Robotic Solutions for Remote Maintenance and Quality Assurance

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BE-CEM

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Acknowledgments

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Content

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

- **Industry 4.0**
  - Robots
  - Artificial intelligence
  - Internet of things
  - Diffuse signals
  - Sensor fusion
  - Simplification in the use of robots

- **Human-robot cooperation**
  - ISO 2011
  - Robots can assist humans
  - Robot learning by demonstration
Robotics: main type of robots

Articulated robots
- Robotic arm
- Scara
- Cartesian
- Cylindrical

Automated guided vehicles (AGVs)

Flying robots

Hyper-redundant/ snakes

Humanoids

Soft robots

Quadrupeds
Robotics: type of robots (based on application)

- Hobbies, competition and entertainment
  - Suitable for high school teaching
- Industrial, farming and agriculture
  - Repetitive tasks
- Medical and healthcare
  - Surgery/Rehabilitation
- Domestic, household, logistics
- Military
- Service and space robot
  - Research
  - Intelligent
Human-robot Interface

- The interface devices are the ones that links the robot to the operators
- They have mainly a double functionality
  - Report the status of the robot
  - Generate commands based on operator actuations
- Classified by their functionality
  - Actuation device: GUI etc.
  - Re-alimentation device: video, graphs etc.
  - Bilateral devices: haptic interfaces
Artificial Intelligence

Intelligence exhibited by machines [1] [2]

- Localization
- Knowledge
- Learning
- Planning
- Decision making
- Perception/Sensing
Great advances in robot vision thanks to supervised deep learning techniques
- Accuracy in object tracking (Fast-RCNN, Mask-RCNN)
- Object grasping points calculation

Control of closed chains kinematic robots
- Still an open issue, Long short-term memory (LSTM) networks for system dynamic learning

Advances in situation awareness for autonomous behaviors
- Possibility of learning to predict external changes in the environment

Human-Robot collaboration
- Advances in speech recognition, gesture recognition, human action prediction
Machine learning in Robotics #2

- Robotics community is investing strongly in machine learning adapted to social robotics
Robots made by *Boston Dynamics*

ATLAS: A mystery for the robotic community
Robots made by *Boston Dynamics*

Spot: A mystery for the robotic community
Recently announced a new robot: TESLA bot
Our dream: Robots made in Hollywood

iRobot, movie of 2004 anticipating what we’ll have in 2035
Robots trying to solve “real” tasks

DARPA Robotics Challenge [5]
Current state of collaborative robots

- Robot still do not appear fast enough
  - Slow in decision making
  - Difficult to adapt to real world scenarios
Where R&D in Robotics Worldwide is Mainly Going?

- **Focus/resources on:**
  - Social robotics
  - Autonomous driving vehicles
  - Surgical robotics
  - Powered by AI
Teleoperation: a step of 80 years

Primary-secondary robot controls with visual feedbacks, unilateral fully mechanic tele-manipulators (during the 40’s, nuclear applications)

Primary-secondary robot controls with haptic feedbacks, bilateral tele-manipulators (today, used for space applications)

Courtesy of Argonne National Labs

Courtesy of DLR
Teleoperation in Universities and Research Centers

- 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

Intuitive Surgical: https://www.youtube.com/watch?v=FYvt1UMtyp8

Mainly test and prototypes devices
- Not necessary designed to be robust
- Industrialization of concepts in most of the cases not easy
Teleoperation in Structured Big Science Facilities

- Joint European Torus (JET)
- Spallation Neutrino Source (SNS)
- International Thermonuclear Experimental Reactor (ITER)

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, need of quick repetitive tasks
- Long history of industrial robots applied to industrial scenarios mainly for manufacturing
- Recently human-robot collaborations have been started for 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
Opportunity for Robotics

Robotics technology will play a very important role for us to overcome the negative effects of Megatrends

Aging population
Climate change
Urbanization
Etc.

Manufacturing
Food production
Construction
Goods fulfillment
Mobility as a service

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Robotic Solutions for Remote Maintenance and Quality Assurance

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?
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. **ALARA principle followed for each intervention**
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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
Availability of Particle Accelerators

<table>
<thead>
<tr>
<th>Reliability</th>
<th>Maintainability</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>Decreases</td>
<td>Decreases</td>
</tr>
<tr>
<td>Constant</td>
<td>Increases</td>
<td>Increases</td>
</tr>
</tbody>
</table>

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
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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)

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Robotic Support for CERN: Type of Robots Overview

- Mechatronics conceptions, designs, proof of concepts, prototyping, series productions, operations, maintenance, tools and procedures

- Teodor robot

- Drone for tele-operation support

- EXTRM robot (CERN controls)

- CERNBot [11-17] in different configurations (CERN made)
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 semi-structured and harsh environments.
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
CERN Telemanipulation semi-Autonomous Unit for Robot Operations

- 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

CERN TAURO framework [7]
CERNTAURO framework

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

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General Scheme of a Teleoperated System

- **Operator Environment** (Operator + Human Interface)
  - Actuation Devices
  - Feedback Devices
  - Interface Devices
  - Command Processor
  - Feedback Processor
  - Interface Algorithms

- **Remote Environment** (Robot + Sensors + Task)
  - Task Processor
  - Information Processor
  - Remote Algorithms
  - Sensor Acquisition
  - Telerobot Actuators
  - Remote Devices

Communication Channel
- Operator commands
- Local Control Loops
- Task information
How the robots are controlled

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
Unilateral vs Bilateral Controls

Unilateral control scheme of CERNTAURO
Unilateral vs Bilateral Controls

Unilateral control scheme of CERNTAURO
Unilateral vs Bilateral Controls

Bilateral control scheme of CERNTAURO. Experience of imitation
Unilateral vs Bilateral Controls

Bilateral control scheme of CERNTAURO. Experience of imitation
Dynamics

Example: Compliant Control

1. Mass spring damper system
   \[ M \ddot{x} = h - Cx - D \dot{x} \]

2. Discrete Frequency domain
   \[ G(z) = \frac{b_0}{1 + a_1 z^{-1} + a_2 z^{-2}} \]

3. Implementation in C++ Framework in Direct Form II

4. Controller

   - Trajectory
   - Inverse Dynamics
   - Robot
   - DF2 Filter

Problem: Low Damping: High Damping:
Haptics

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

Virtual Wall – often as a linear spring, \( k \) is the stiffness coefficient

\[
F(x) = \begin{cases} 
-kx, & \text{if } x > 0 \\
0, & \text{otherwise}
\end{cases}
\]

Simple shapes – often as a potential well (repulsive or attractive), e.g. sphere

\[
F(x,y,z) = \begin{cases} 
-k(x^2 + y^2 + z^2 - r^2), & \text{if } x^2 + y^2 + z^2 < r^2 \\
0, & \text{otherwise}
\end{cases}
\]

Tactile Sensors – lighter contact, up to 10kHz bandwidth
- Thermoreceptors (temperature)
- Mechanoreceptors (see below)
- Nocireceptors (pain)

Kinesthetic/Proprioceptive Sensors – heavier contact, ~0.1-100Hz bandwidth
- Force sensors (Golgi tendon organs)
- Position and motion sensors (muscle spindles)

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

More on E. Matheson Academic lecture
https://indico.cern.ch/event/1055745/
Bilateral Controls and Haptics

High sensitivity
Impedance-Mode Control

\[ F_{\text{op}} = Z_{\text{op}}(\dot{x}_{\text{op}}), \text{where } Z_{\text{op}} \text{ in the operator impedance} \]
\[ F_{\text{env}} = Z_{\text{env}}(\dot{x}_{\text{env}}), \text{where } Z_{\text{env}} \text{ in the environment impedance} \]
\[ F_{\text{op}} = F_{\text{env}} \text{ is equivalent to perfect transparency} \]
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
CERNTAURO image processing module for the operator could automatically adjust the picture orientation/rotation given to the operator to increase the tele proprioception and to increase the transparency of the teleoperation system.
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 Academic lecture, https://indico.cern.ch/event/1055745/
Main Robots integrated/controlled within facilities at CERN

TIM (x4)

Kuka Robots (x3), Collaboration with EN-HE

MIRA - CERNbot

CHARMbot
Novel TIM robotic wagon

- 6 DoF (rotational axis) + 1 DoF (linear axis) for dexterity
- 2 DoF (harmonic drive, backlash-free) for transversal positioning
- 1 stabilization axis
- 5 cameras
Modular Robot/Concept (CERNbot)
Modular Controls

- Particle beam target maintenance, integration of CERNTAyro on industrial robot
  - CERNTAyro adaptability → seamless control of multi-robots
  - Manipulation from unstable support
Current use of Enhanced Reality in BE-CEM

- 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 Academic lecture https://indico.cern.ch/event/1055745/
Mixed Reality Human-Robot Interface

- Train Inspection Monorail (TIM) transporting the robotic manipulator
- BLM robotic manipulator (9 DOF)
- Robot's effector
- Beam Loss Monitor (BLM)

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

- 2D GUI (Windows Presentation Foundation, C#)
- 3D (Mixed Reality) GUI (Unity, C#)
- LOCAL OPERATOR'S COMPUTER

More on K. Szczurek lecture
Mixed Reality Human-Robot Interface
Robotics Interventions

<table>
<thead>
<tr>
<th>Nr. of Interventions since 2014</th>
<th>Nr. of tasks performed</th>
<th>Robot operation time in harsh environment [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>~500</td>
<td>~ 500</td>
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</table>

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

ITHACA HL-LHC WG (https://edms.cern.ch/document/2067140/1.0/)
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*.
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
MARCHUSE project: Health Contactless Monitoring

30 FPS
30 images/second
Logitech 1080p FULL HD
CPU NVIDIA GTX 1080p

Neural Network

Input

Common inner layers

Output

Skin pixels
No-skin pixels

$C_0(t) = I_0(t) \cdot [v_0(t) + v_1(t)] + v_0(t)$

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

$C_0(t) = I_0(1 + i(t)) \cdot [u_c \cdot c_0 + u_s \cdot s(t) + u_p \cdot p(t)]$

Neural Network

MASK

Algorithm

Pulse

BVP
HR
HRV

MASK PROCESSING

PHYSIOLOGICAL OUTPUT ANALYSIS

In collaboration and funded by KT group

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Online Tunnel Structure Monitoring

- 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

Detection → Analysis

3D Engine

Scheme of the working principle

Example of water leak found by TIM2 during TS3 2018

Example of crack found using vision based machine learning techniques

Collaboration with SCE-DOD

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

Definitions

Camera positions (end-effector): 
\[ x_{ee} = \begin{pmatrix} x_e \\ y_e \\ \Psi_e \end{pmatrix} \]  
Joints Space: 
\[ q_{ee} = \begin{pmatrix} q_1 \\ q_2 \end{pmatrix} \]

Forward & Inverse Kinematics

\[ \dot{x}_{ee} = J_A(q) \dot{q} \]
\[ \Delta q = J_A(q)^{-1} \Delta x_{ee} \]
\[ q_{Next} = q_{Actual} + \Delta q \]

Collaboration with SY-RF, Courtesy of A. Luthi

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

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Design and robotic trajectory optimization

1) Cavity Inner Surface Reconstruction (based on fabrication drawings)

2) Trajectory Generation
   - Perpendicular to the surface
   - 30% of overlap

   • Camera Working distance: 23mm

New light system design (camera triggered LED flash)
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
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Intervention done in 2015

Intervention Examples

- Radioactive sources handling in old dosemeter calibration hall (b.172)
  - Source of different shape and weight
  - Installed since more than 30 years
  - No drawings
Intervention done in 2015, b172

Handling of source Cs
462 mSv/h @ 40 cm
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

BDF T6: Removal and samples extraction
CERNBot + Teodor
Challenging Teleoperation Example

- Water leak inspection and fix in extremely radioactive area
  - Access particularly difficult
  - 1 km inside 1\textsuperscript{st} beamline access
  - Teleoperated from human safe area
  - CERNbot for teleoperation and EXTRM for support
  - 10 hours of operation

- CERNTAURO modularity allowed quick robot reconfiguration, sensors and tools integration to environmental changes
Challenging Teleoperation Example

BA80 TCSC Water Leak
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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 nToF 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

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Robots for Search and Rescue

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

Collaboration with HSE-FRS

Respiration activity

Respiration interrupted (small ripples represent heartbeat)

Amplitude (relative units)
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

Examples of BLMs detection/segmentation using ML
TIM Junior

- ROV inside TIM wagon to be lowered down in the LHC
Robots for Future Accelerators (FCC)

- Novel robotics platforms and controls for remote maintenance and interventions

More on H. Gamper Academic lecture, https://indico.cern.ch/event/1055745/
Robots for Future Accelerators (FCC)

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


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
## Established Collaborations

<table>
<thead>
<tr>
<th>Institute</th>
<th>Collaboration Nr.</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>UKAEA</td>
<td>KN4867</td>
<td>sharing teleoperation expertise</td>
</tr>
<tr>
<td>CREATE</td>
<td>KE3947</td>
<td>robotics operation strategies</td>
</tr>
<tr>
<td>University Federico II</td>
<td>KE3630</td>
<td>robots control theory</td>
</tr>
<tr>
<td>Unicampus Biomedico</td>
<td>KN4437</td>
<td>medical applications (MARCHESE)</td>
</tr>
<tr>
<td>Polytechnic Madrid</td>
<td>KE4297</td>
<td>enhanced reality and teleoperation</td>
</tr>
<tr>
<td>University Jaume I</td>
<td>KE4202</td>
<td>human robot interface</td>
</tr>
</tbody>
</table>
KT: CERNTAURO running on Industrial Robots

- KT contract with Ross Robotics (KM3211) that is using CERNTAURO controls on their robotic platform
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 Robotics Research Centres and Universities is crucial to take advantage of the cutting edge technology.
Are Robot “serving” humans?
Are Robot “serving” humans? … or we are serving robots?
Robots and robotic instrumentation need a crew to use them and maintain and experts in-house to be effective.

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