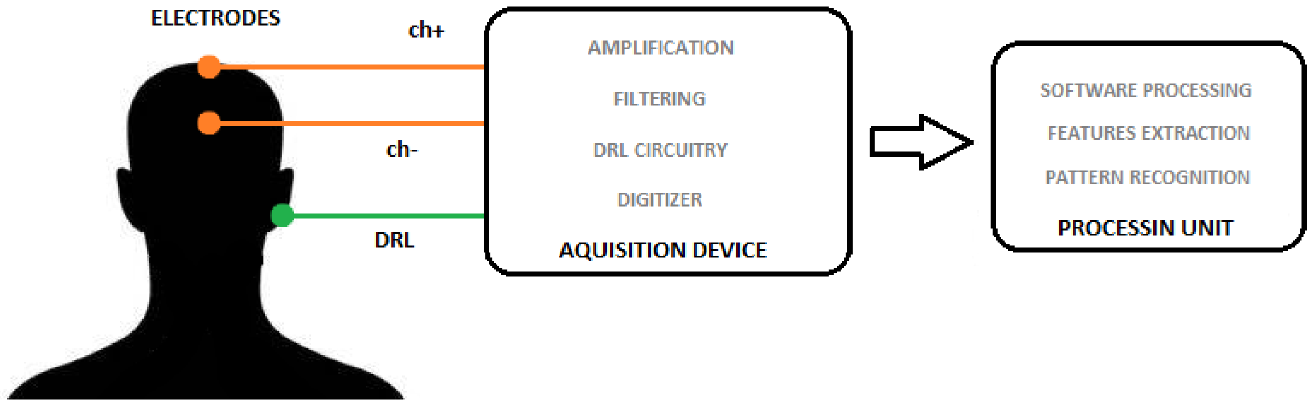


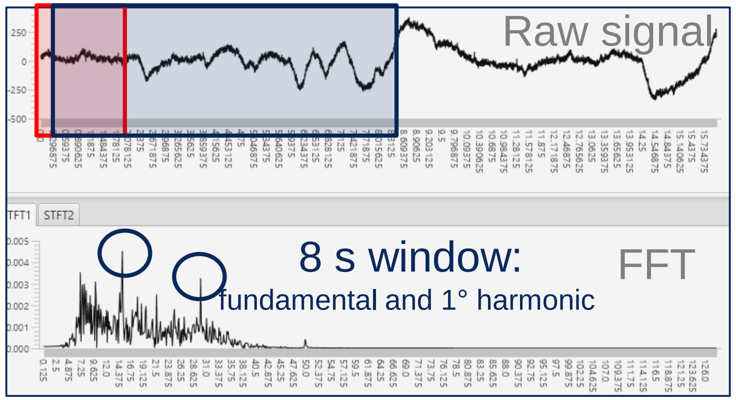
4X resolution enhancement + noise reduction; 282 kb; computation time 4 ms

Brain-Robot Interface for robot arm control

- Online analysis of brain signal
- Augmented reality glasses used for commands display
- Eyes focus point detected by CNN processing Steady State Visual Evoked Potentials (SSVEP [15]) which are synchronous responses produced in the visual cortex area when observing flickering stimuli

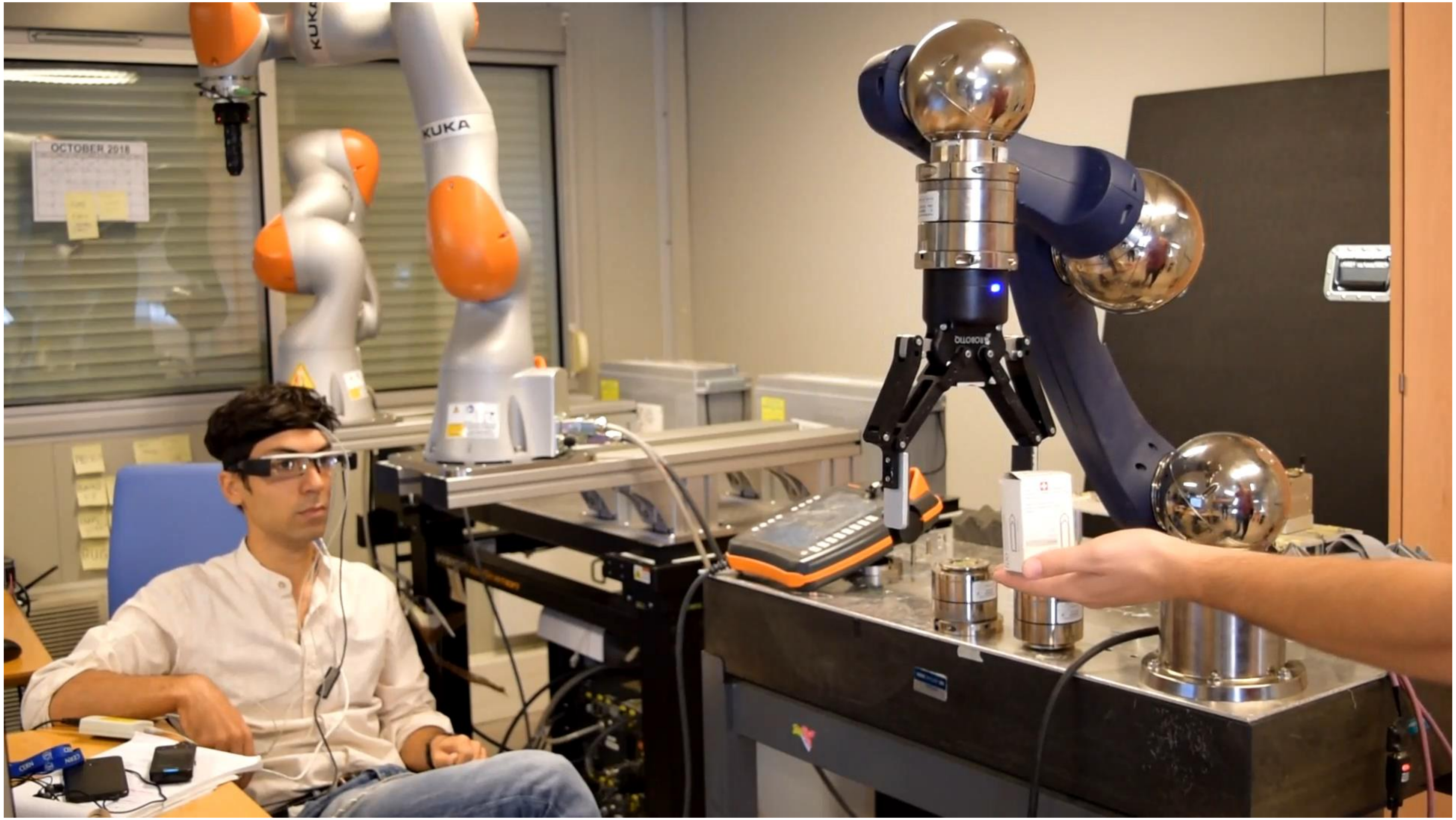
Hardware used for the brain monitoring





Example of brain activity monitoring

Brain-Robot Interface for robot arm control

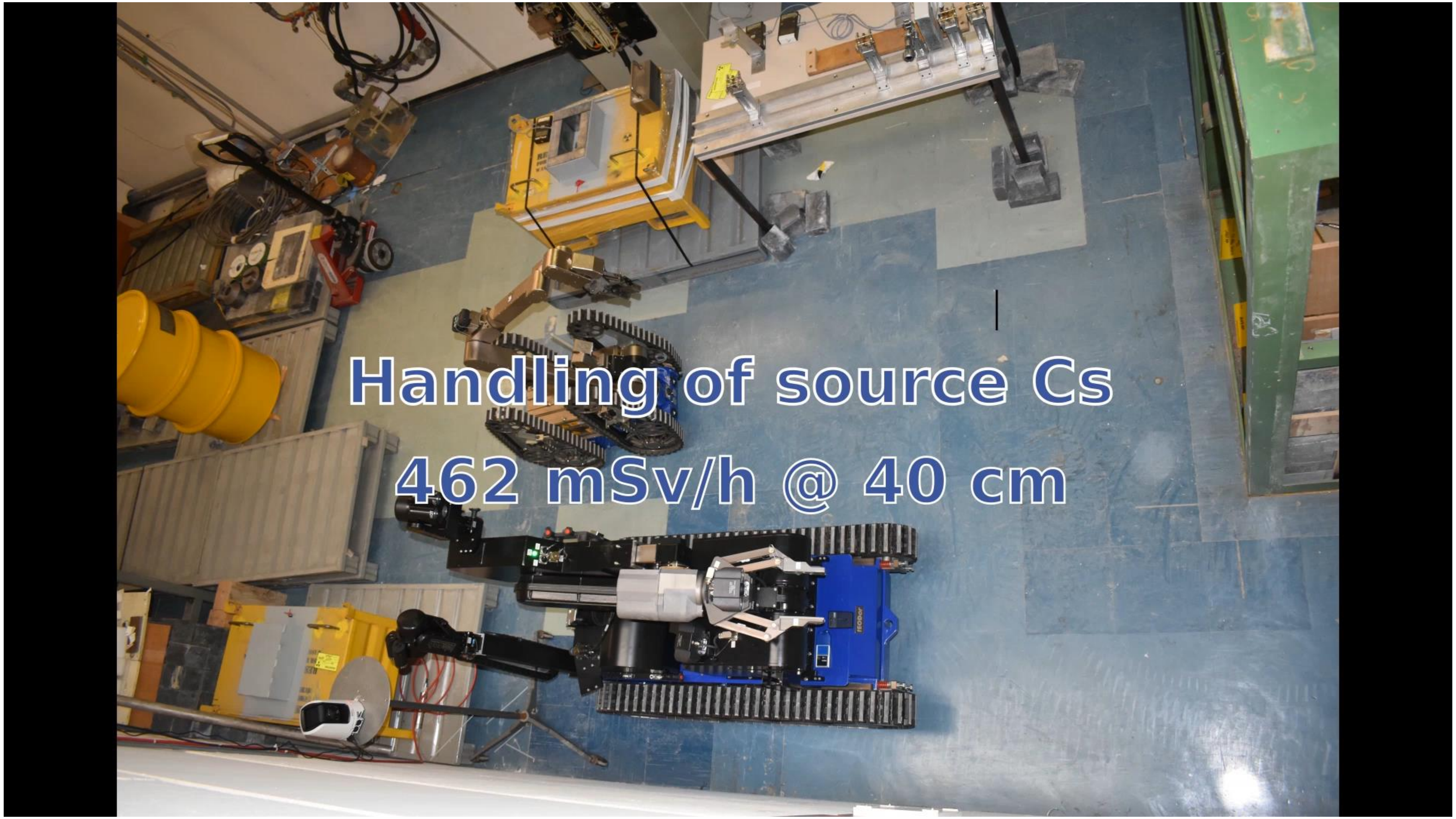


Content

- Needs and challenges for robotics at CERN
- The robotic service in BE-CEM
- Some challenging robotic missions
- Future objectives
- Conclusions

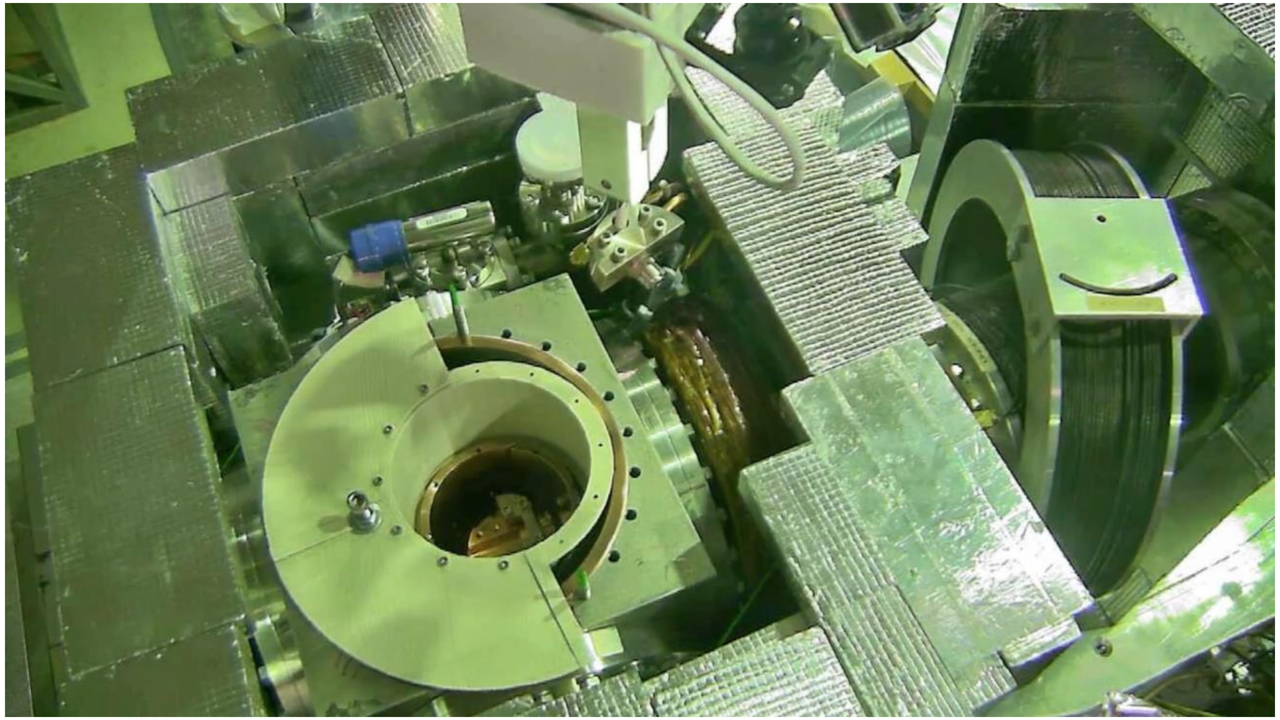
Intervention done in 2015

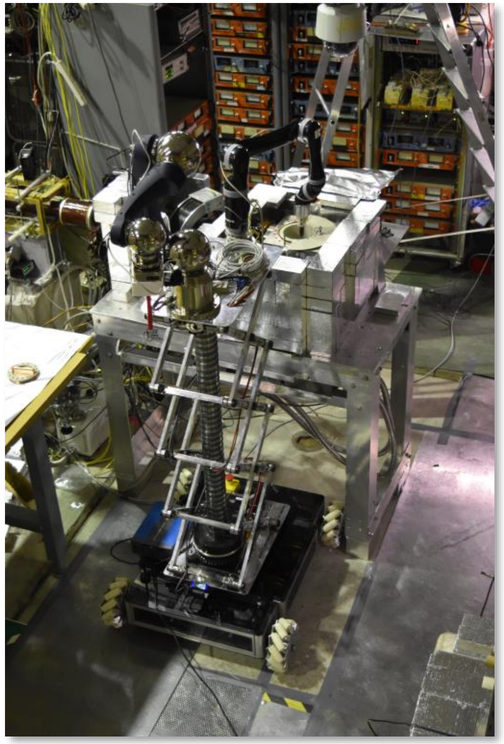
Intervention done in 2015, b172

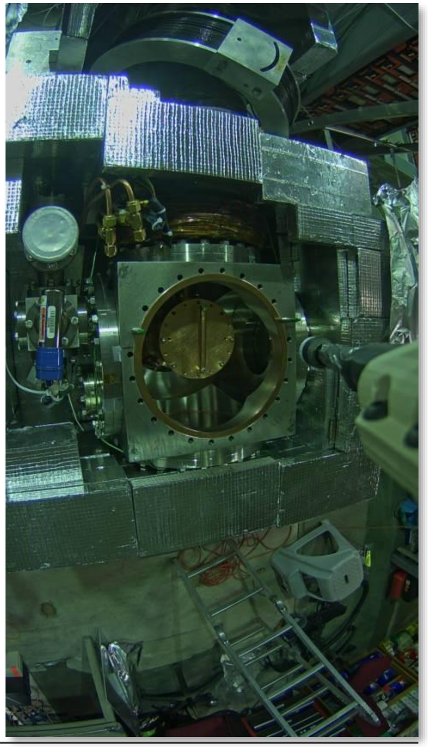


Challenging Teleoperation Example#1

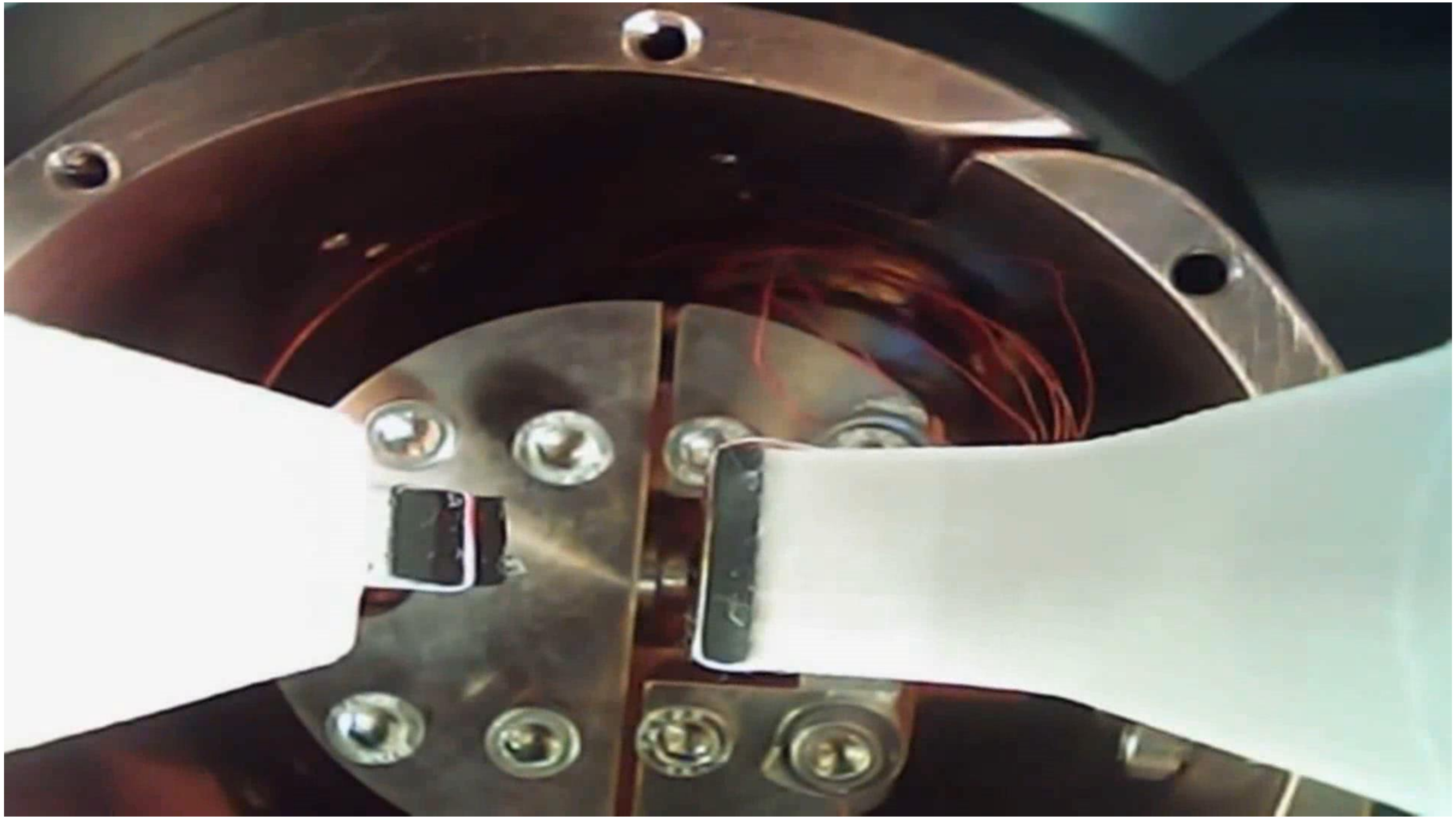
- Radioactive source handling at 2.5 m height using CERNbot 2
  - ✓ **Intervention not possible to be performed by humans**
  - ✓ Bimanual operation, novel procedures and tooling
  - ✓ **CERNTAURO RH procedures and recovery scenarios allowed intervention acceptance by big science facility management**
  - ✓ **CERNTAURO bilateral master-slave control allowed precise telemanipulation of delicate objects**







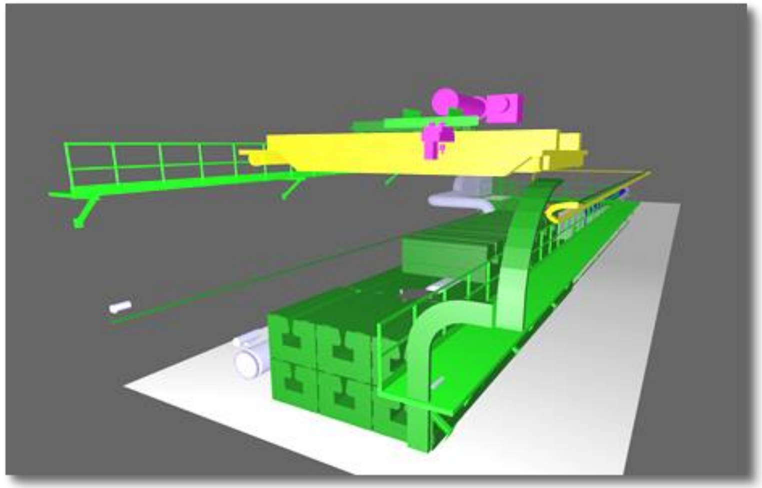
Challenging Teleoperation Example#1

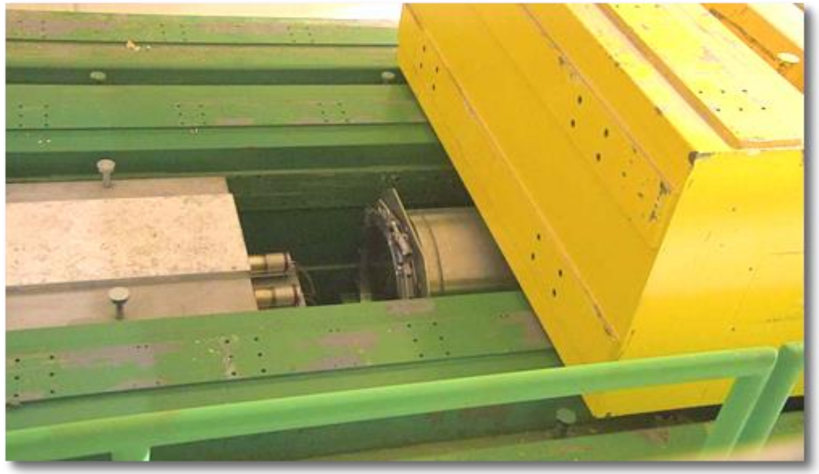


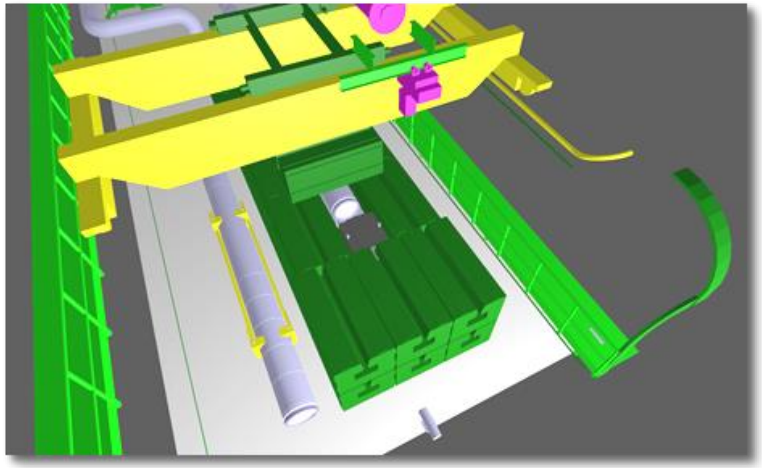
Challenging Teleoperation Example#2

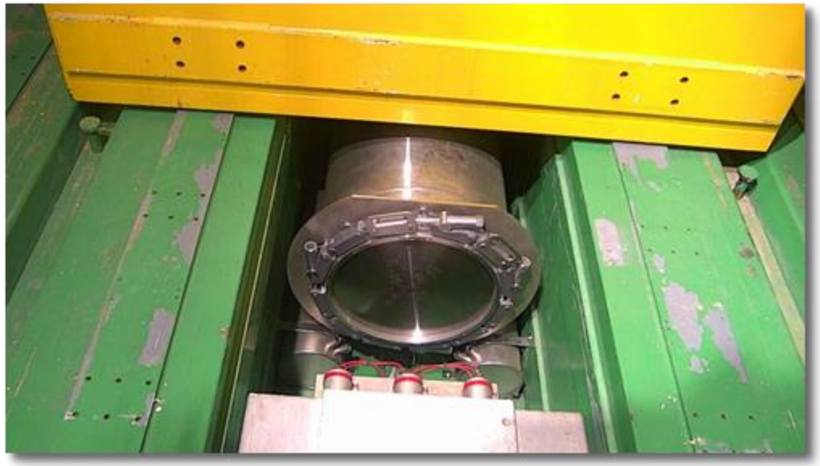
- LHC TDE inspection

CERNbot v1.0 core



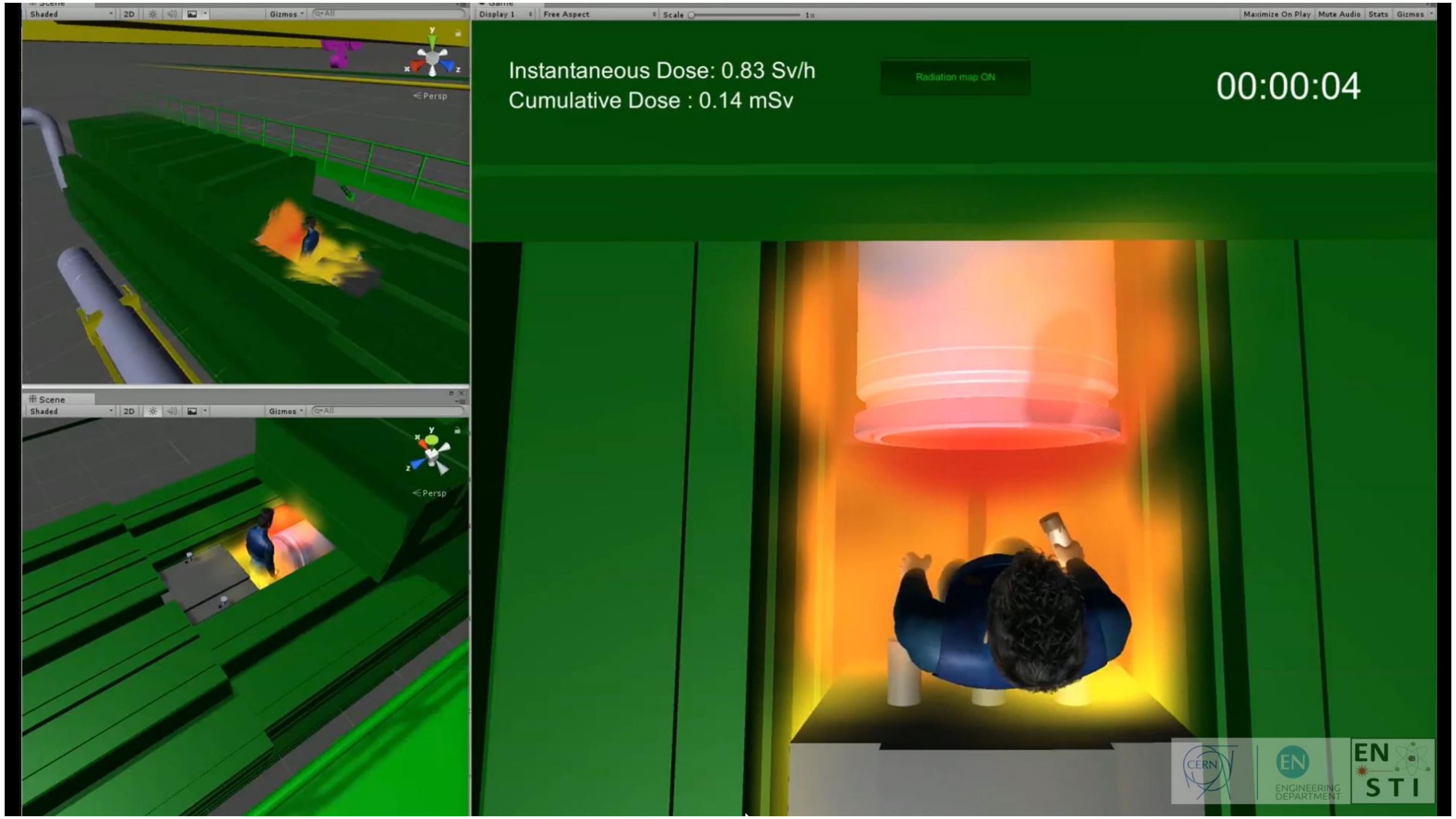


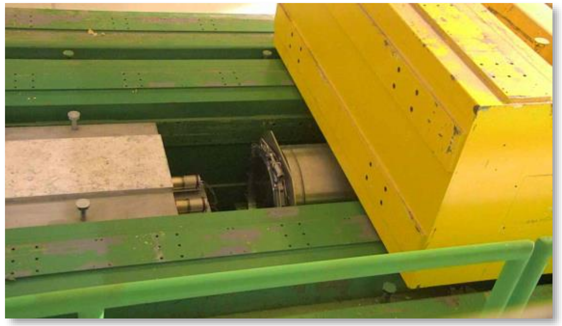


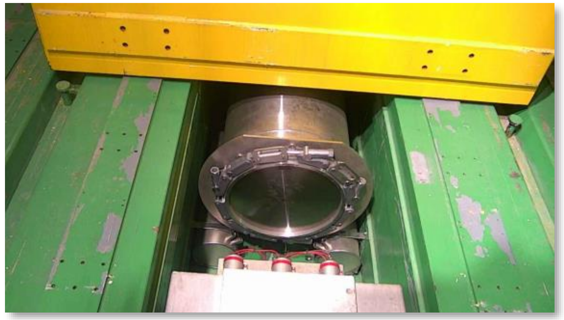


Challenging Teleoperation Example#2

- LHC TDE inspection

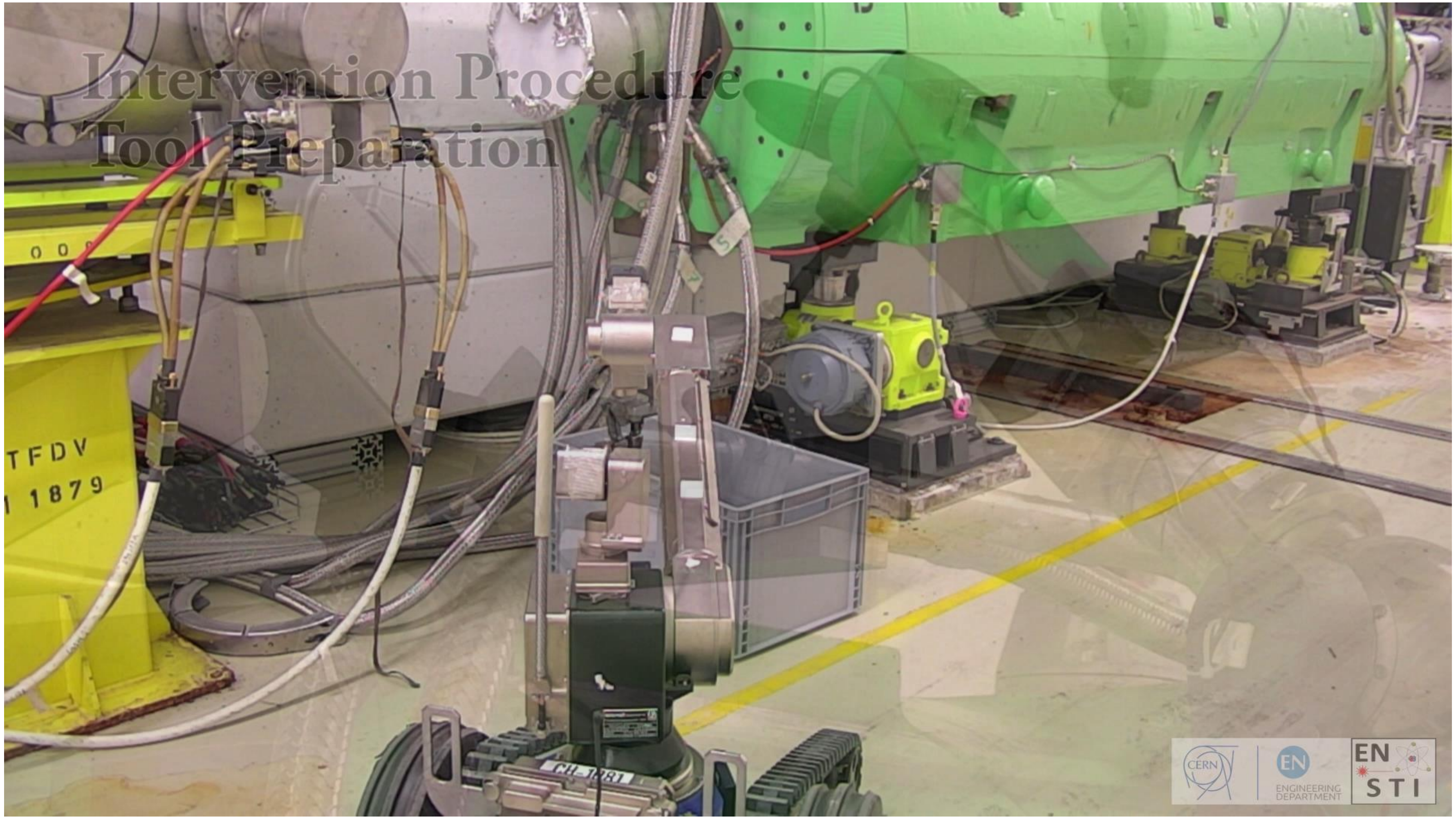






Challenging Teleoperation Example#3
Support for the dismantling of n_ToF target

Robotics used for postmortem analysis (SPS - TIDVG)



Main Robotics Interventions in 2020

Content

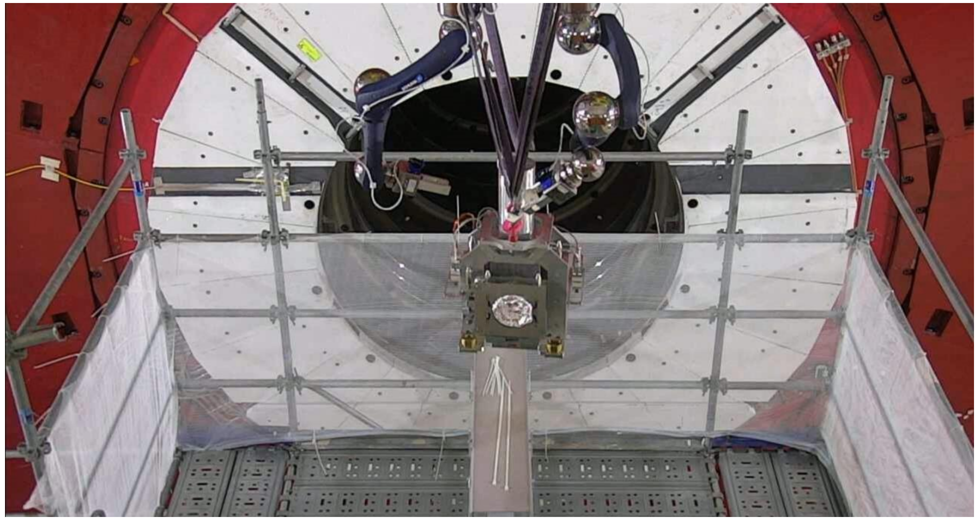
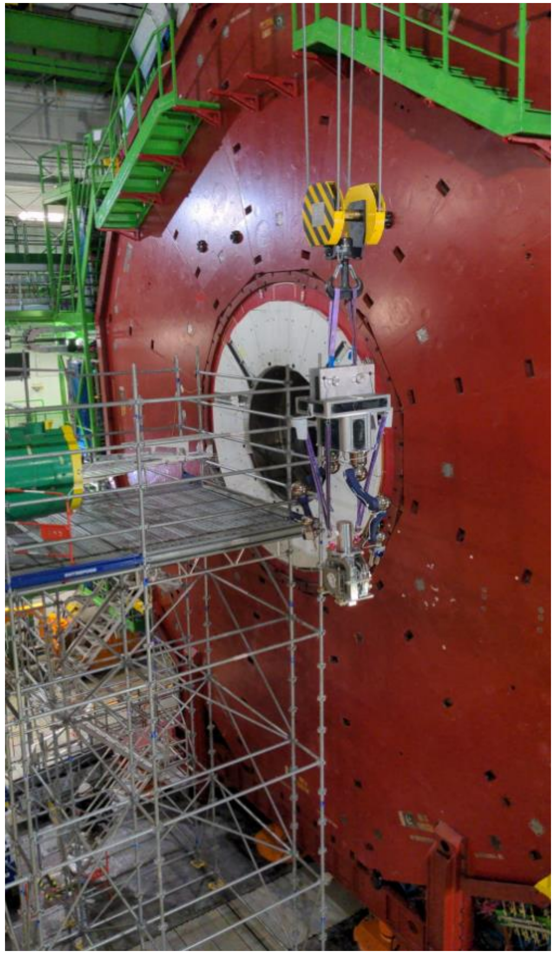
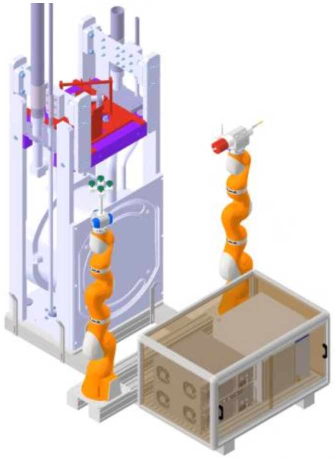
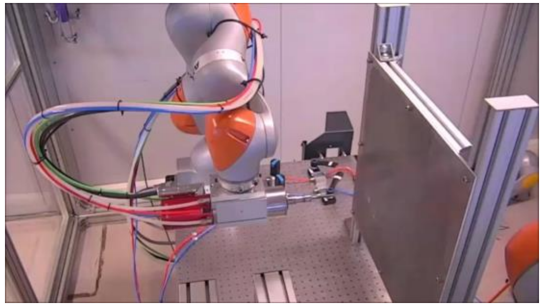
- Needs and challenges for robotics at CERN
- The robotic service in BE-CEM
- Some challenging robotic missions
- Future objectives
- Conclusions

Future main missions

- old nToF target opening, robots for NA (TCCD), ntoF NEAR target exchange, new CMS VAX maintenance with CRANEbot, ATLAS shielding doors robotic milling

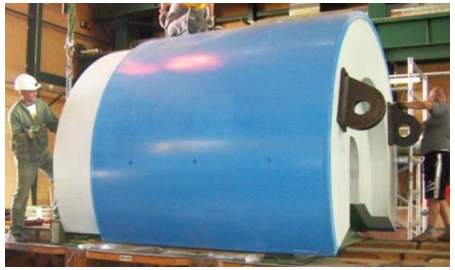
- **VAX remote maintenance**



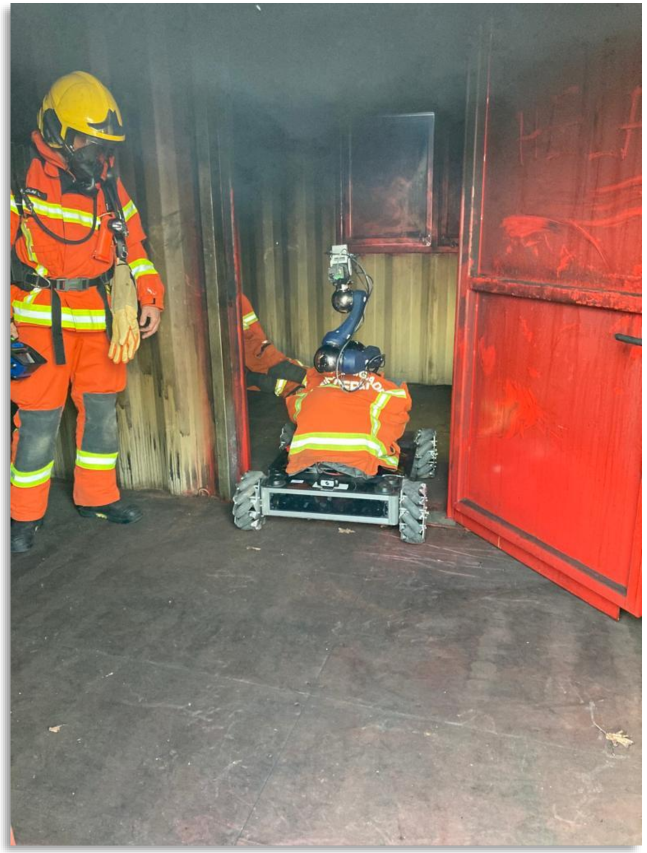
- **old n_ToF target opening**

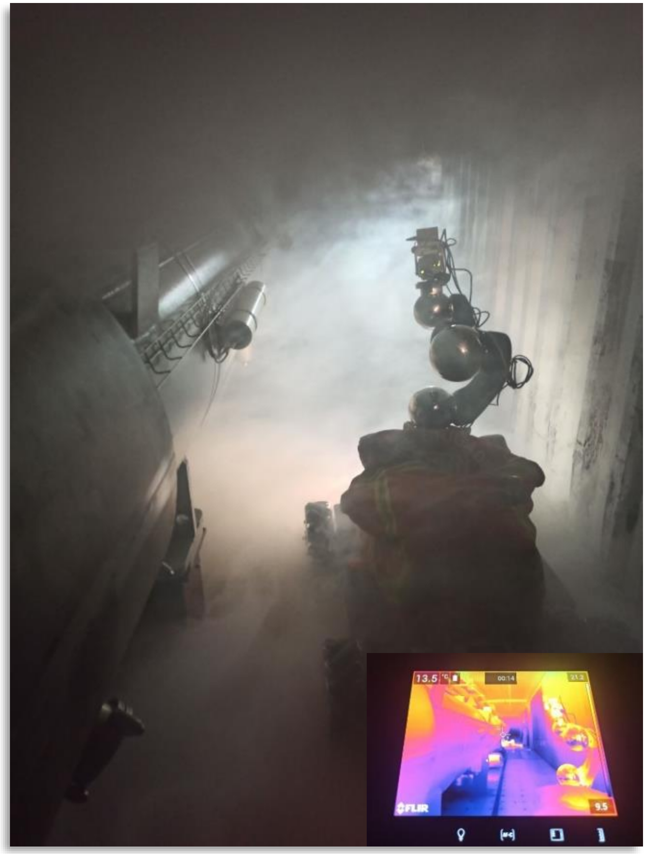
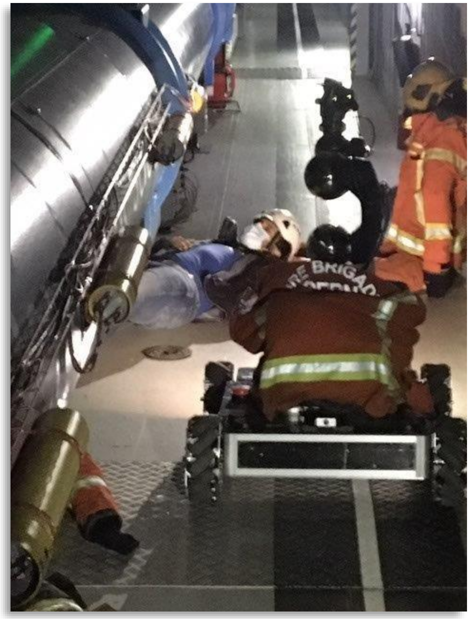
- **ATLAS shielings modification using robotic CNC techniques developed in-house**




Robots for Search and Rescue

- First test of for **FB-CERNbot** collaboration for search and rescue in disaster zones



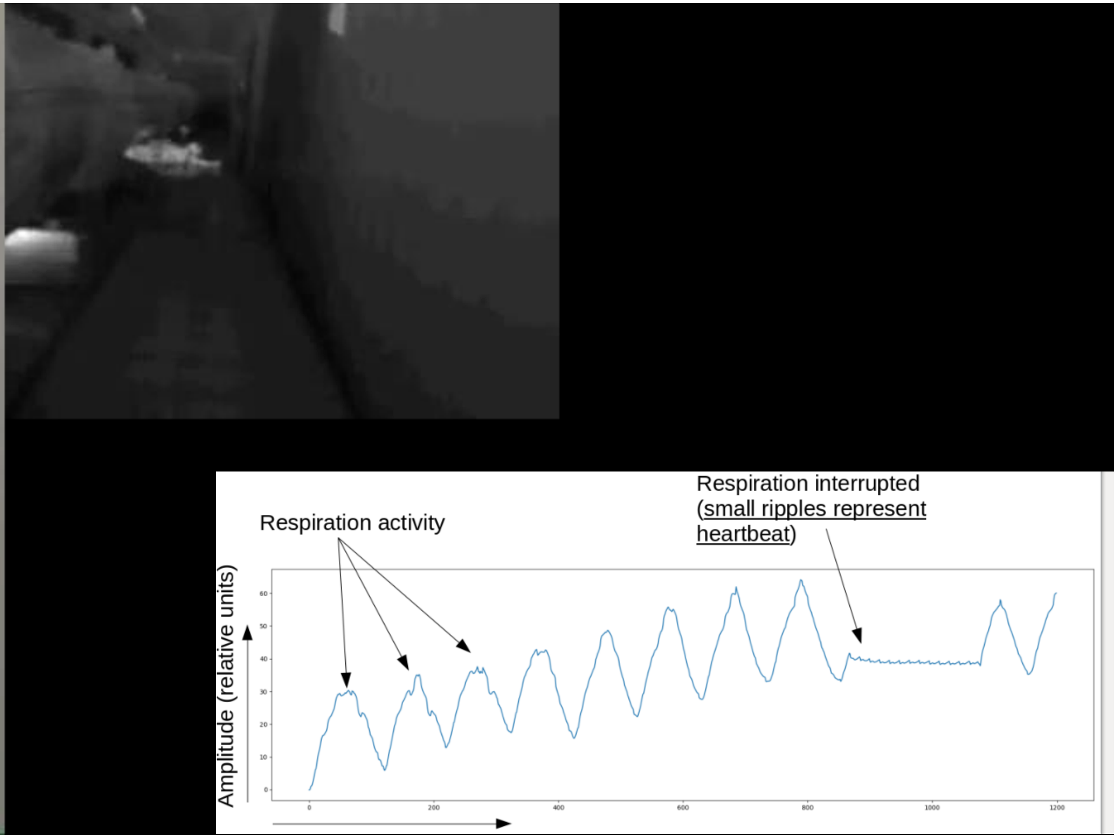




Collaboration with HSE-FRS

Robots for Search and Rescue

Collaboration with HSE-FRS

2D IMAGE

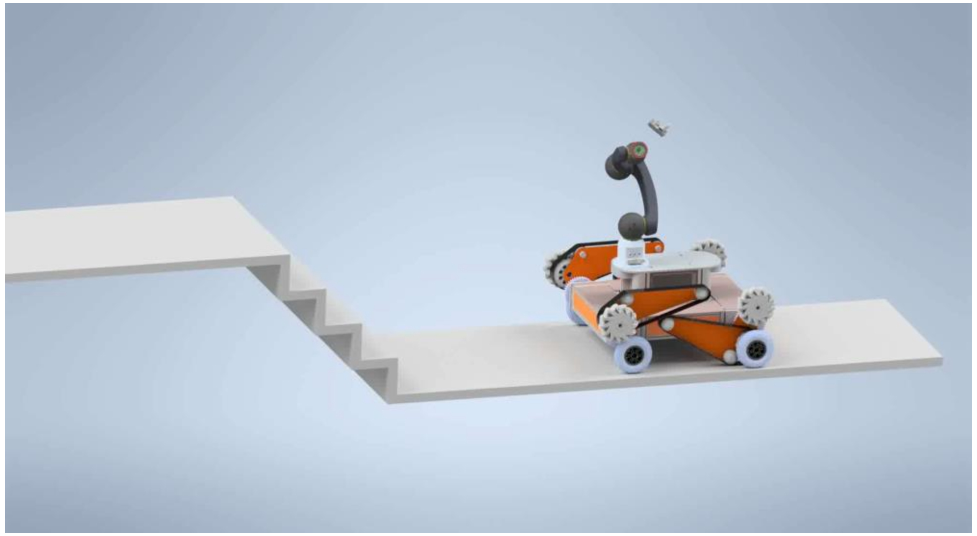


IR+RADAR (for respiration and heart beat monitoring

Video of CERNbot searching for victims in disaster zones with presence of heavy smoke, comparison of standard 2D image with IR+RADAR

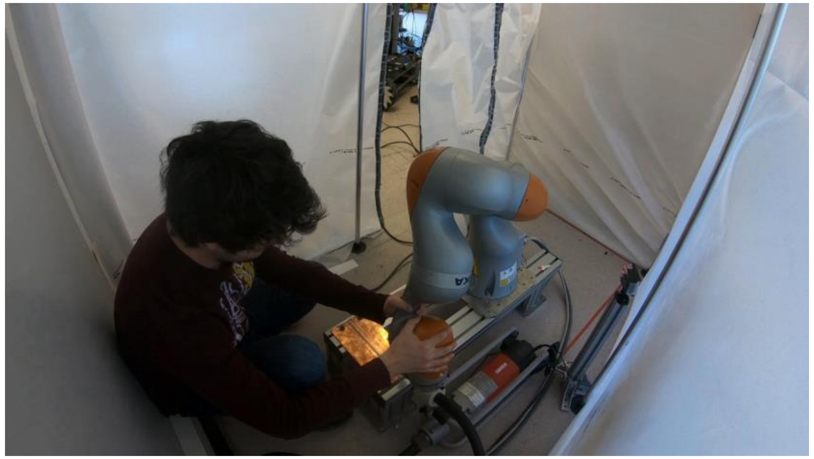
Modular Robots

- Adaptive traction system for ground robots
- Drones and hyper-redundant (snake) robot for inspection and teleoperation support (third eye) in confined space (including beam pipe inspection)
- Fusing hydraulic and mechanic technologies for a novel robotic arm (more precision and payload) for portable machining/CNC system allowing in-situ interventions on highly radioactive objects
- Improvement of autonomy of robotic operation using machine learning

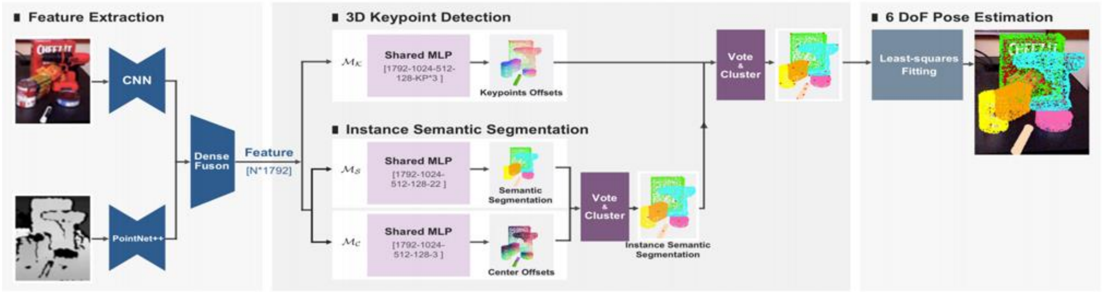


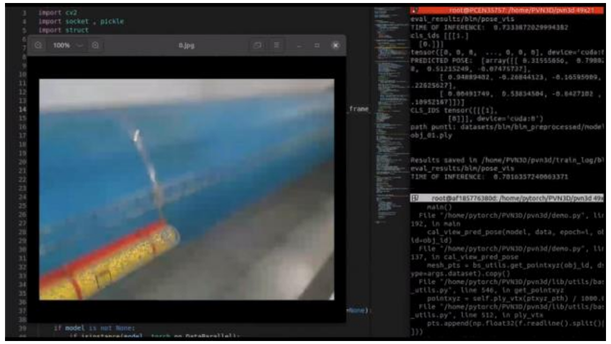
User-friendly teleoperation system

- Novel Master device equipped with haptic devices to increase operators proprioception
- Autonomous operation based on learning by demonstration technology
- Integration and commissioning of Machine Learning technologies for operator awareness and autonomy improvements

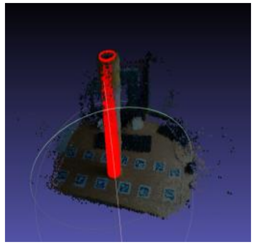


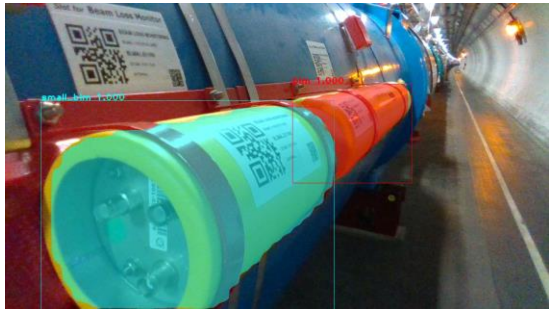
BLMs detection and 6 DoF pose estimation using ML

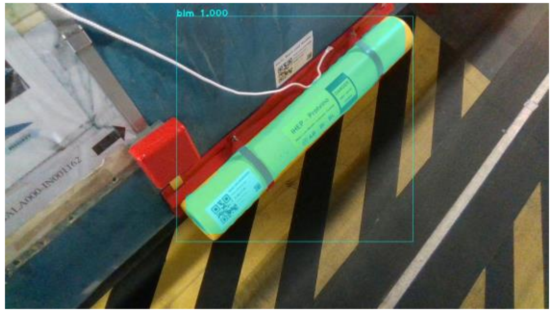


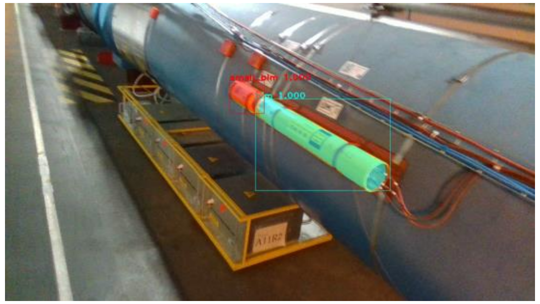


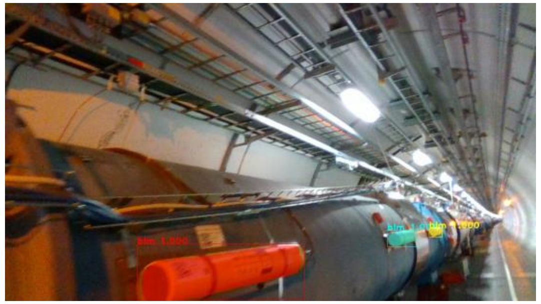
BLMs detection and pose estimation framework

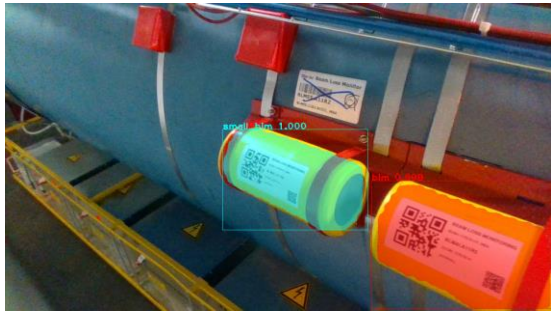


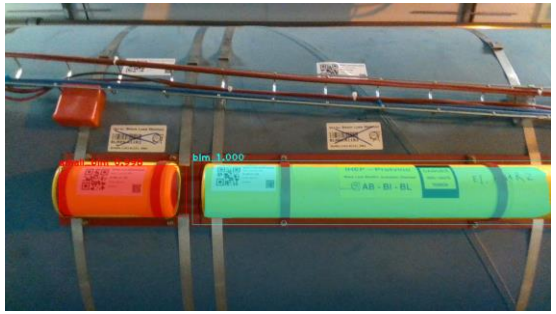


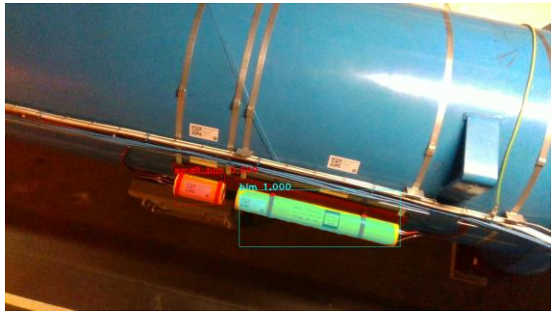








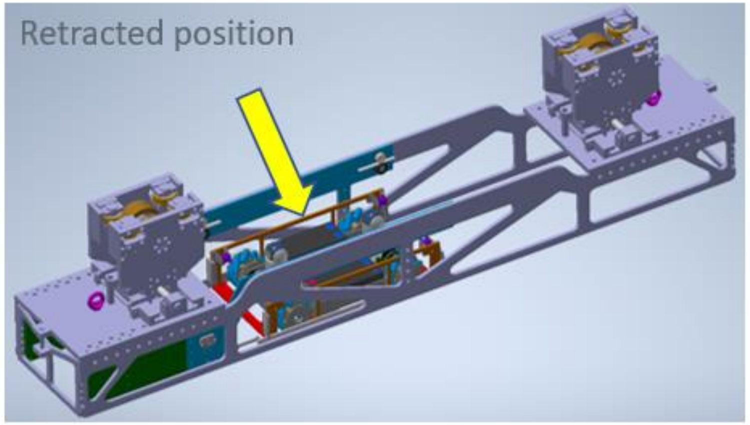


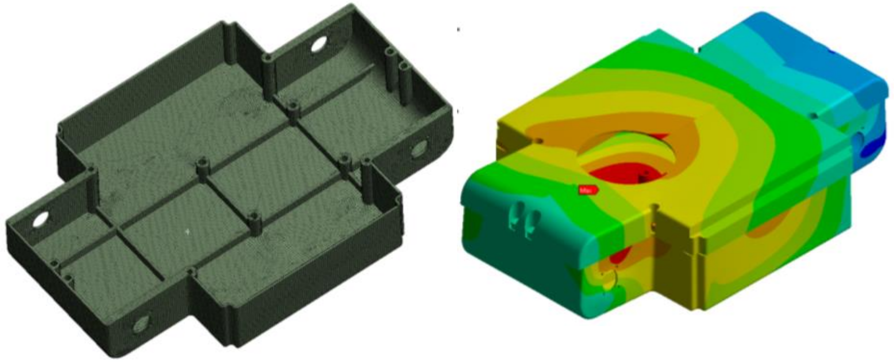


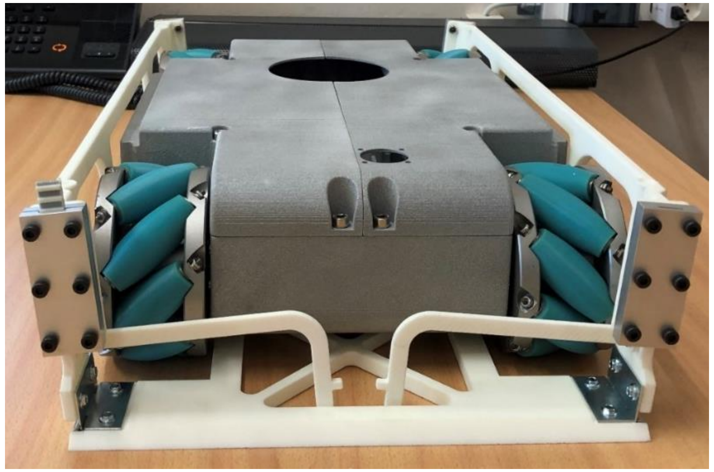
Examples of BLMs detection/segmentation using ML

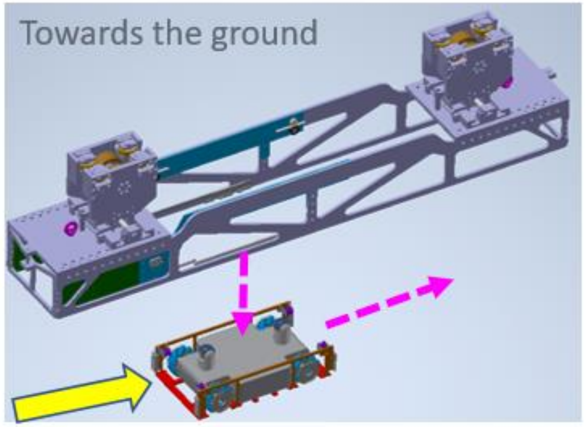
TIM Junior

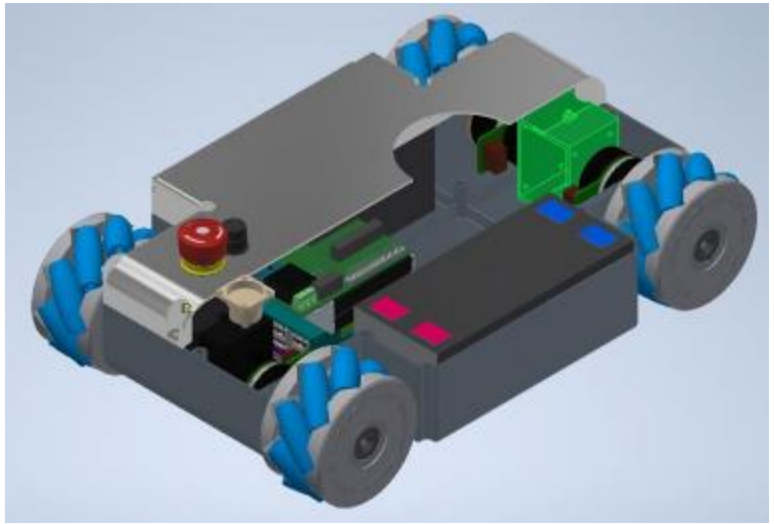
- ROV inside TIM wagon to be lowered down in the LHC

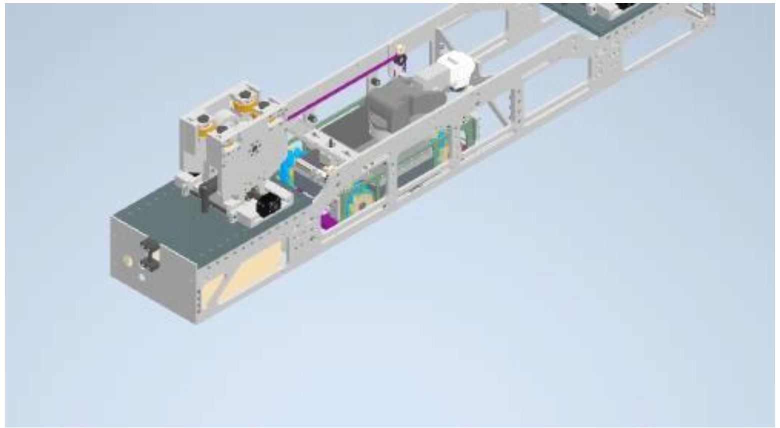




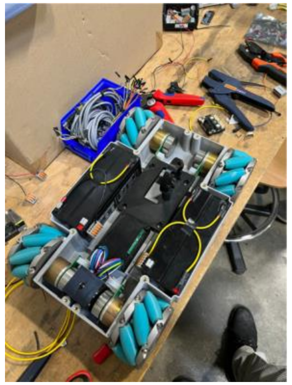


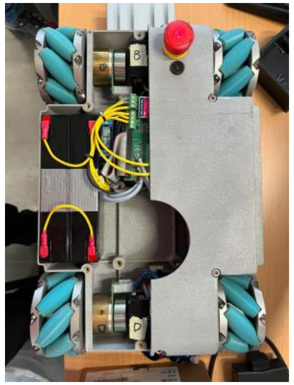


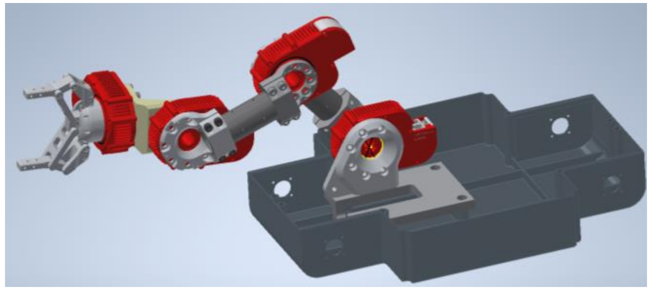


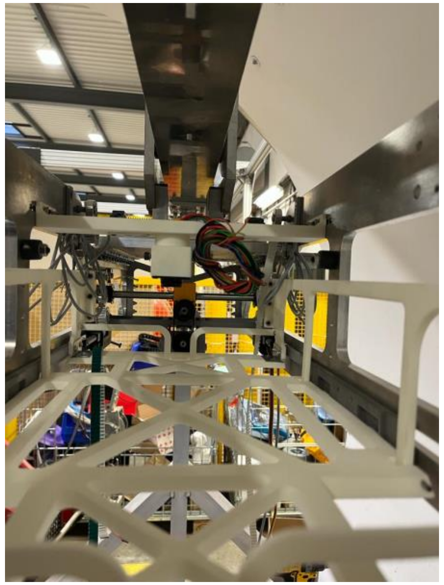


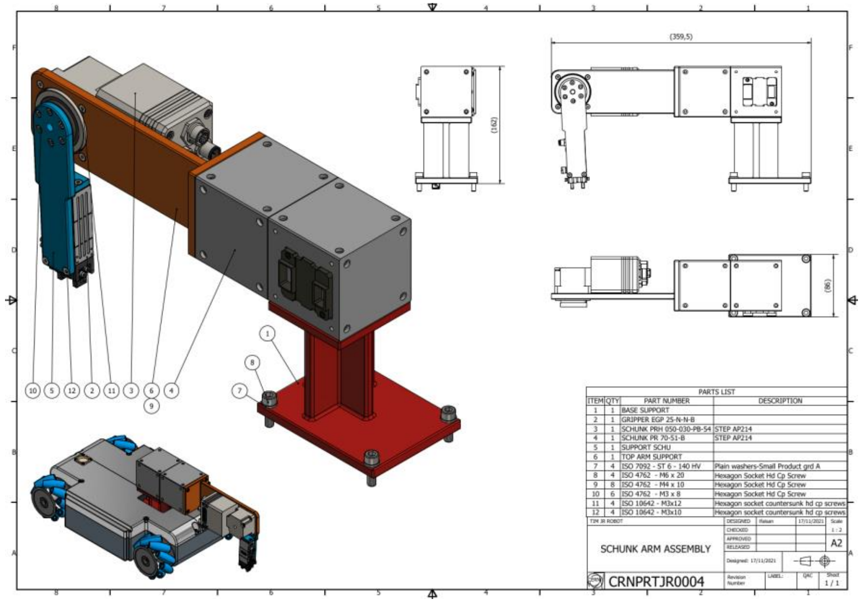
TIM Junior










(359,5)
(162)
(98)
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ITEM QTY PART NUMBER DESCRIPTION
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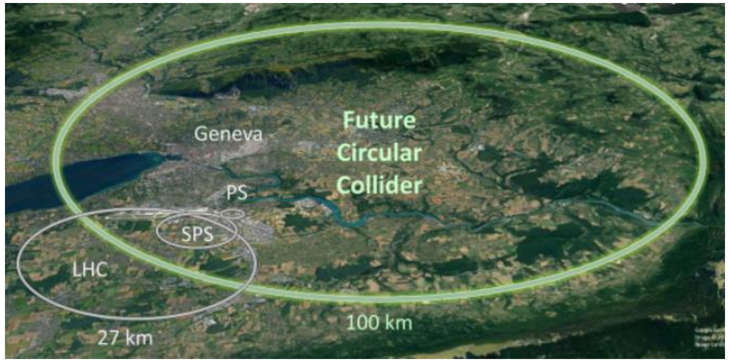
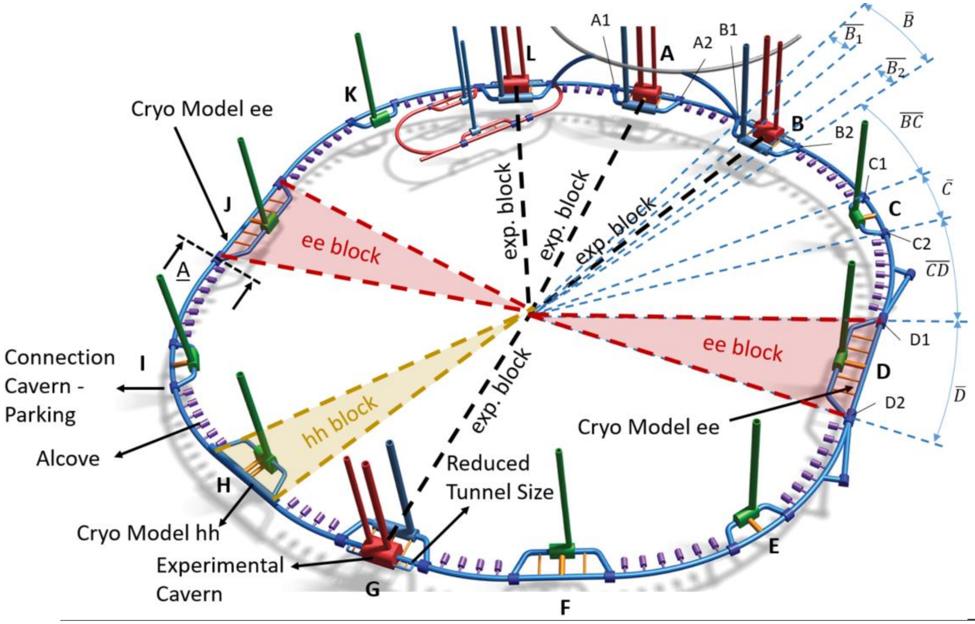
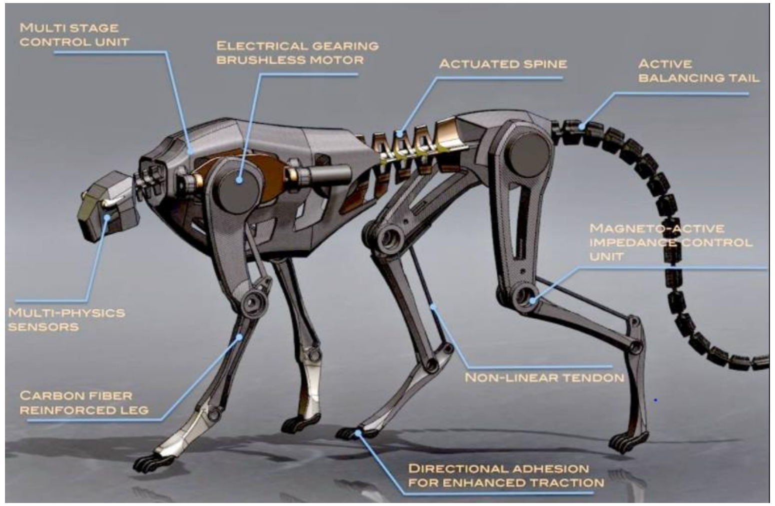
2 1 GRIPPER EGP 25-N-N-B
3 1 SCHUNK PRH 050-030-PB-54 STEP AP214
4 1 SCHUNK PR 70-51-B STEP AP214
5 1 SUPPORT SCHU
6 1 TOP ARM SUPPORT
7 4 ISO 7092 - ST 6 - 140 HV Plain washers-Small Product grd A
8 4 ISO 4762 - M6 x 20 Hexagon Socket Hd Cp Screw
9 8 ISO 4762 - M4 x 10 Hexagon Socket Hd Cp Screw
10 6 ISO 4762 - M3 x 8 Hexagon Socket Hd Cp Screw
11 4 ISO 10642 - M3x12 Hexagon socket countersunk hd cp screws
12 4 ISO 10642 - M3x10 Hexagon socket countersunk hd cp screws
TIM JR ROBOT
SCHUNK ARM ASSEMBLY
DESIGNED 17/11/2021
Scale 1 : 2
A2
Designed: 17/11/2021
CRNPRTJR0004
Sheet 1 / 1

Robots for Future Accelerators (FCC)

- Novel robotics platforms and controls for remote maintenance and interventions



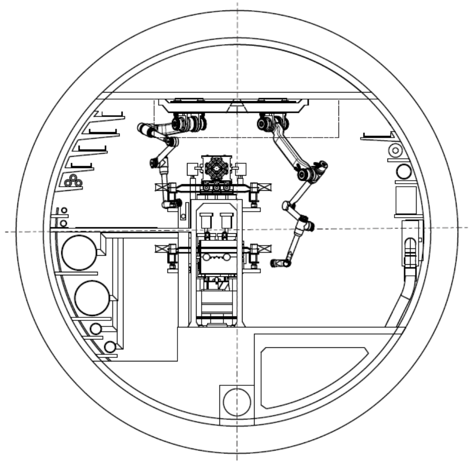


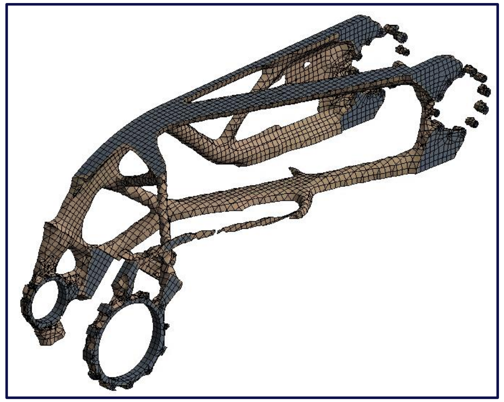


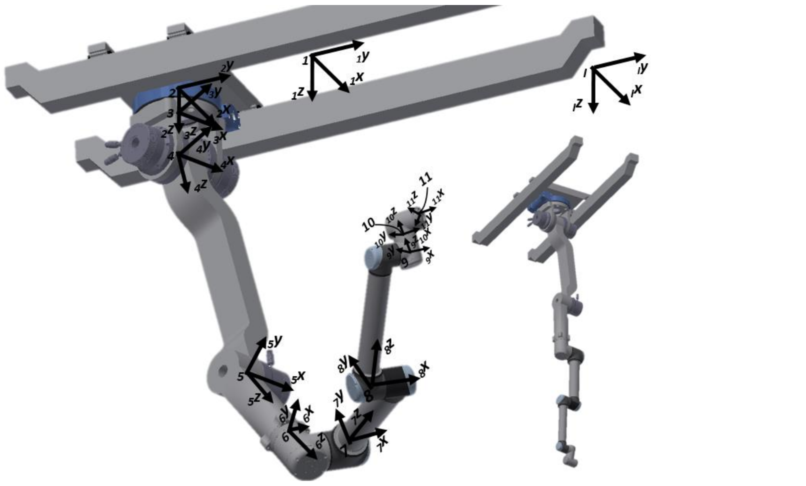
Robots for Future Accelerators (FCC)

H. Gamper PhD work

$$
\begin{aligned}
\min_{\mathbf{x},\ \mathbf{p}_l} \quad & J(\mathbf{x},\ \mathbf{p}_l) \\
\text{s.t.} \quad & \mathbf{f}(\mathbf{x},\ \mathbf{p}_l) - \mathbf{z}_{des} = \mathbf{0} \\
& -\mathbf{c}(\mathbf{x},\ \mathbf{p}_l) \leq \mathbf{0} \\
& \mathbf{ub}(\mathbf{x},\ \mathbf{p}_l) \leq \mathbf{0} \\
& \mathbf{lb}(\mathbf{x},\ \mathbf{p}_l) \leq \mathbf{0}
\end{aligned}
$$







$$
J(\mathbf{x},\ \mathbf{p}_l) = \underbrace{\mathbf{Q}^T(\mathbf{x},\ \mathbf{p}_l)\mathbf{K}_Q\mathbf{Q}(\mathbf{x},\ \mathbf{p}_l)}_{J_1} + \underbrace{\mathbf{k}_p^T \arctan(\mathbf{p}_l)}_{J_2} + \underbrace{\mathbf{k}_w^T \mathbf{w}(\mathbf{x},\ \mathbf{p}_l)}_{J_3}
$$

General version of this algorithm was used to find the optimal design of a cavity inspection manipulator

Gamper, H.; Gattringer, H.; Müller, A. and Di Castro, M. (2021). **Design Optimization of a Manipulator for CERN's Future Circular Collider (FCC),** ICINCO 2021

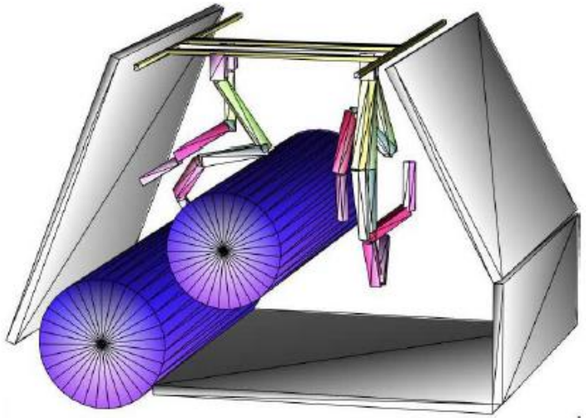
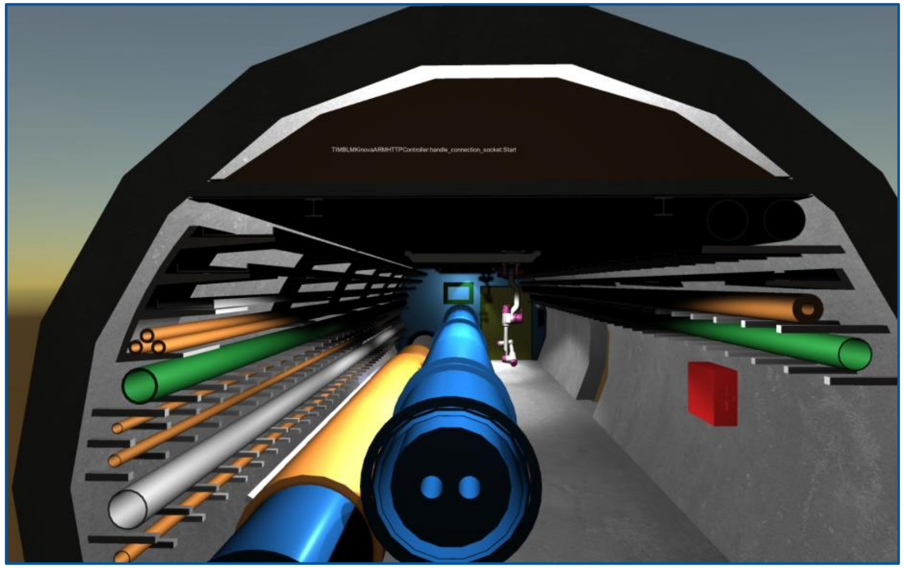


Figure 11: Optimization results FCC-hh (collision objects)



Established partnerships for European Projects

- We are chairing the Teleoperation topic group of the EuRobotics consortium (https://www.eu-robotics.net/)

- Consortiums built for European Projects calls (RECONDITION, BIANCA, HUROSHARE, SCORE, POLE)

- Participation in the European robotic Challenge (EUROC) and Puresafe projects

Conclusions

- Particle accelerators devices are normally installed for many years and tasks of dismantling radioactive objects is inherited by the future generation of physicists/technicians/engineers

- Maintenance and dismantling tasks, over a lifetime of a particle accelerator device, must be taken into account at design phase

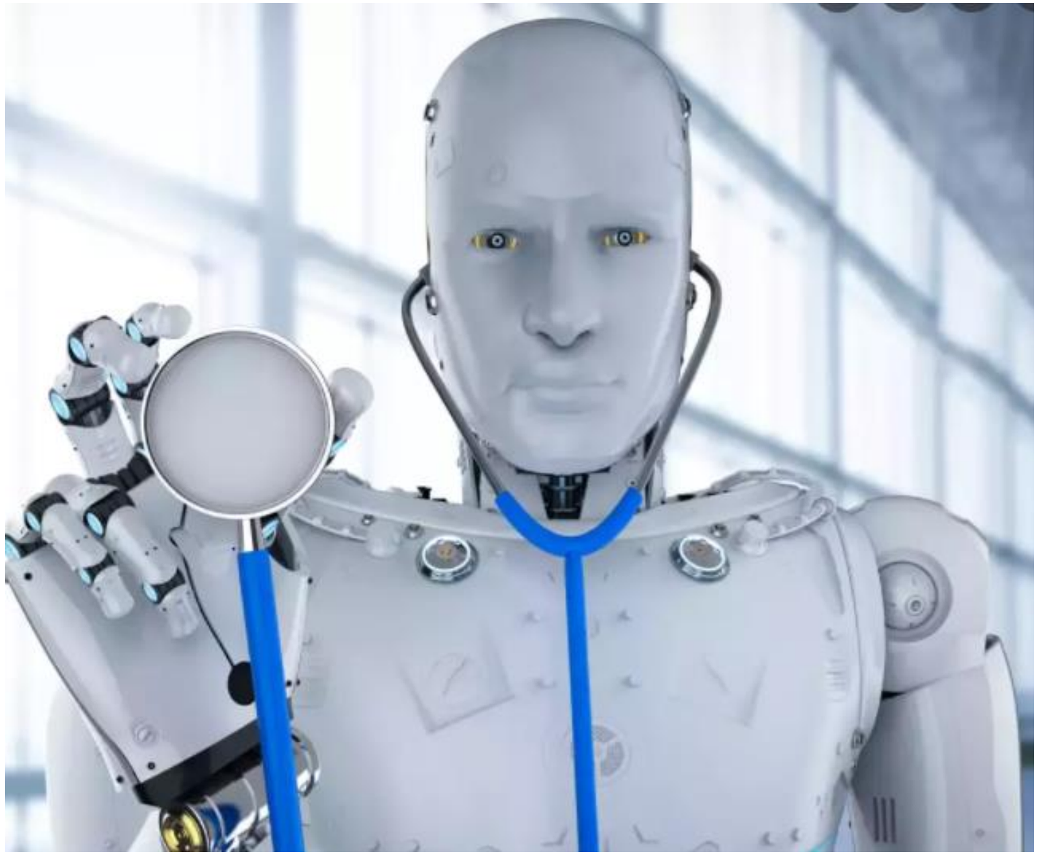
- Robotic intelligent and robust systems can increase personnel safety and machine availability in performing such tasks

- Ready-to-use industrial solutions do not exist for user friendly remote maintenance and inspection

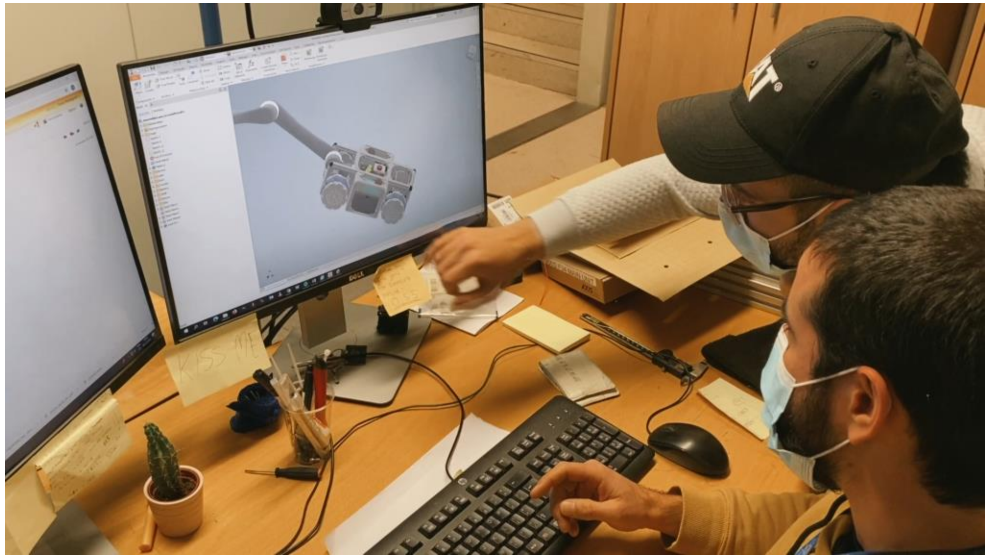
- We gained an important knowledge and experience in designing, producing and applying robots in harsh and hazardous environment

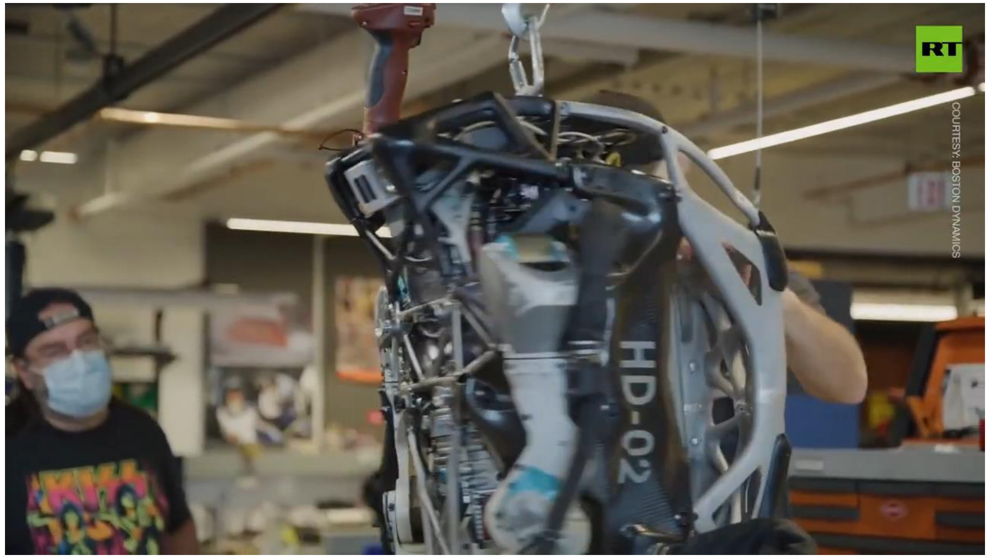
- External collaboration with research centers and Universities is crucial to improve, to share knowledge and to take advantage of the cutting edge technology

Are Robot “serving” humans?



Are Robot "serving" humans? … or we are serving robots?





Many colleagues contributed to the robotic activities during the last years ….
Lots of students (TRNEE, TECH, DOCT)

Robots and robotic instrumentation need a crew to use them and maintain and experts in-house to be effective

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Additional detailed info could be found at the CERN Academic Seminar lectures on Robotics
→ https://indico.cern.ch/event/1055745/

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