Robotics Solutions in EN-SMM for Remote Inspection and Teleoperation

M. DI CASTRO
EN-SMM

SLAWG #41 Meeting: remote inspection and handling (part 1), 13th of March 2019
Contents

- Introduction to Robotics
- Needs and Challenges for Robotic Solutions
- Operational Systems
- R&D
- Future Challenges
- Conclusions
Robotics

- **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: type of robots (based on controls)

- **Robots**
  - Teleoperated
    - Wired
    - Wireless
  - Semi-autonomous
  - Autonomous
    - Pre-programmed
    - Self learning
Robotics: type of robots (based on application)

- Hobbies, competition and entertainment
  - Suitable for high school teaching
- Industrial
  - Repetitive tasks
- Medical
  - Surgery/Rehabilitation
- Domestic or household
- Military
- Service and space robot
  - Research
  - Intelligent
The only reliable robotic solutions exist in industry for repetitive tasks

Plenty of ideas and prototypes coming from university, but none of them work reliably for harsh and unstructured environments

- At Fukushima, no robot has been capable of safely inspecting the zone and returning to the base [6]
Robotics mandate at CERN

- The “mission” of tele-robotics at CERN may be resumed in the following:

  Ensuring safety of Personnel
  improving availability of CERN’s accelerators
Challenges for robotic solutions @ CERN

- Design of new equipment has however to keep in mind our goals:
  - Safety of Personnel
  - Maximize availability

- We cannot risk that a robot stops in the middle of the accelerator, or provokes an accident heavier than the problem it is trying to solve

- Risk analysis and recovery scenarios in the implementation of robotic solutions comes before any decision for the intervention
Needs for tele-robotics at CERN

- Inspection, operation and maintenance of radioactive particle accelerators, experimental areas and objects not built to be remote handled/inspected
  - Most of them are obsolete, without proper documentation and drawings, any intervention may lead to **surprises**
  - Risk of **contamination**
Difficulties for tele-robotics at CERN

- Radiation, magnetic disturbances, delicate equipment not designed for robots, big distances, communication, time for the intervention, highly skilled technicians required (non robotic operators), etc.
CERNTAURO framework

Mechatronic System

- **New robot and robotic control developed** [9]
  - Human robot interface

- **New user-friendly bilateral tele-manipulation system**
  - Haptic feedback
  - Assisted teleoperation

- **Artificial intelligence**
  - Perception and autonomy
  - Deep learning

- **Operator and robot training system**
  - Virtual and augmented reality
  - Learning by demonstration
Robotic Support for CERN
Robotic Support for CERN

More than 20 robots in operation
- AUTONOMOUS INSPECTIONS
- OPERATOR DRIVEN INSPECTION
- ASSISTED INSPECTION
- TELEOPERATIONS
- ASSISTED TELEMANIPULATION
- AUTONOMOUS REMOTE OPERATION
- SAFETY, SEARCH AND RESCUE
VERO: Virtual Environment for intelligent Robotic Operations

INPUT DATA

Virtual mockup (Integration)

Studies

New equipment design
Whole scenario simulation
Anti-collision and Virtual fixtures

Implementation

Operator training in VR
Force feedbacks
Assistance for real operations
Robotic Activities in EN-SMM

Design and Integration
## Robotic Support at CERN

<table>
<thead>
<tr>
<th>Nr. of Interventions in the last 40 months</th>
<th>Nr. of tasks performed in the last 40 months</th>
<th>Robot operation time in harsh environment [h]</th>
<th>Dose Saved [mSv]</th>
</tr>
</thead>
<tbody>
<tr>
<td>135</td>
<td>250</td>
<td>~ 300</td>
<td>~ 120*</td>
</tr>
</tbody>
</table>

* Calculated on human intervention time  
60% of the interventions were unforeseen and done with very short preparation time

**Types of Interventions**

- Telemanipulation: 34%  
- Radiation Survey: 19%  
- Reconnaissance and visual inspections: 47%

**Main Telemanipulation Tasks**

- Cutting: 25%  
- Grasping: 23%  
- Seizing: 7%  
- Scanning: 48%

---

**Best practice for equipment design and intervention**
Robotic Support at CERN

Started to apply CERN custom made robotic solutions. Remote handling capabilities and modularity strongly increased!
Importance of the design phase, procedures and tools

- Intervention **procedures and tools** are important as the robot/device that does the remote intervention
  - HL-LHC WG, ITHACA - InTerventions in Highly ACTivated Areas in HL-LHC
    - Guidelines for equipment design and maintenance best practice to reduce personnel radiation exposure.
  - Taking advantages of robots operational experience for new equipment design (TIDVG, BDF target, AD target, TAXS, TAXN etc.)
Importance of the design phase, procedures and tools

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

Easier remote or hands-on manipulation than chain-type connection.
Current Capabilities for Inspection and Environmental Measurements

- Visual inspection using RGB, RGB-D and thermal cameras
- Radiation, temperature, Oxygen %, magnetic field etc. all coupled with a map (point cloud) of the zone for fine spatial positioning of the properties measured
- Environmental reconstruction from point clouds (scans) or structure from motion
- Helium spray for precise vacuum leak detection (in collaboration with TE-VSC)
- Object scan and reconstruction in 3D
- AI (deep learning) to identify machine elements and visual fault/problem
Radiation measurement using robotic embedded sensors

- Autonomous radiation measurements
- Control of the arm driven by environmental measurement
  - Precise mapping of radiation
    - 3D point cloud + Robot control + Novel RP sensor
    - Projection of the virtual reality scenarios on 3D headset
Digital Image Processing and Photogrammetry for Tunnel Structure monitoring

- Tunnel inspections may demand personnel to access hazardous environments soliciting the need for robotic operations
- Therefore, we use image processing to conduct different tasks for tunnel inspection and structural health monitoring
- Goals achieved so far:
  - State of the art study in automated tunnel inspection
  - Database of images from different locations
  - Change detection using a single camera on TIM
  - 3D reconstruction using multiple images
  - Viewing tunnel wall sections in VR
  - Distance Measurement
  - Temperature Measurement
Change detection using a single camera

1. Correct
   - Low-light conditions
   - Non-uniform lighting
   - Shadows

2. Stitch
   - Feature extraction
   - Registration

3. Change Detection

MOSAICING
Tunnel Structural Monitoring

- Automating detection of anomalies and classification of walls’ cracks using machine and deep learning (same framework used for teleoperation)

*more on this topic in [30] [31]
Distance Measurement for Inspection

- Using Multiple Images to reconstruct sections of the tunnel wall in a 3D model
- Selection of particular points
- Measurement of distance between two points, such as for crack measurement
Structure from motion in VR
Master-Slave Haptic-Based Teleoperations

- In house **user friendly** and portable telemanipulation system to allow equipment owners and/or expert technicians to use robot in a “transparent way”

  ✓ **No need of expert robotic operators**
Robots at CERN: TIM

Built at CERN, used for inspection, radiation mapping of the LHC and survey. Operational Experience and technology could be useful for general tunnels inspections [10]
Robots at CERN: TIM
Robots at CERN: CERNbot

Built at CERN, used for inspection, environmental measurements including radiation, teleoperation and in-situ maintenance [11]
Robots at CERN: CERNbot

- **CERNbot robotic base**
  - Hardware and control software completely developed in-house
  - Weight ~ 50 kg
  - Continuous operation ~ 4 hr
  - **Payload ~ 150 kg**
  - Arm Payload ~15 kg (can host 2 arms)
  - Max speed = 10 km/h
  - Runs over Wifi/3G/4G
  - Entirely controllable from surface
  - User friendly human-robot interface
  - Can be fully autonomous
  - Embedded novel energy management system
  - Inspection, helium sniffer for vacuum leak detection, RP survey, telemanipulation (cutting, grasping, screwing, sewing etc.)
Robots at CERN: CERNbot
Robots at CERN: Tele-operation and in-situ maintenance

- Radioactive sources handling
Robots at CERN: Tele-operation and in-situ maintenance

- Radioactive sources handling

- 4 Sources
  - Cs: 823 μSv/h @ 40 cm
  - Cs: 6.8 mSv/h @ 40 cm
  - Pu-Be: 18 mSv/h @ 40 cm
  - Cs: 48 mSv/h @ 40 cm

- 3 Sources
  - Co: 5.5 mSv/h @ 40 cm
  - **Cs: 420 mSv/h @ 40 cm**
  - Am: 2.8 mSv/h @ 40 cm
Robots at CERN: Tele-operation and in-situ maintenance

- Radioactive sources handling

Handling of Source Cs
420 mSv/h @ 40 cm
Robots at CERN: Tele-operation and in-situ maintenance

- Radioactive sources handling
Intervention Examples

- LHC TDE inspection
Intervention Examples

- LHC TDE inspection

![LHC TDE inspection image]
Intervention Examples

AD ATRAP
Iridium Source
Installation
Intervention Examples
Intervention Examples: BDF
Intervention Examples: HIRADMAT

HiRadMat Tank Opening
VMTIA maintenance of the LHC Collimators
VMTIA maintenance of the LHC Collimators
Opening of the quick vacuum flange using robots
Autonomous tests of LHC Collimators switches
Autonomous tests of LHC Collimators switches

- Deep learning for object and pose recognition
- Machine learning for autonomous operations
- Safety using virtual fixtures to avoid collisions
Machine learning

Robot can learn from humans and collaborate with them to speed up tasks
Robots at CERN: Industrial robots

- Automatic spectroscopy of radioactive samples
Current use of VR in EN-SMM

➢ 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 (also used for ITHACA WG)
  ✓ 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
Current use of VR in EN-SMM

- 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 (also used for ITHACA WG)
  - 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

Small VR corner (2x3 m) in b.628
Robotic Intervention Simulation

- Robots integration and task simulation
  - Procedures, tools design and recovery scenarios
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
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
Virtual and Augmented Reality

Train personnel in emergency situation
Virtual Reality
Virtual and Augmented Reality

- For personnel training and risk assessment
- FLUKA/radiation-exposure simulations in VR
Virtual and Augmented Reality

For Integration, procedures, operator training and operator assistance during teleoperations, in-situ maintenance
Texture in VR

- Very important to guarantee transparency
- We can import in VR textures of objects from 2D pictures
- Experience in operation with VR and publication has shown that without real texture the gaming effect will be too strong!

Collimator before and after texturing
Texturing in VR

- Strong increase of realism
  - Helps to go out from the “gaming” effect
  - Decrease the fatigue and stress while using VR
Learning by Demonstration

- **Machine imitation learning**
  - Generate movement trajectories using Gaussian Mixture Model (GMM) on a Riemannian manifold from several human demos

- **Learning Benefits**
  - Robots adapted to the tasks and the environment
  - Fully autonomous task implementation possible
  - Assistive robotic technology supporting remote operators

---

Blue: robot moves in its base frame
Red: robot moves in target’s frame
Orange: generated/reproduced movement for robot
SSVEP–based, single channel EEG Brain Computer Interface

General Aims

- Development of a low-cost, stand-alone SSVEP-based*, brain computer interface (BCI) integrated with a VR/AR visor for the improvement of human interactions and the treatment of people with disease.

* Steady State Visual Evoked Potentials (SSVEP) refers to synchronous responses produced in the visual cortex area when observing flickering stimuli and are suitable in applications where low training is required.

Technology

- The system is composed of four main parts:
  - The VR/AR environment: any scenario in which visual stimuli are provided, for inducing SSVEP responses in the subject.
  - The acquisition device: captures brain signals through electrodes positioned on the scalp. Only few electrodes must be used to guarantee the user comfort.
  - The processing unit: elaborates and discriminates the acquired signals to produce multiple instructions. A machine learning approach, could improve considerably the accuracy of the system.
  - The application controller: to be implemented on the VR/AR device, it continuously asks for instructions to perform actions in the VR/AR environment.
SSVEP–based, single channel EEG Brain Computer Interface

The EEG acquisition device

- Electrical signal from brain, refers to the voltage difference between two electrodes positioned on the skull. For multiple electrodes, signals are referred to a common electrode usually positioned on the earlobe.
- Brain signals are very weak (~10 uV) and subject to environmental noise. An additional electrode (DRL) placed preferably near the head, could be used to actively reduce the common mode noise (e.g. 50-60 Hz power line) providing a signal feedback to the body.
- Choice of the electrodes is crucial. For a fast and comfortable use dry electrodes are preferred and require a proper design: amplification on-electrode, low impedance materials (AgCl, Gold …), comb shape to reach the scalp through hair.
- Most of the cerebral activity falls in the 3~150 Hz (from low α to high γ) frequency range. The digitizing unit should have a sample rate at least 10 times higher than the maximum frequency of interest.
Knowledge Transfer

- Knowledge transfer with Ross Robotics
  - KT on robotic controls, autonomous navigation, perception and teleoperation
Collaborations
Lesson Learnt an Conclusions

- Designing machines that can be maintained by robots using appropriate and easily accessible interfaces will drastically increase the availability and decrease human exposure to hazards.
- Intervention procedures and tools are important as the robot/device that does the remote intervention.
- R&D and continuous developments models are needed because ready-to-use robotic solutions that can fulfill CERN needs for remote inspection and user-friendly teleoperation do not exist.
- EN-SMM has acquired knowledge and expertise to provide robotic support and robotic-friendly design guidelines to other CERN groups according to the resources available.
References


[34] Xu, T., Jin "Preliminary results of noncontact respiration and heartbeat detection using IR-UWB/radar," 2018, IEEE


[40] Xu, T., Jin "Preliminary results of noncontact respiration and heartbeat detection using IR-UWB/radar," 2018, IEEE


Thank you for your attention