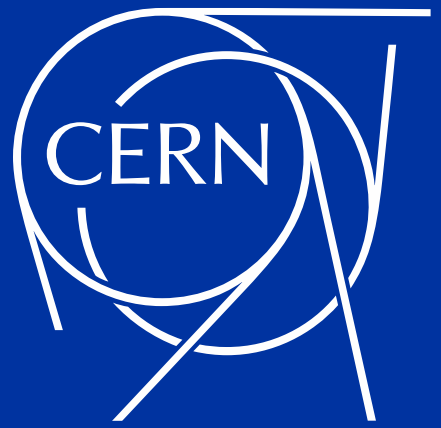


Robotics at CERN

Eloise Matheson

BE-CEM

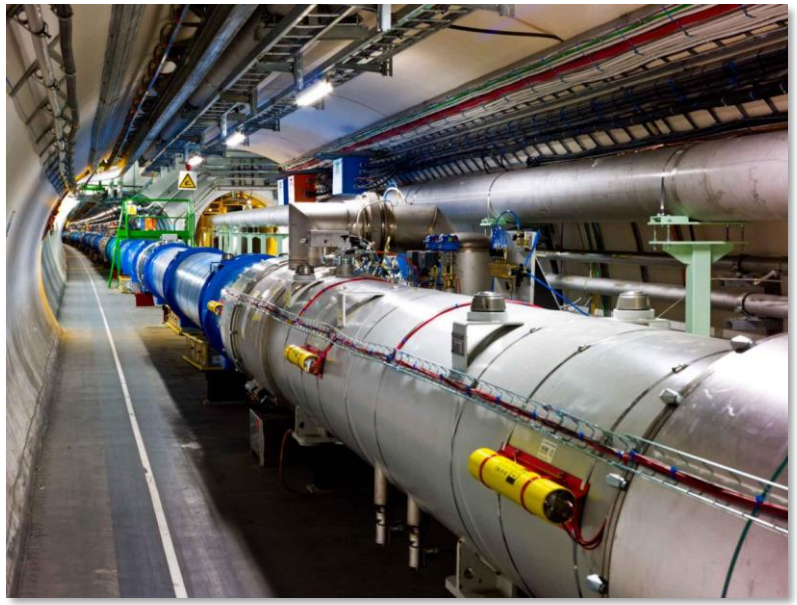
Contents

- Needs and Challenges for Robotics
- State of the art outside CERN
- The Robotic Service at CERN
- Future Objectives

Contents

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

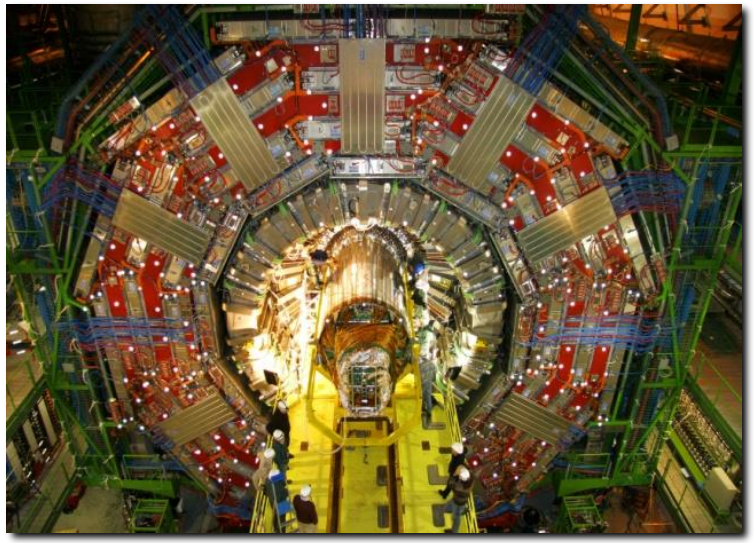
North Area experimental zone

Radioactive sample handled by a robot

Main Challenges for Robotics at CERN

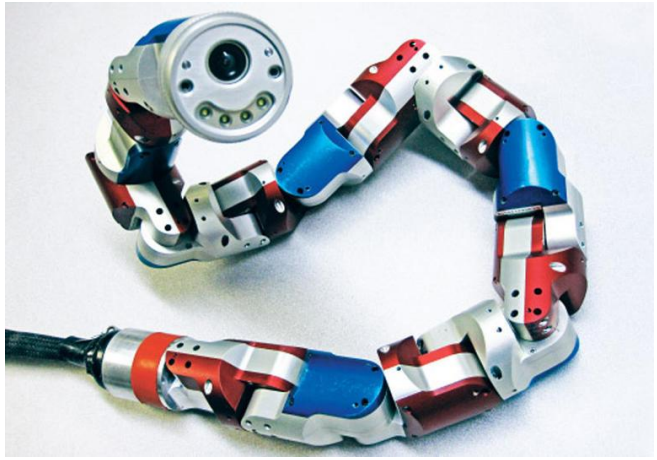
- Maintenance, intervention and inspection in harsh and semi-structured environments
- Radiation, magnetic disturbances, delicate equipment not designed for robots, big distances, communication, time for the intervention, highly skilled technicians required (non robotic operators), etc.



Robotics in Big Science Facilities

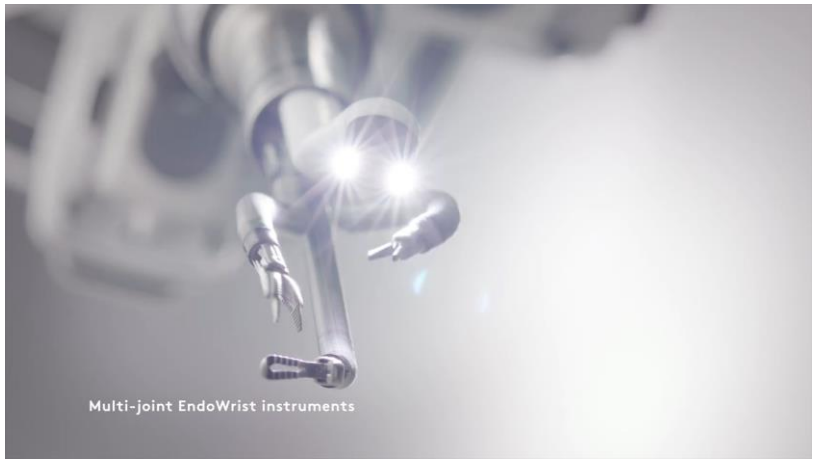
- No single existing robotic solutions can fulfill the needs
- Mobility and manipulation capabilities are required
  - ✓ A “fusion” of several types of robot would be needed
  - ✓ **A modular robot could fulfill several needs**



Contents

Teleoperation in Universities and Research Centres

- Many recent developments towards maintenance and robotic exploration in space applications
  - ✓ Developments towards human behavior reproduction
  - ✓ Need for well-defined interfaces and tools, as well as hyper-trained operators
- Specific developments for medical applications with constraints not always present in big science facility scenarios (limited supervisory control, no autonomy, large scaling of motion etc.)



Intuitive Surgical: https://www.youtube.com/watch?v=TGjnb86HndU

DLR SUPVIS-JUSTIN: https://www.youtube.com/watch?v=FYvt1UMtyp8

- Mainly test and prototypes devices
- Not necessarily designed to be robust
- Industrialization of concepts in most of the cases not possible

Teleoperation in Structured Big Science Facilities

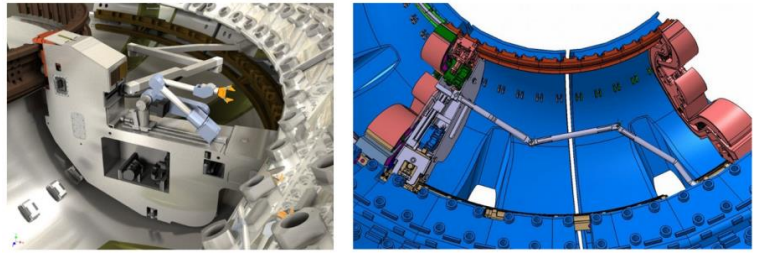
➢Joint European Torus (JET)

JET Torus (left) and remote handling approach using the MASCOT system

➢Spallation Neutrino Source (SNS)

Remote handling control room and the Telerob EMSM 2B tele-manipulator system in use at SNS

➢International Thermonuclear Experimental Reactor (ITER)

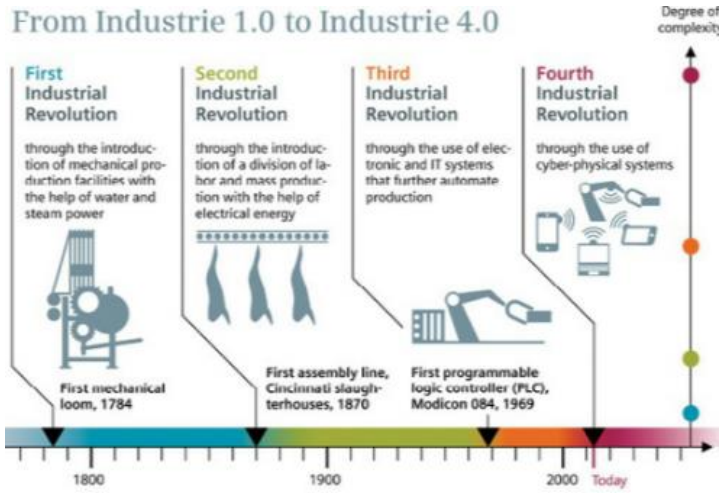


3D image of the remote handling system for the ITER divertor right

- ➢ Mainly master-slave tele-manipulators
  - ✓ Bulky installation in structured environment
  - ✓ Tasks well defined
  - ✓ Extremely well-trained operators
    - ❖ High maintenance costs
- ➢ Unavailability in big science facilities has the most impact on costs
- ➢ Maintenance intervention time is extremely critical

Robotics in Industry

- "No room" for teleoperation applications, generally need robots for quick repetitive tasks
- Long history of industrial robots applied to industrial scenarios, mainly for manufacturing
- Recently human-robot collaborations have been started in highly repetitive scenarios



- Mainly robots performing repetitive tasks in well structured environment
- Changing environment/type-of-place where the robots are deployed often implies a refactoring of mechatronic components
  - ✓ Bulky installation in structured environment
  - ✓ Tasks well defined

Contents

CERN's Robots

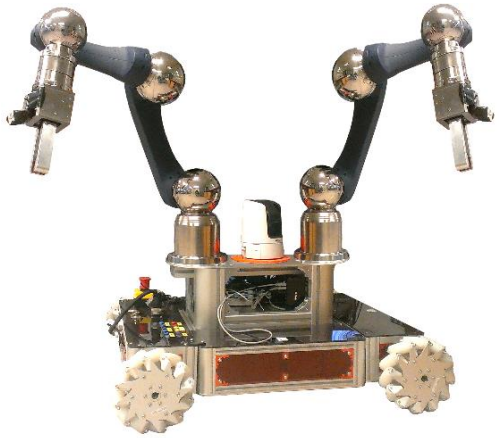
Telemax robot

Teodor robot

Train Inspection Monorail (CERN made)

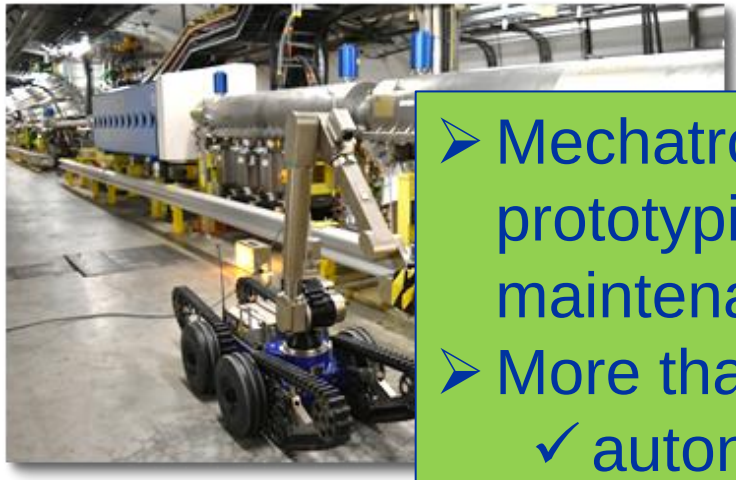
CERNBot (CERN made)

EXTRM Robot (CERN made)

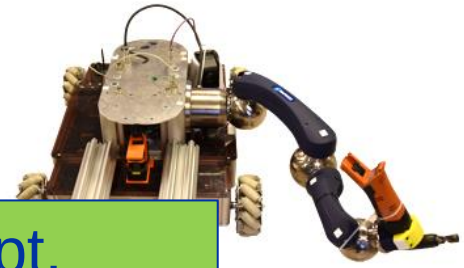


CERNBot in different configurations

CERN's Robots



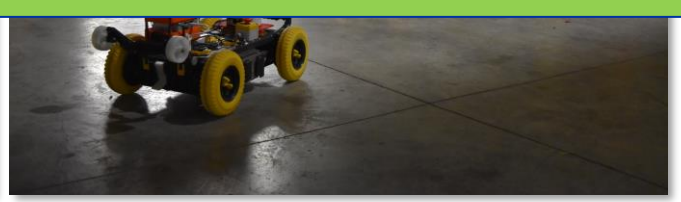
Telemax rob



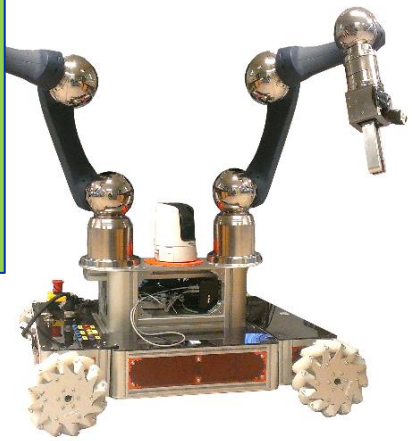
- Mechatronics conception, design, proof of concept, prototyping, series production, operations, maintenance, tools and procedures
- More than 20 robots in operation
  - ✓ autonomous inspections
  - ✓ teleoperations
  - ✓ assisted telemanipulation
  - ✓ autonomous remote operation
  - ✓ safety, search and rescue

Train Inspection Monorail (CERN made)

CERNBot (CERN made)



EXTRM Robot (CERN made)



CERNBot in different configurations

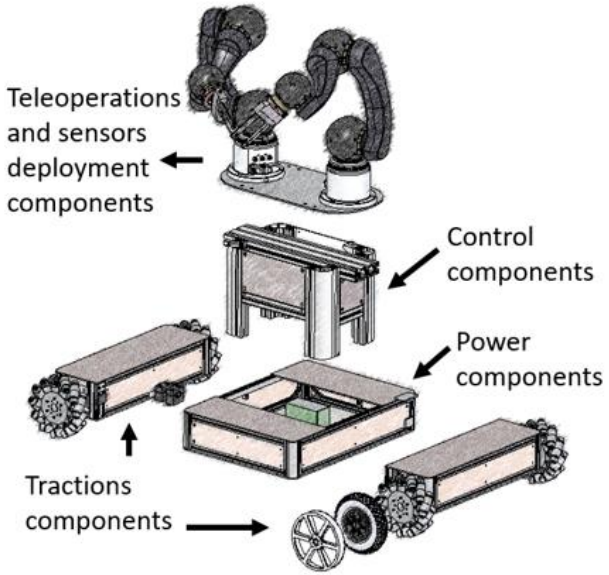
Robots are mainly used at CERN for:

- 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

Main Motivations for Custom Robotic Development

- Industrial solutions do not cover all of CERN needs for remote maintenance and quality control
- Strong need to develop **a modular and adaptable robotic framework/system for** unstructured and harsh environments
- Necessity of having the human, the machine and the interface working together adopting **user friendly interfaces**
  - ✓ Increase of proprioception reducing operator's stress

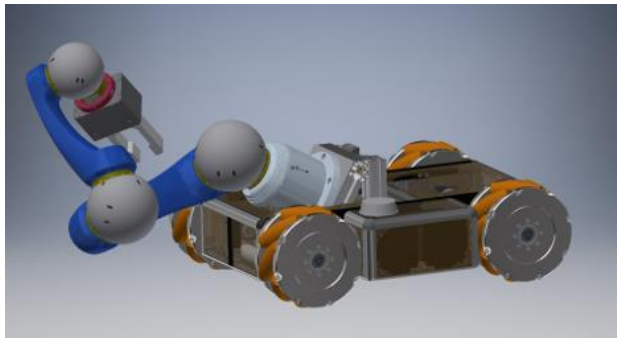
CERNbot Robotic platform design

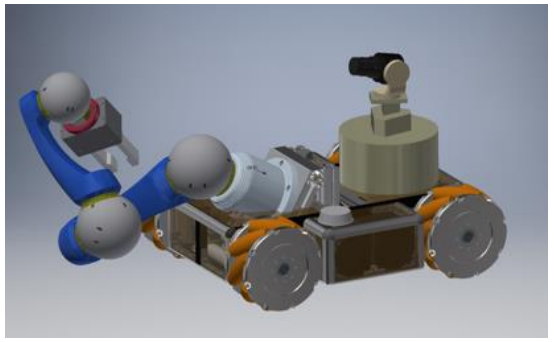


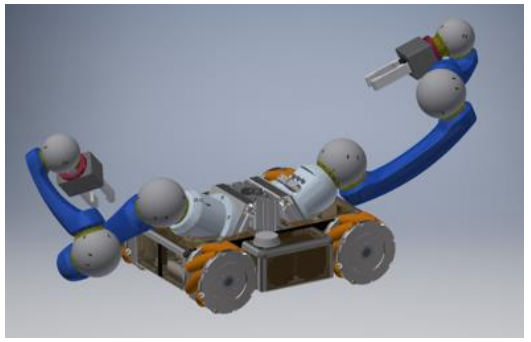
- CERNBot is a custom ground robotic platform normally equipped with two robotic 6DOF arms and grippers for bimanual operation
- Modularity means the same base can be used in different ways to adapt the structure to the task
- The robot has the capability to remove or add modules in order to add functionality or adapt the shape

CERNbot compact design

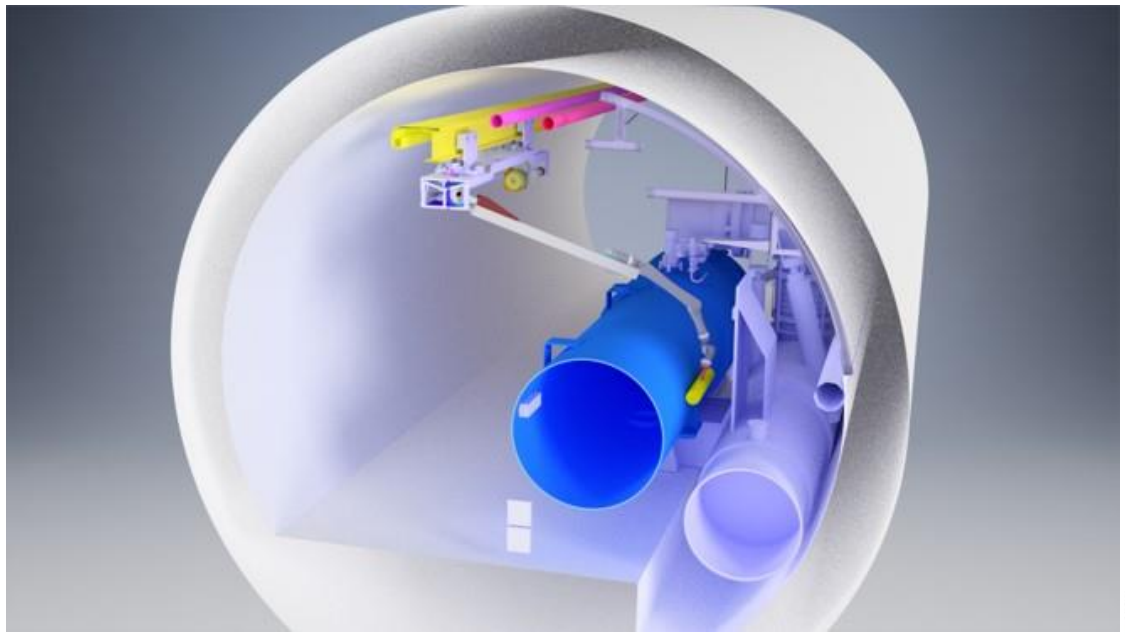
- Starting from the CERNBot, a new family of robotic platforms has been developed to address the needs of compact platforms in constrained spaces/access
- Modularity saves design time and reduces costs

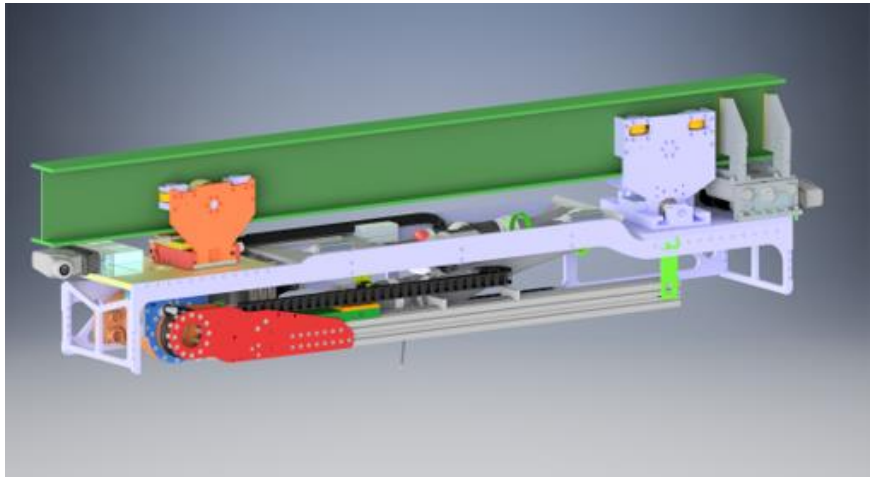


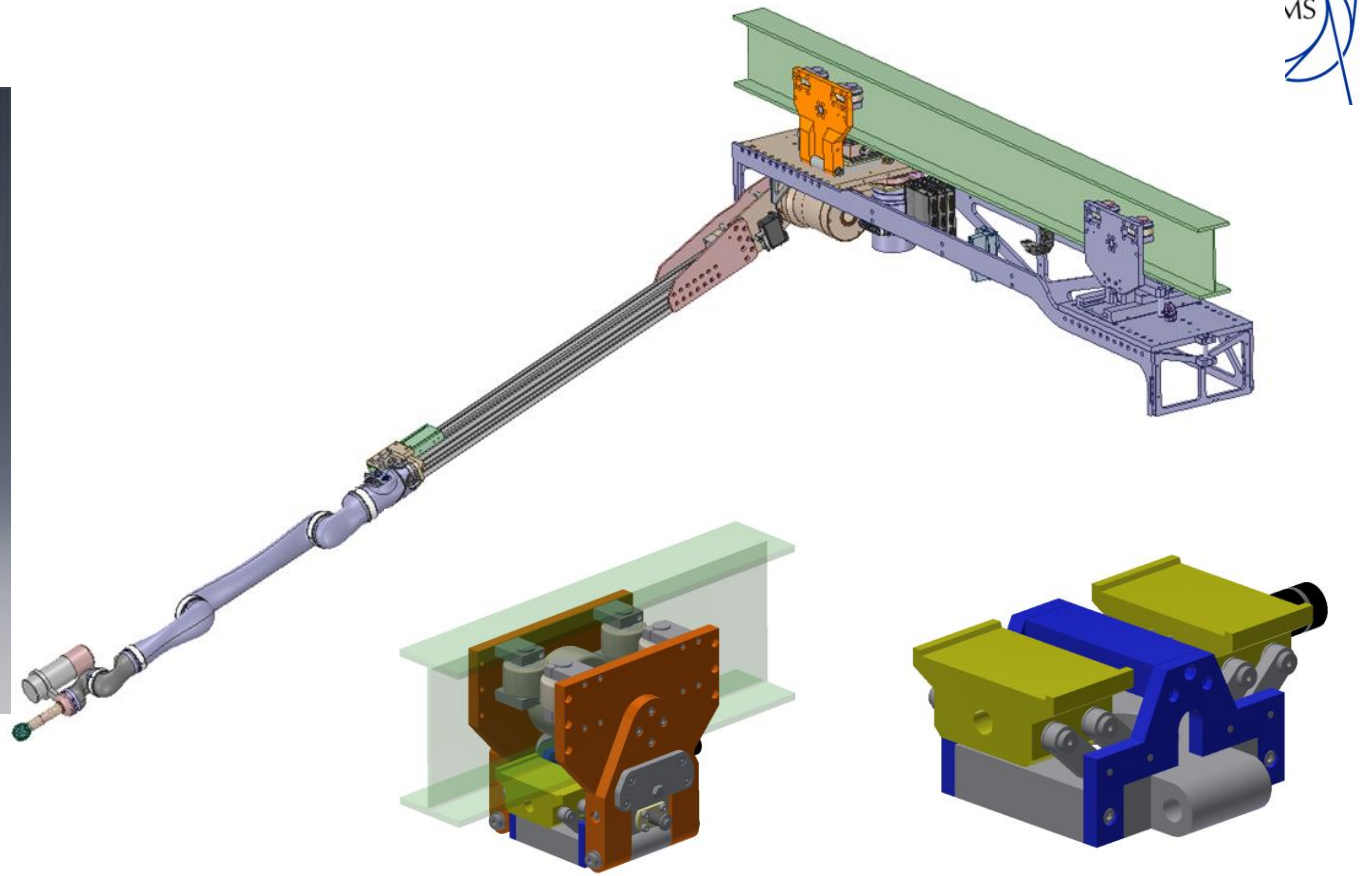




TIM Platform design



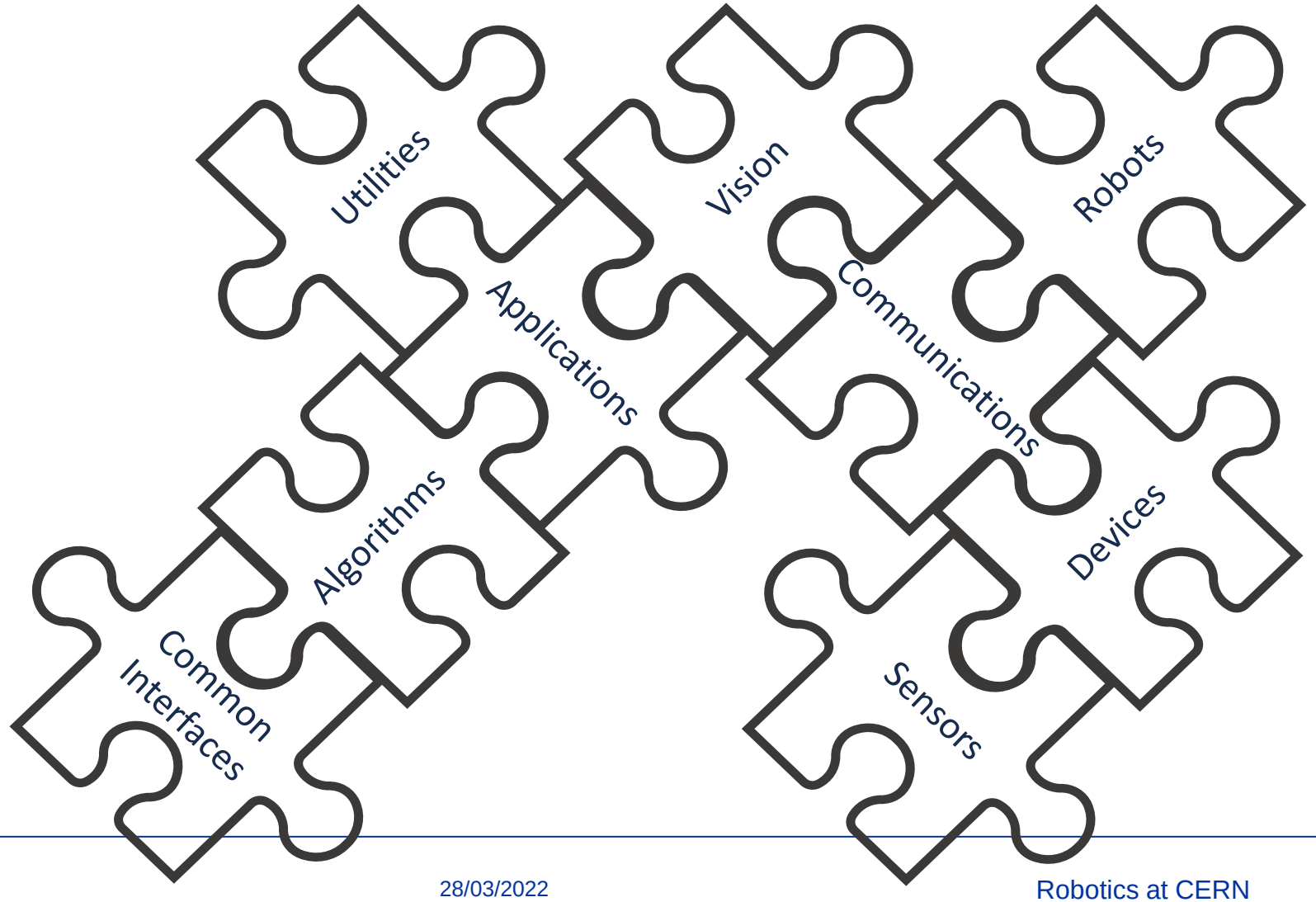


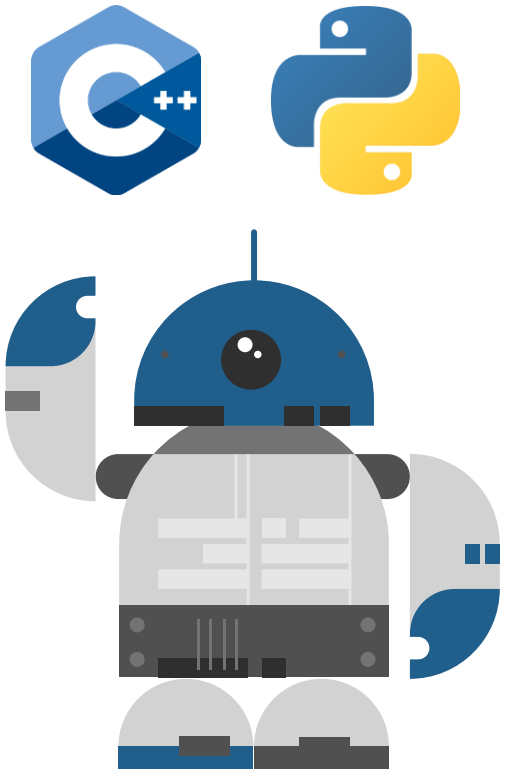


- Monorail mounted robot with different wagons – motors, batteries, sensors, arms
- Different wagons for specific missions

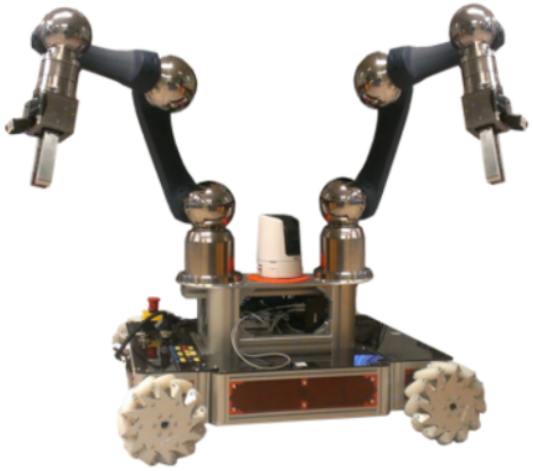
CERN Software: CERNTAURO framework

- Modular Architecture containing onboard software for robotic operations





CERN Software: Control Framework



ROBOT WITH INSTALLED EQUIPMENT AND ITS ON-BOARD COMPUTER

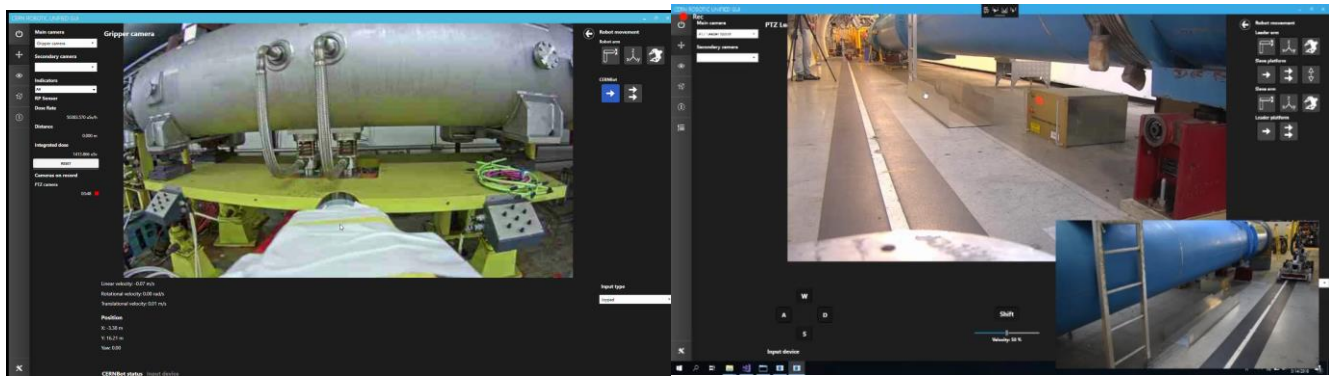
- CERN ROBOTIC FRAMEWORK (C++ framework)
- Communication with devices
- Processing the information from sensors
- Real-time control
- Communication points

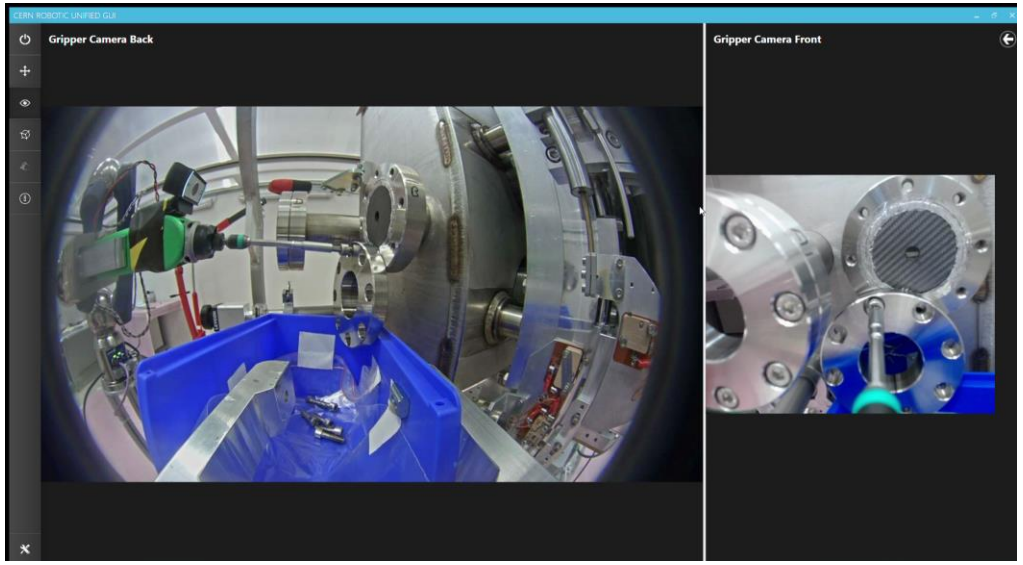
Communication over mobile 4G network, WiFi or CERN internal network

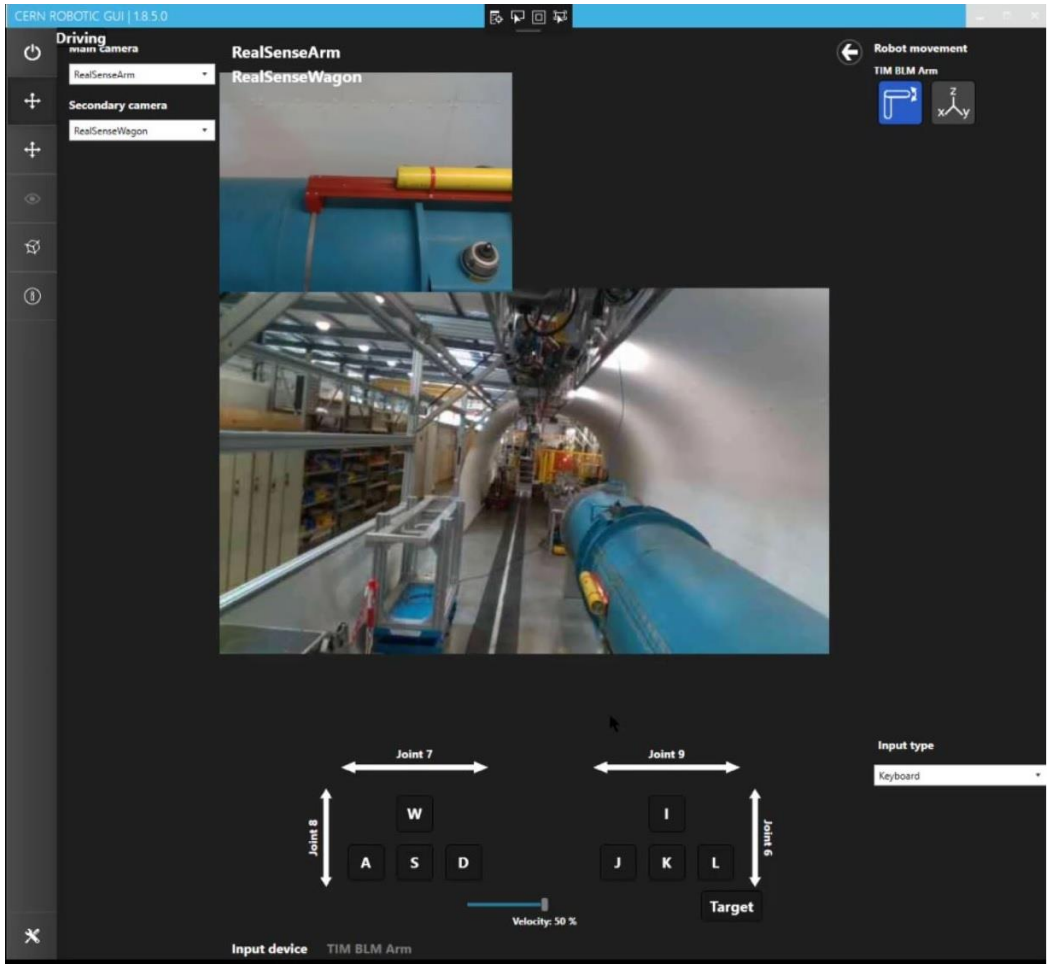
- 2D GUI (Windows Presentation Foundation, C#)
- **3D (Mixed Reality) GUI (Unity, C#)**

TELEOPERATOR CONTROLLING THE ROBOT VIA A PC OR USING HEAD-MOUNTED DEVICES

CERN Software: 2D GUI



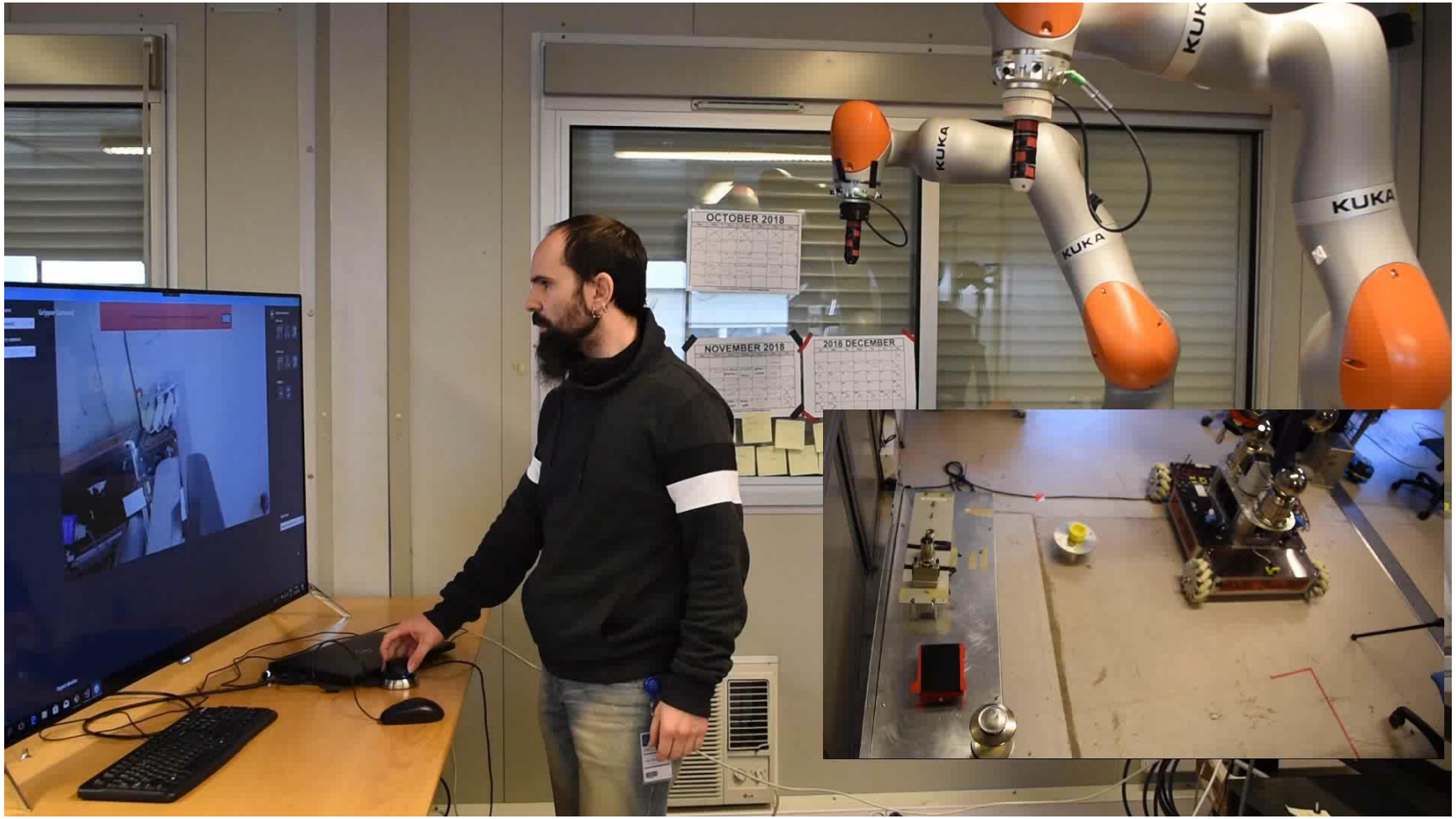




Research Focus Areas

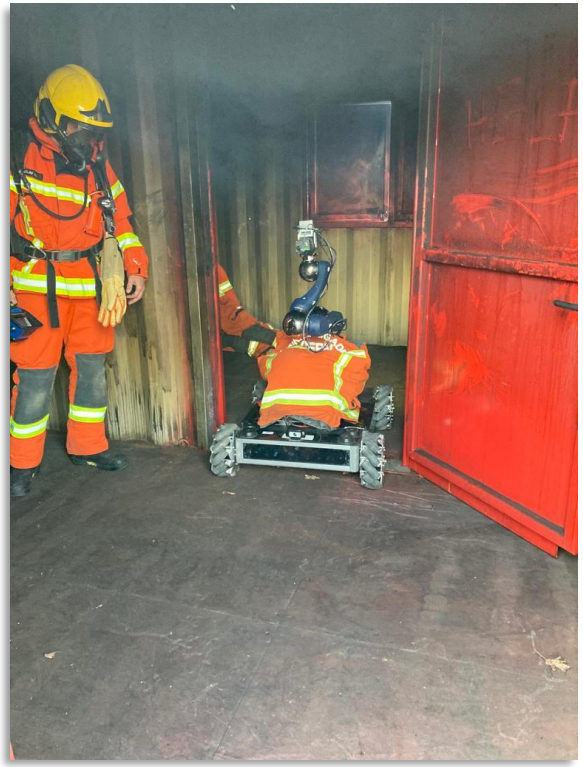
- Human Robot Interfaces
- Operator Monitoring
- Robot Performance Optimisation
- Shared Control and Autonomy
- Robot Design and Topology

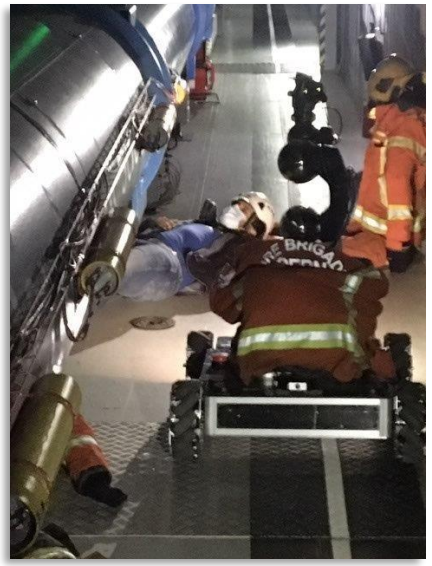
Multi-Arm Teleoperation with Haptic Feedback



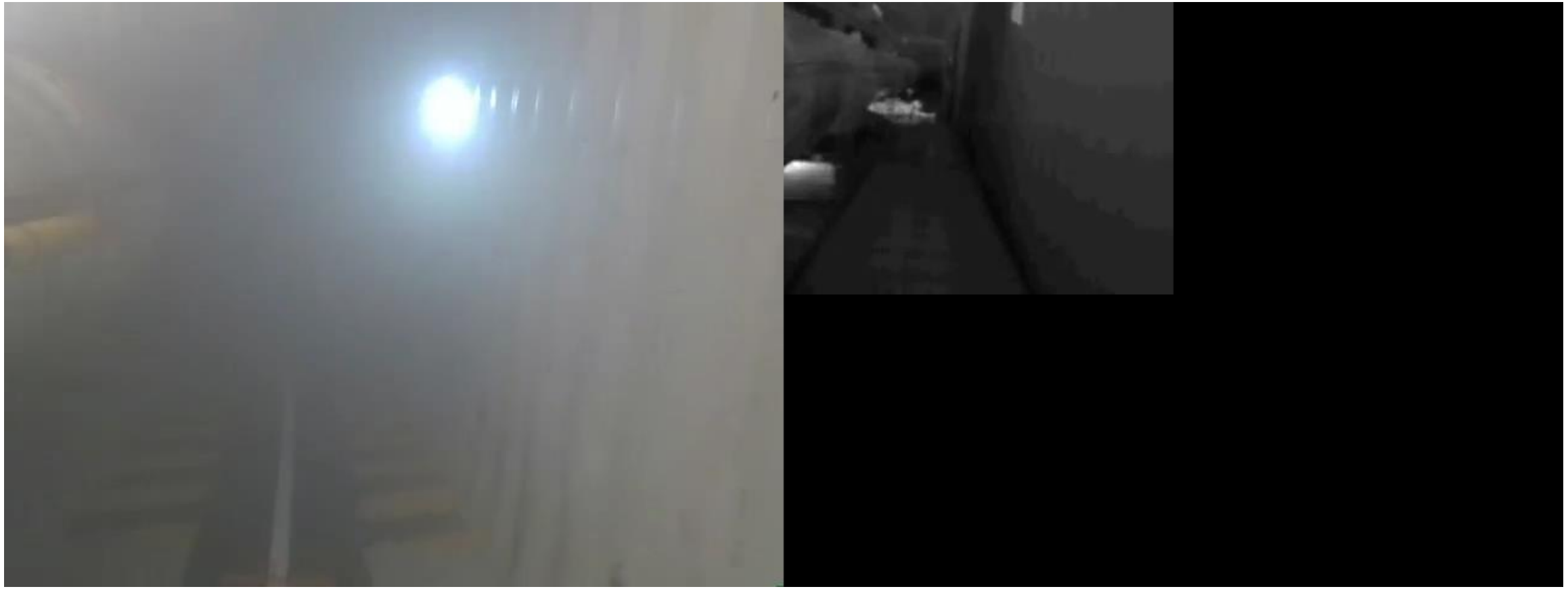
Robots for Search and Rescue

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



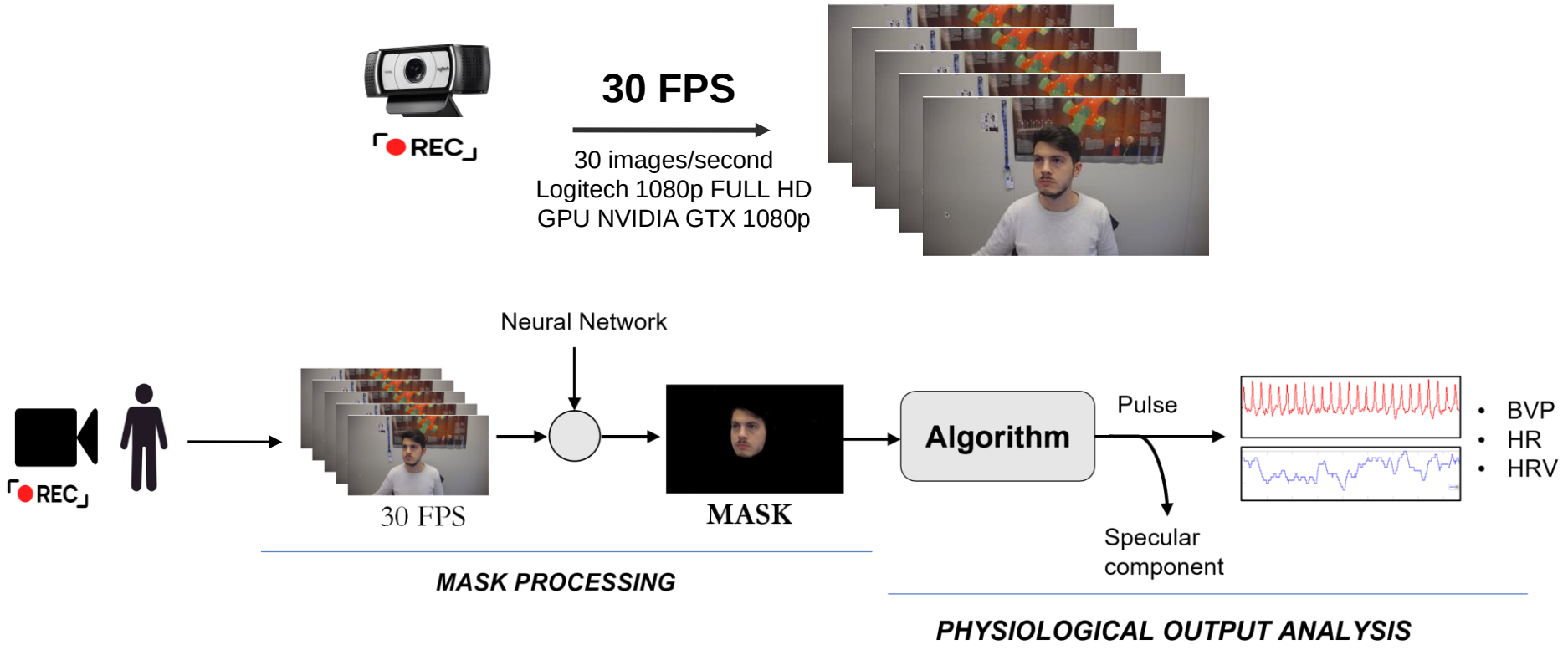


Robots for Search and Rescue



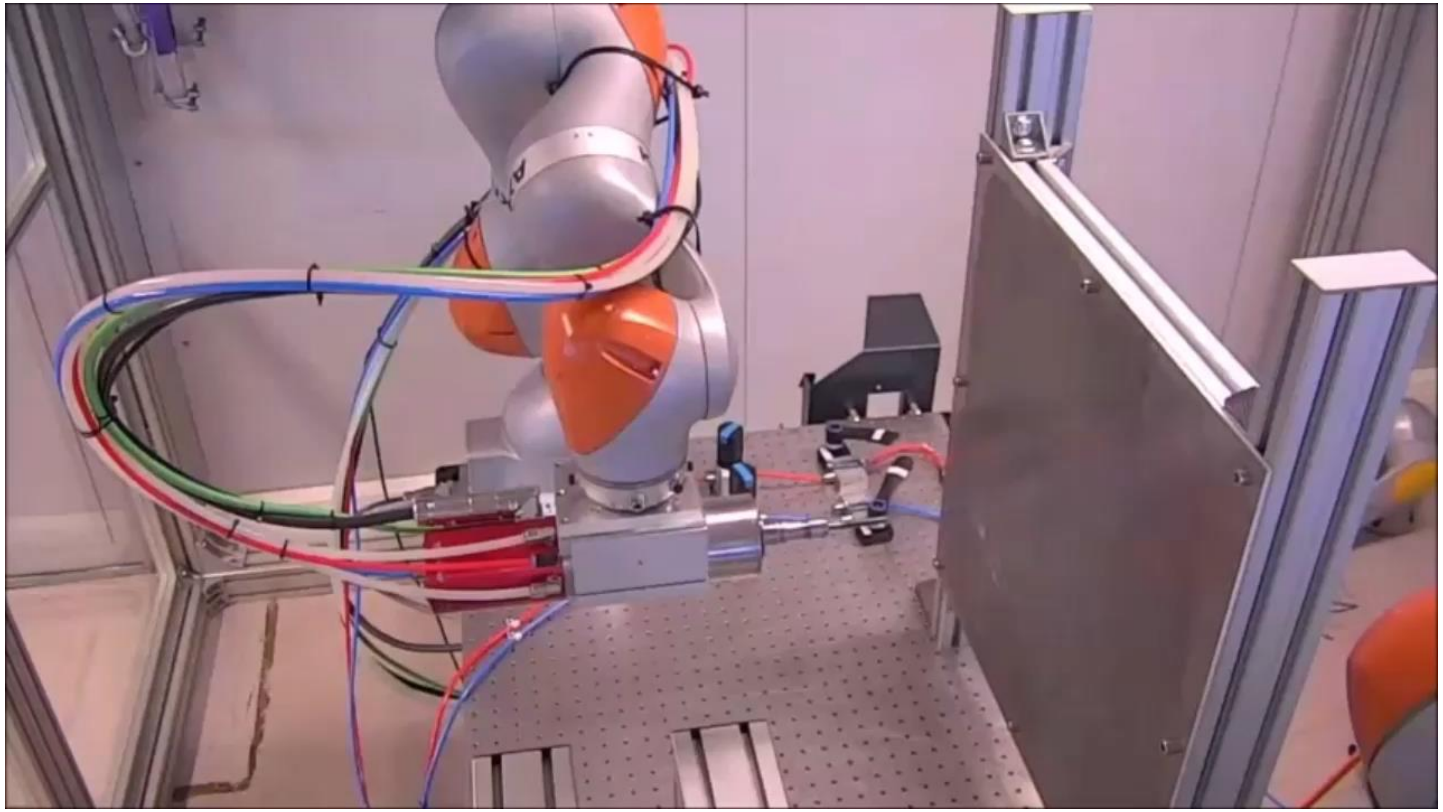
Robots for Health Monitoring

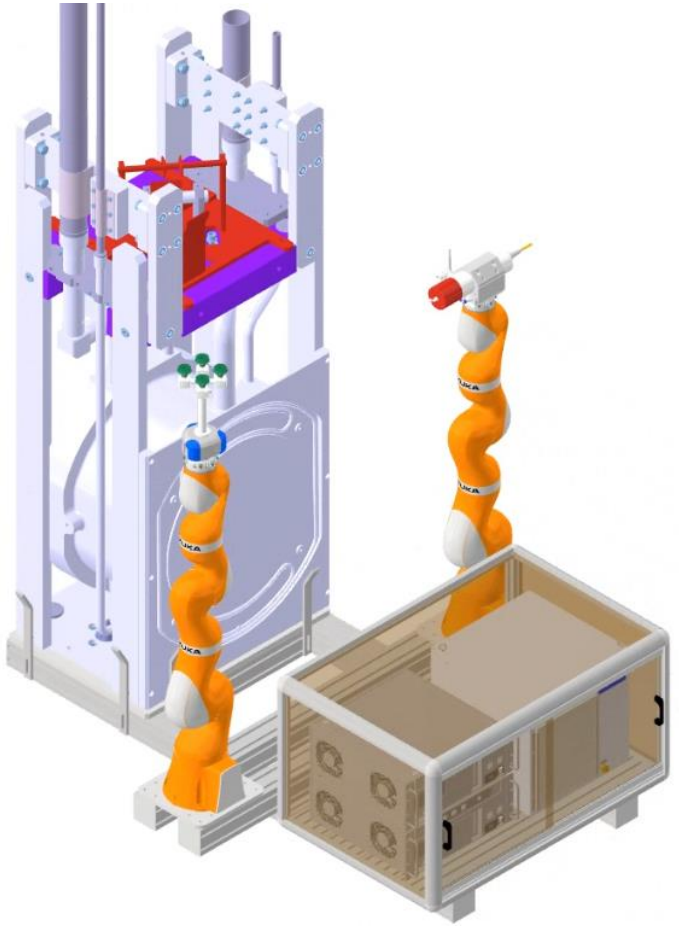
Machine Learning based Human Recognition and Health Monitoring System (MARCHESE)



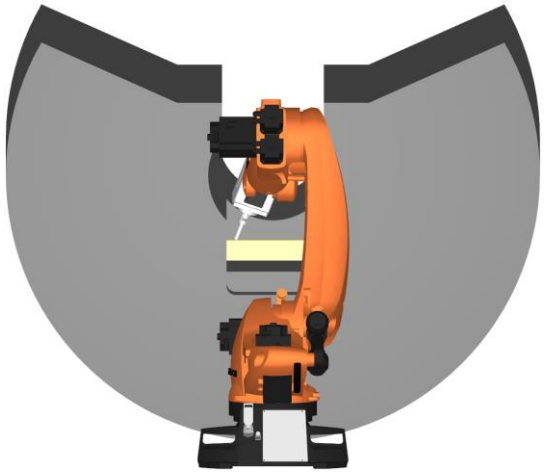
Robots for Milling: nTof

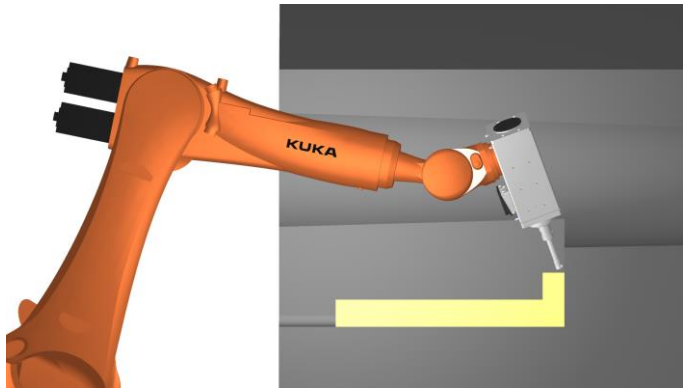
- nTof core inspection and sampling study
- Opening the target by robotic milling solution
- Core inspection and sample extraction





Robots for Milling: ATLAS

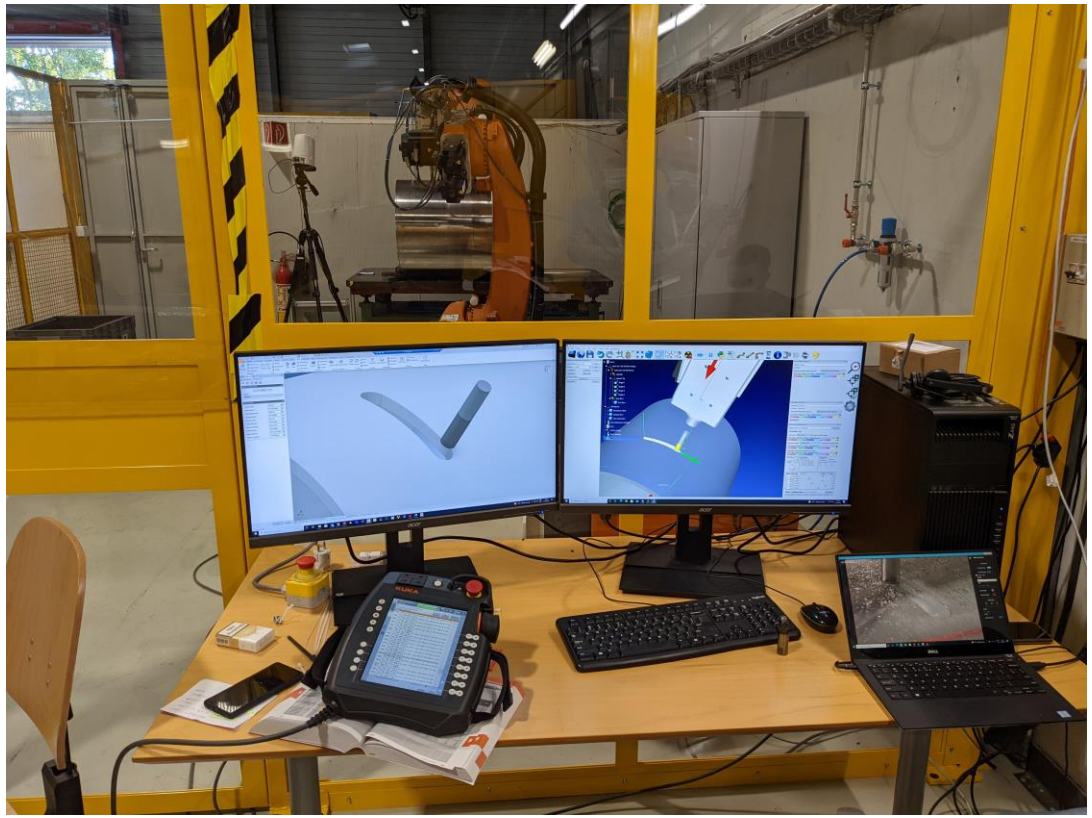




- ATLAS Shielding JFC3 modification by robotic machining

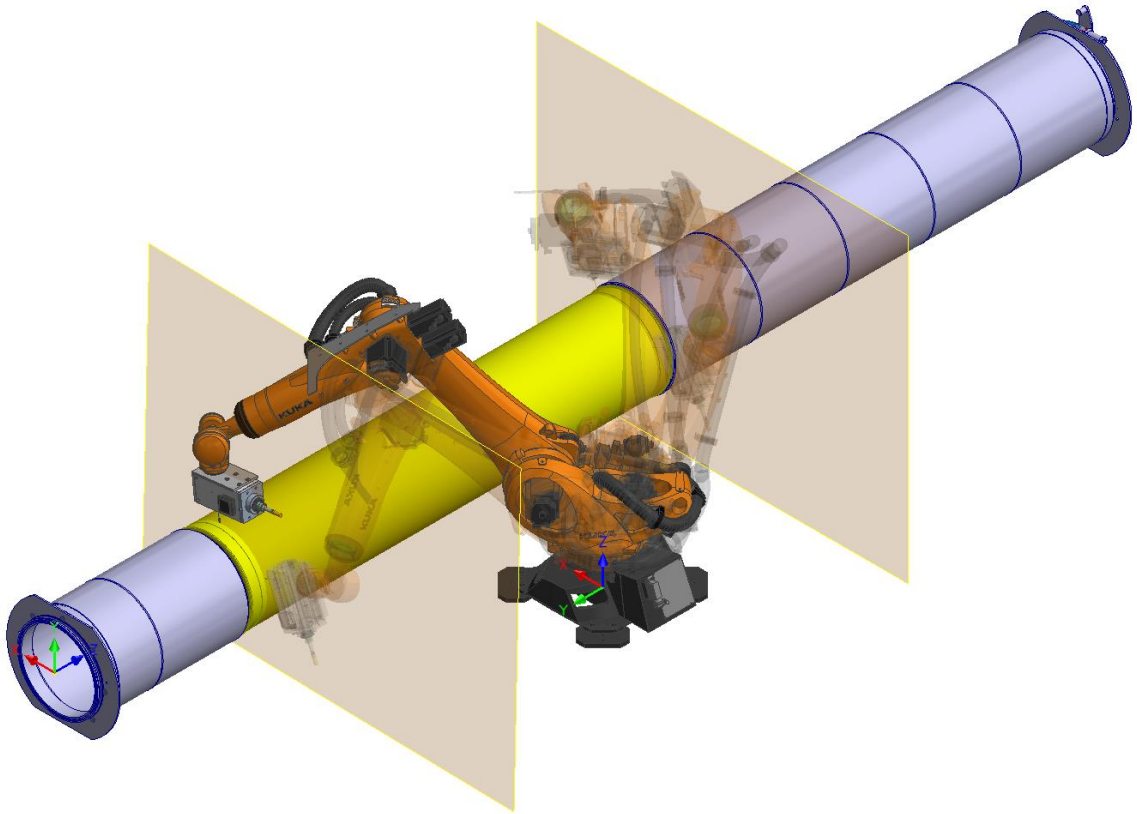
Robots for Milling: LHC TDE

- Milling of 318 LN high strength stainless steel vessel
- Dry and low temperature cutting
- No production of volatile particles or contaminated fluids



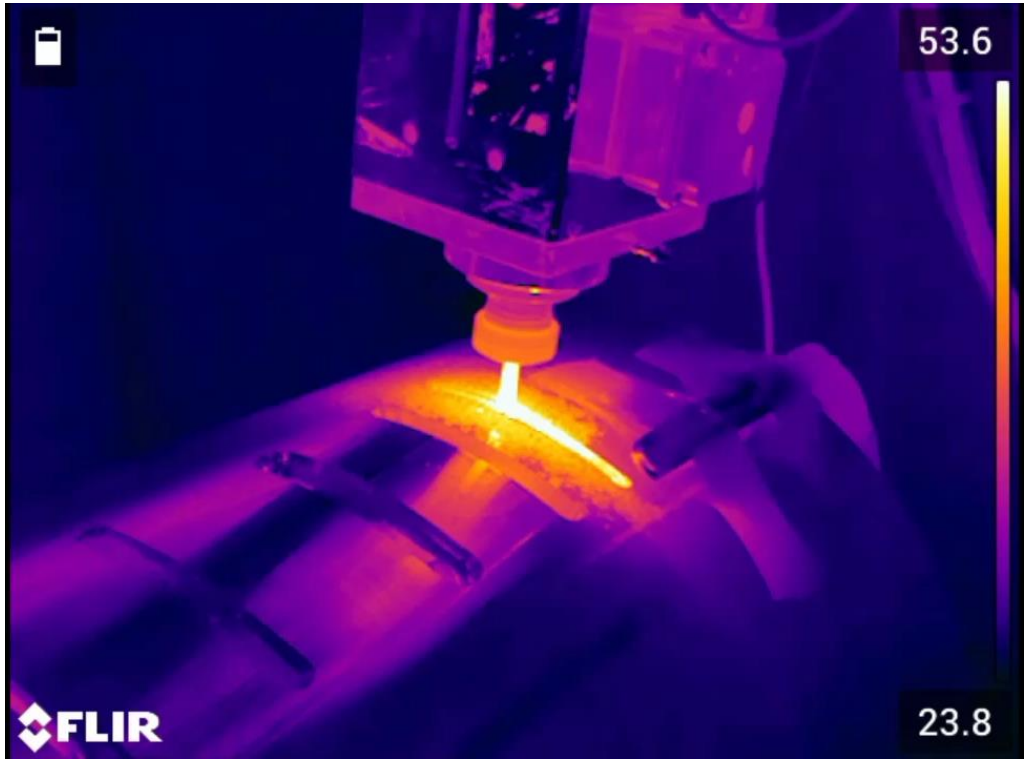
Robots for Milling: LHC TDE

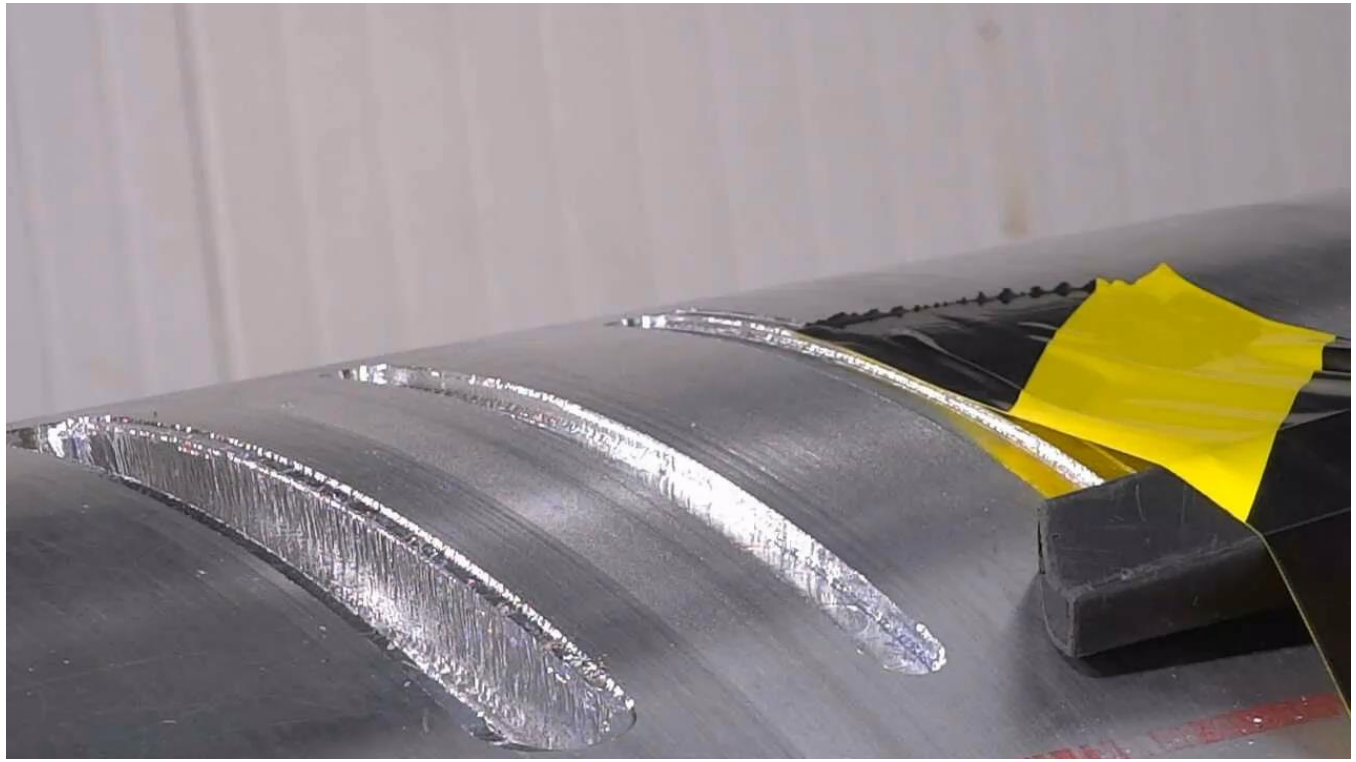
- Calibration is required to increase the machining precision
- A precise linear sensor is used in order to detect contact points to define the reference system or the pipe



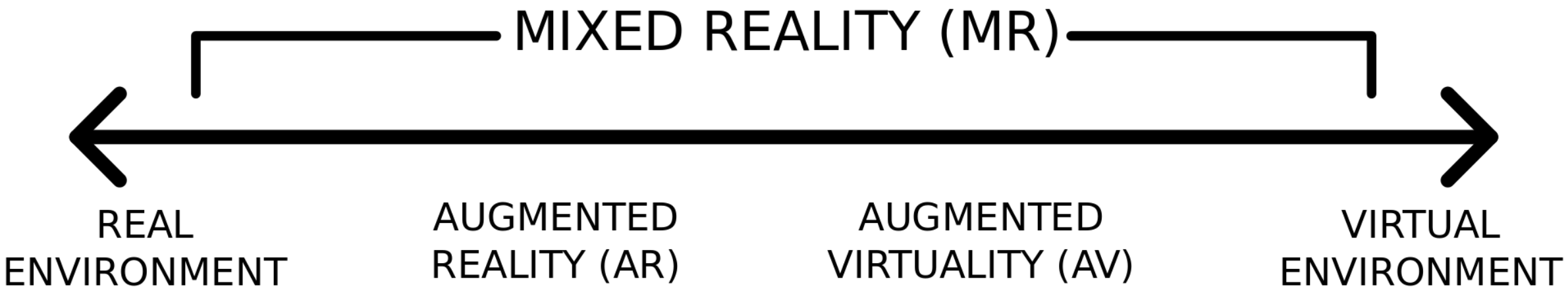
Robots for Milling: LHC TDE

- The cutting parameters created chips (length ~ 5 mm) confined to the working area
- A vacuum cleaning system was mounted on the spindle

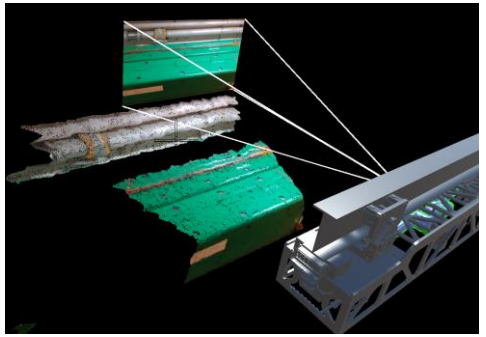


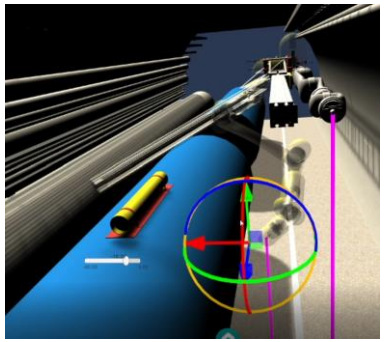


Next Generation Graphical User Interface

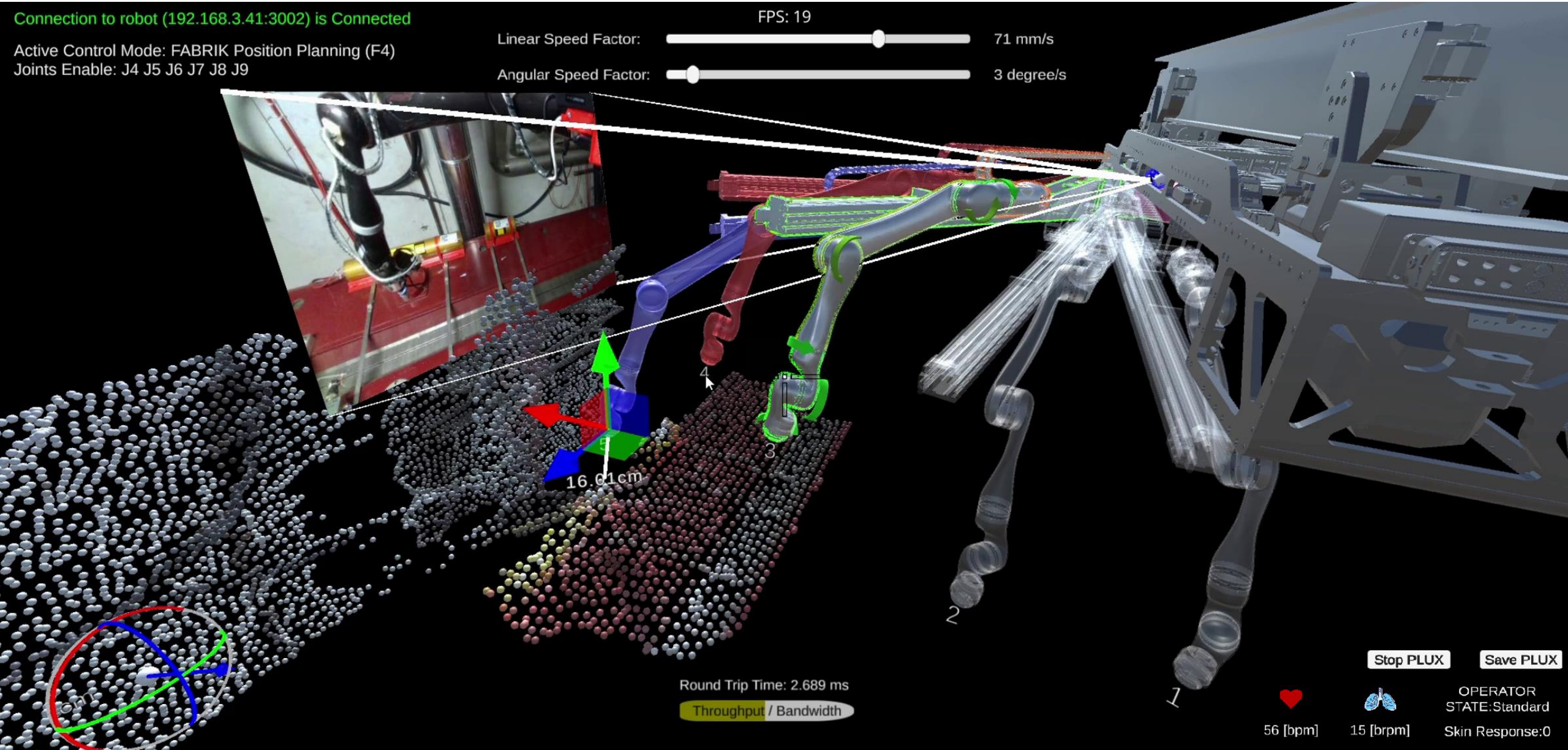


Here Are We

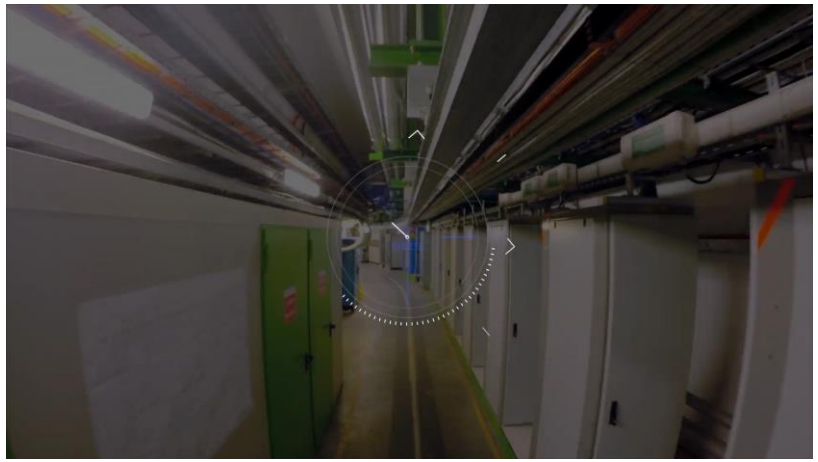




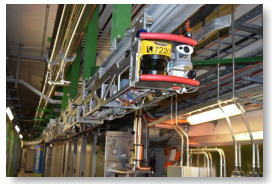
Next Generation Graphical User Interface

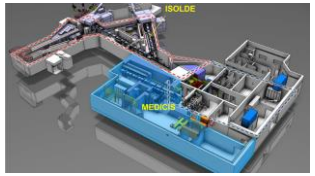


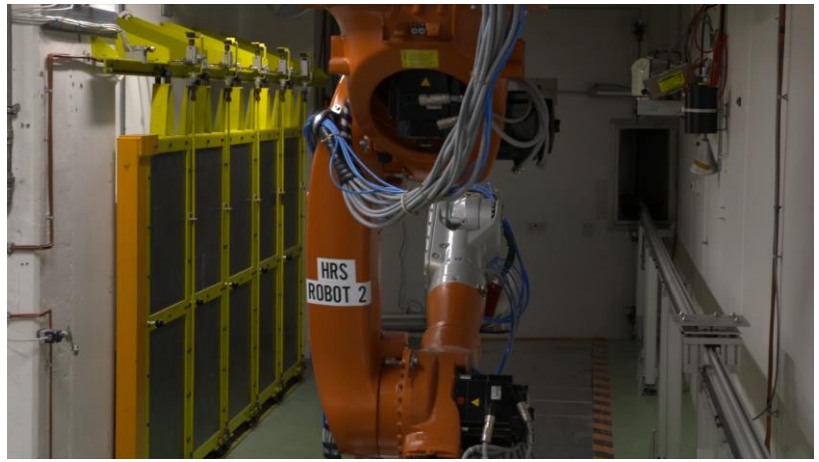
Integration in the Accelerator Complex



TIM Robot

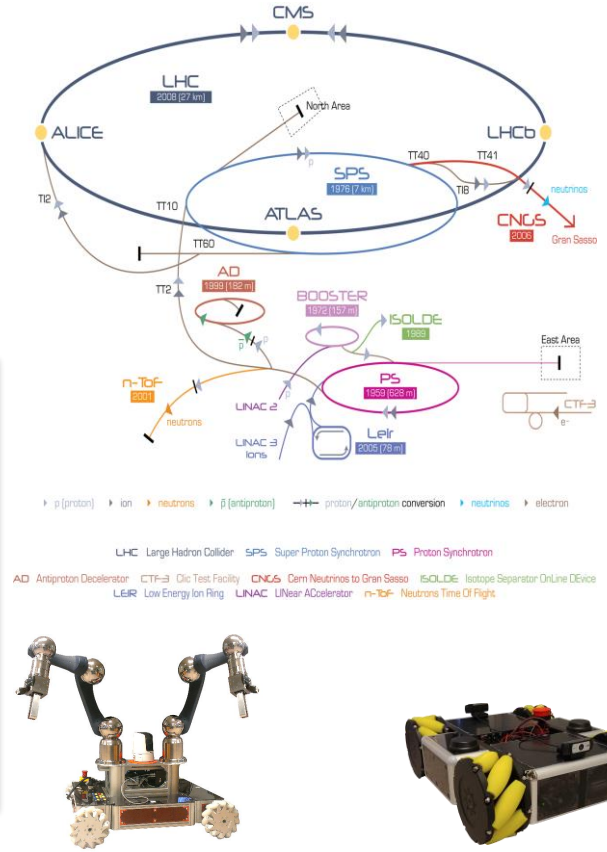






ISOLDE MEDICIS

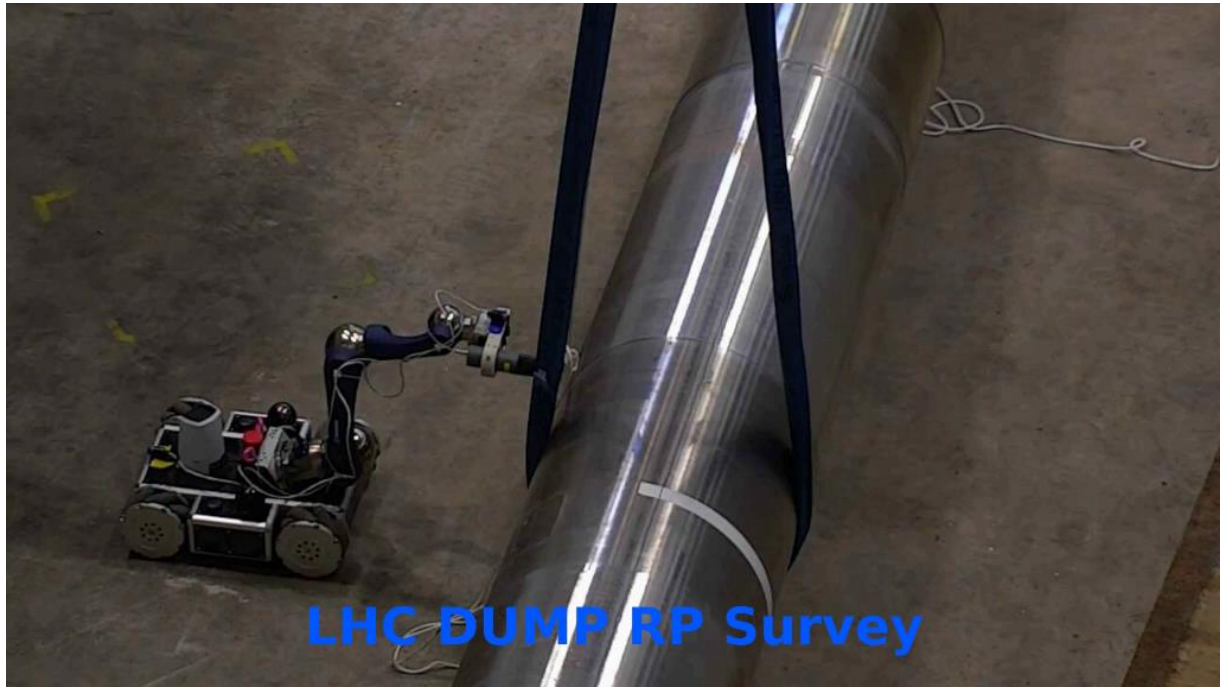
CERNBot



CHARMBot

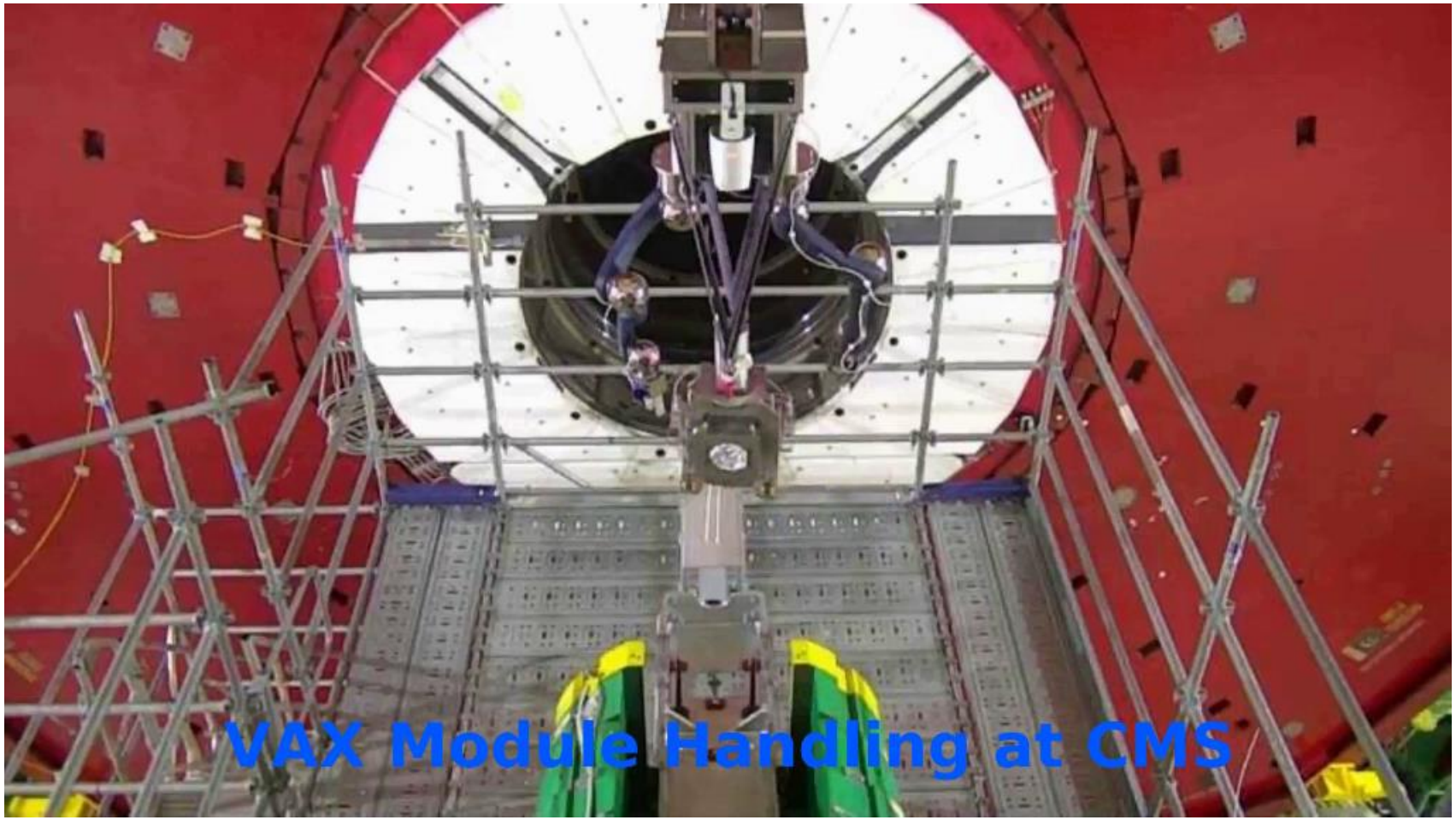
Intervention: CERNBot

Intervention: CERNBot compact use cases



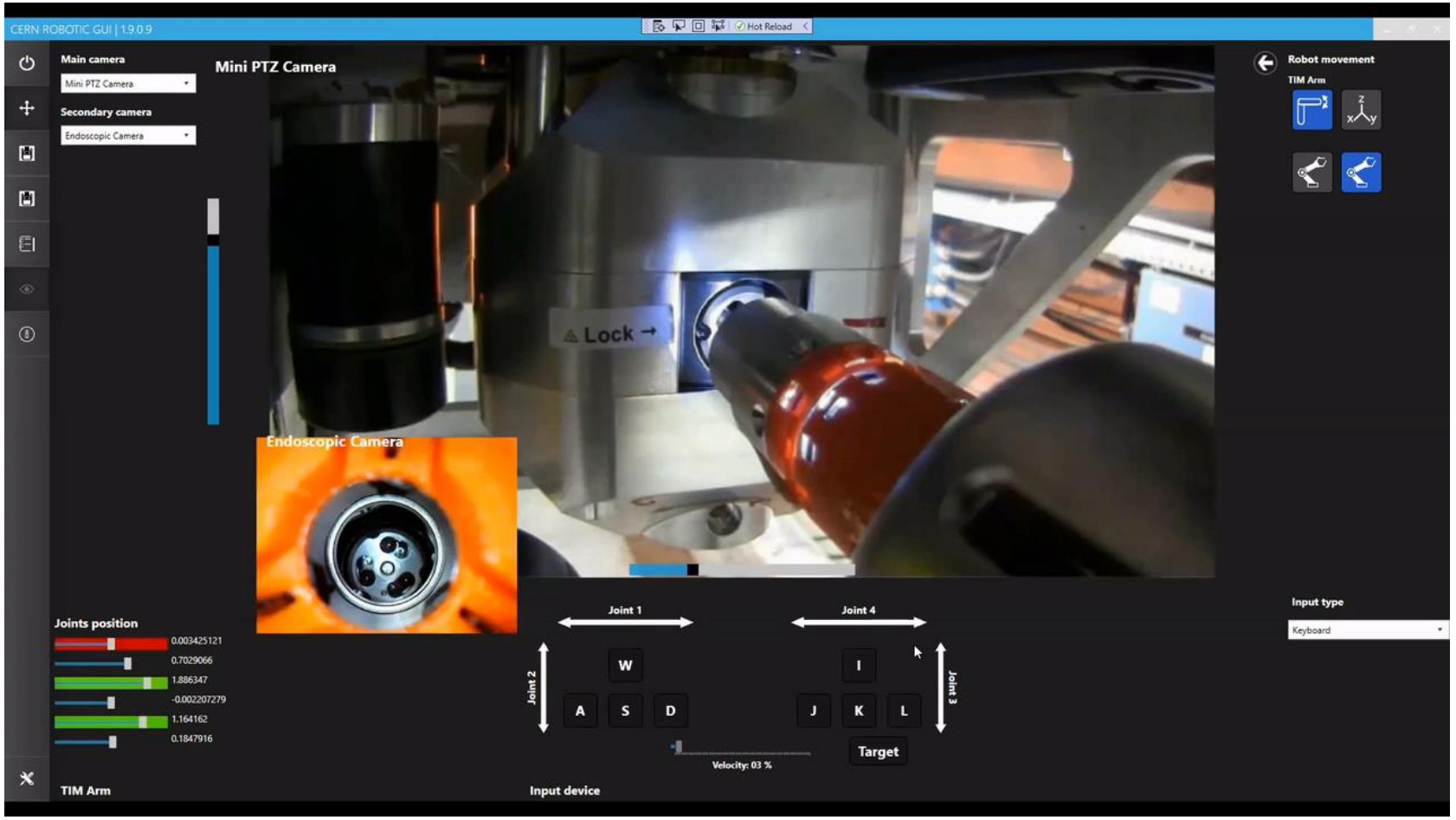
Intervention: SPS inspection robot

Intervention: CRANEBot



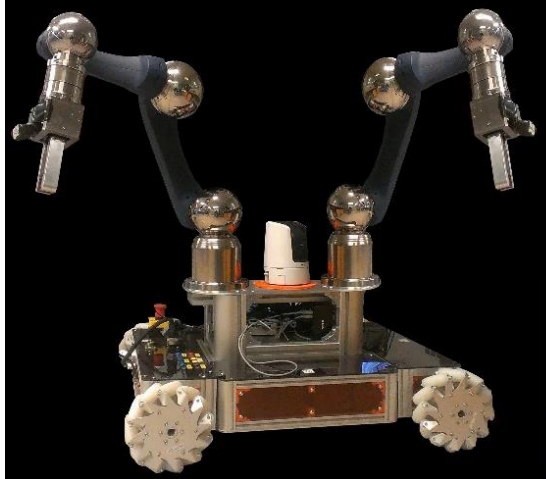
Intervention: TIM Robot in the LHC

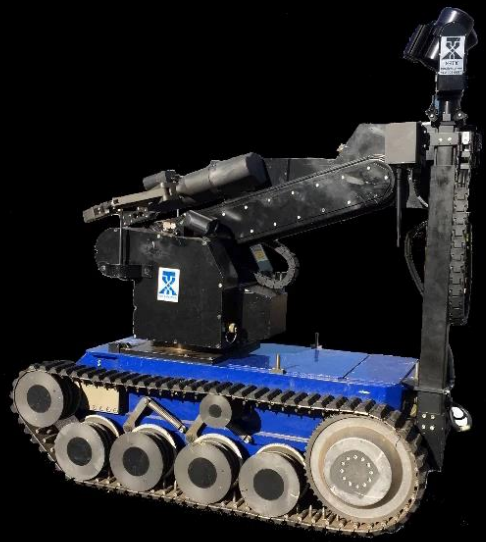
Intervention: Teleoperated BLM Measurements



Interventions: 2020

BDF T6: Removal and samples extraction
CERNBot + Teodor





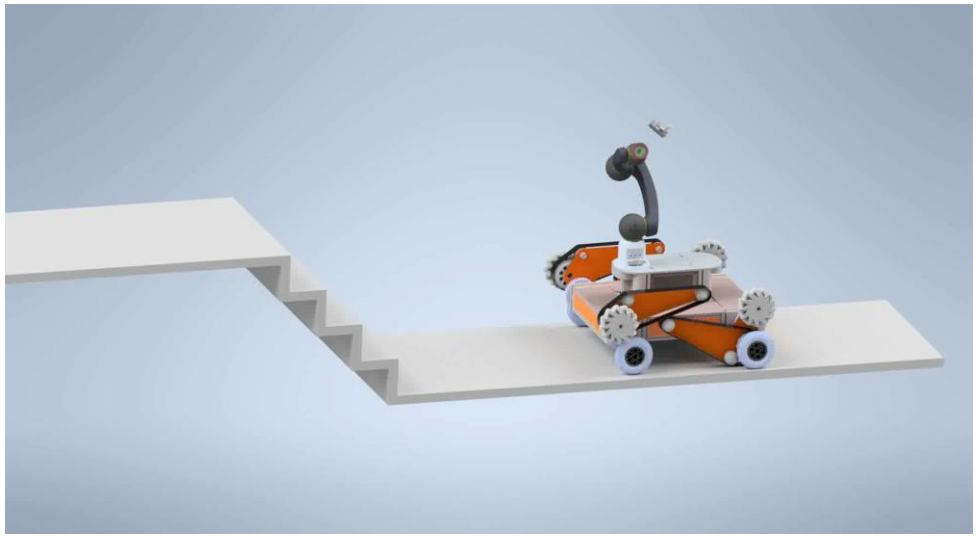
Our Impact

- More than 15 modular robots developed
- Novel tools and intervention procedures based on feedback from operators (towards development of ‘best practices’)
- Novel simulation tools for training and dose estimations
- Novel control software and HRI
- Several Master and PhD Thesis supervised (>30)
- Several publications to conferences and high impact factor journals (>50)
- Organization of the HSSIP + Italian teacher programs for mentoring
- Over 6 ongoing research collaborations
- Chair of the EURobotics Teleoperation Working Group

Contents

Modular Robots

- Adaptive traction system for ground robots
- 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



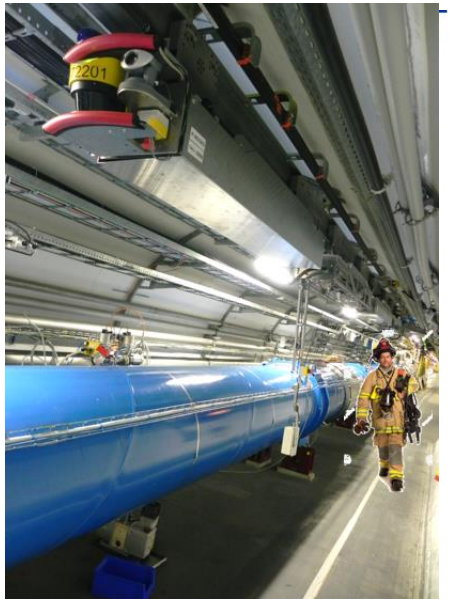
User-friendly Teleoperations

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

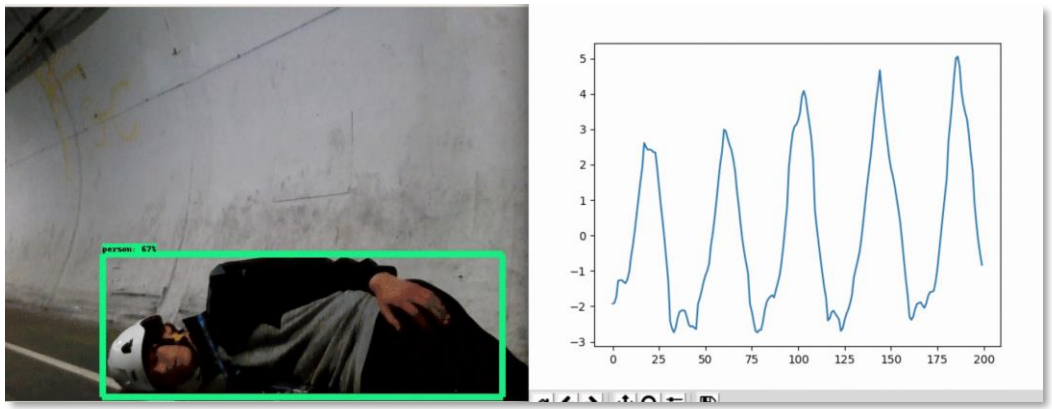
Search and Rescue Robot

- Follow and “drone” accessing firefighting team
- Precise staff localization in harsh environment
- Environmental measurements into augmented reality showed on tablet or glasses for example

Example of Augmented reality glasses



TIM escorting fire brigade personnel



Online respiration monitoring

Online people recognition and tracking

Robots for Future Accelerators (FCC)

- Novel robotics platforms and controls for remote maintenance and intervention in case of accident