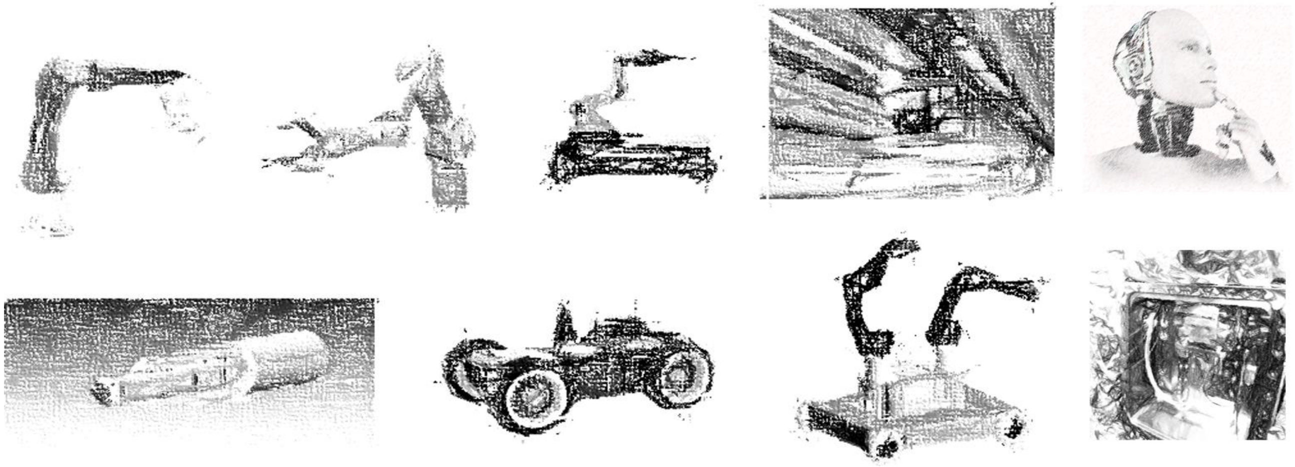
Overview of the Robotic Service at CERN for accelerator maintenance

Luca R. Buonocore
BE-CEM-MRO



March 2021

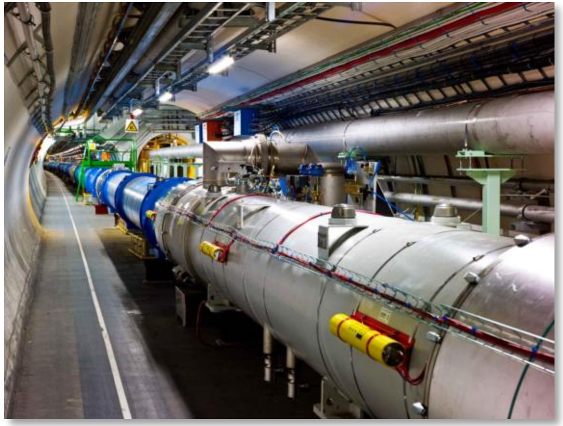
Contents

Contents

- Needs and Challenges for Robotics
- The Robotic Service at CERN
- Future Objectives

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

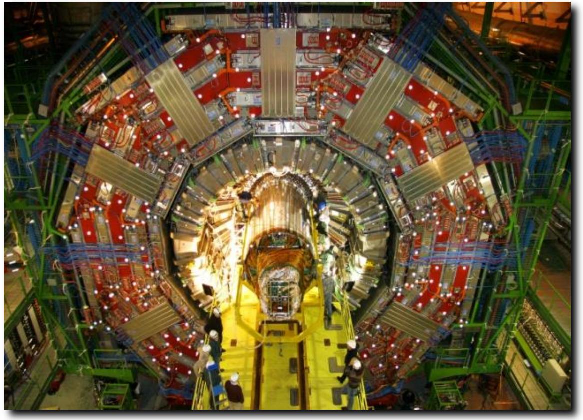
North Area experimental zone

Radioactive sample handled by a robot

Main 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.**



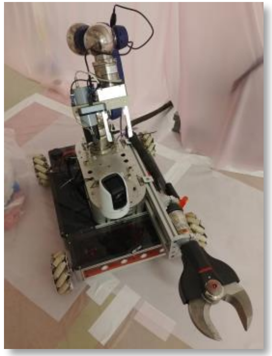
Contents

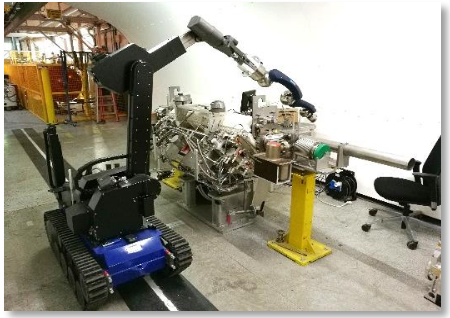
- Needs and Challenges for Robotics
- The Robotic Service at CERN
- Future Objectives

Robotic Support for CERN: Type of Robots Overview

Telemax robot

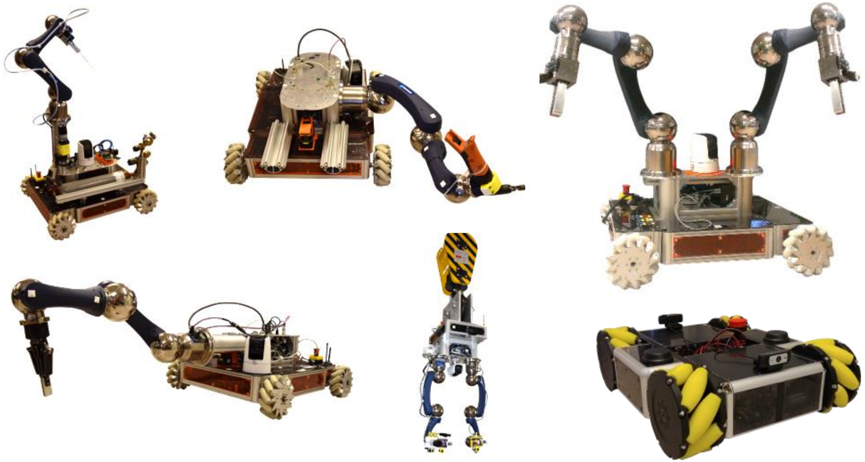
Train Inspection Monorail [10] (CERN made)





Teodor robot

EXTRM robot (CERN made)

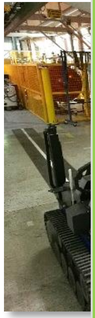


CERNBot [11-17] in different configurations (CERN made)

Robotic Support for CERN: Type of Robots Overview








- Mechatronics conceptions, designs, proof of concepts, prototyping, series productions, <u>operations</u>, maintenance, tools and procedures
- More than 20 robots in operation
  - ✓ autonomous inspections
  - ✓ teleoperations
  - ✓ assisted telemanipulation
  - ✓ autonomous remote operation
  - ✓ safety, search and rescue

CERNTAURO framework [7]

Mechatronic System

Perception

Actuation

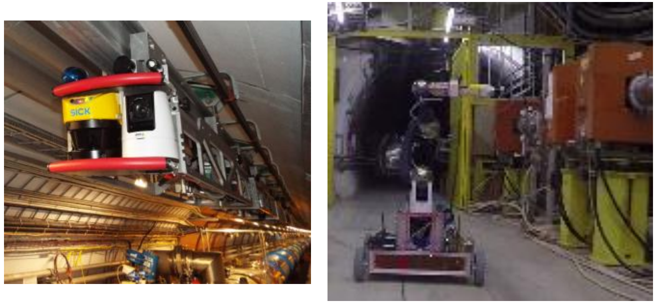
Motion

- **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

Robotic preventive maintenance and inspection

SPS MKP oilers refill



Remote radioprotection surveys

Cabling status inspection

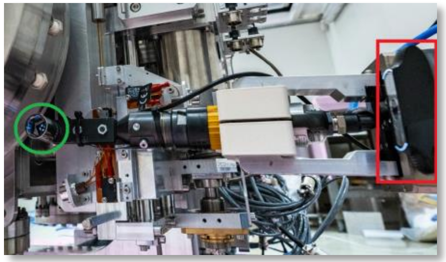
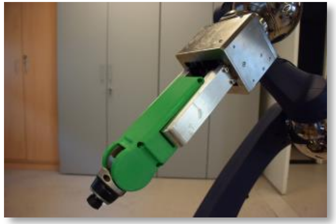
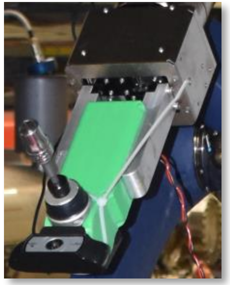
Temperature sensor installation on AD target

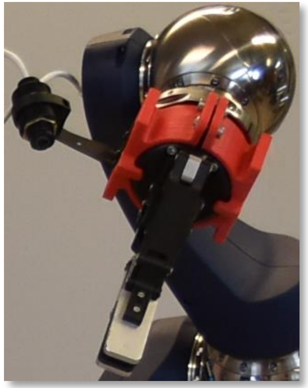
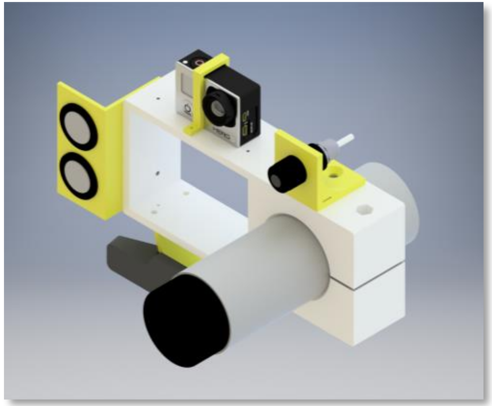
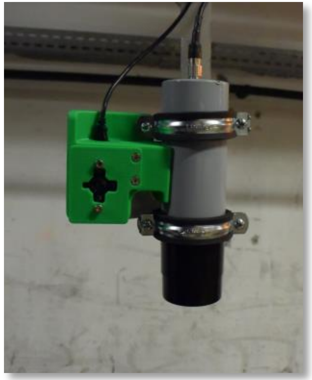
Tunnel structure monitoring

Remote Vacuum Leak detection

Procedures and Tools

- Several tools and sensors integrated for various tasks, also in emergency
  - ✓ Intervention procedures, recovery scenarios, tools and mock-ups are as important as the robot/device that does the remote intervention

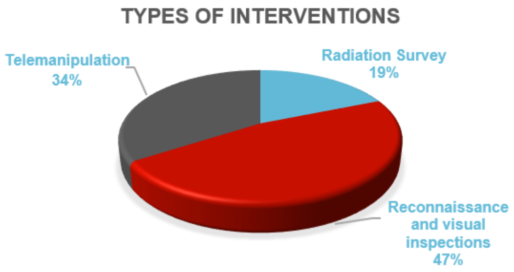





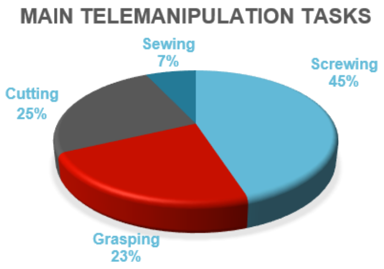






Robotic Interventions

Nr. of Interventions in 2020	Nr. of tasks performed	Robot operation time in harsh environment [h]	Dose Saved [mSv] *	Dose Taken by robots [mSv]
18	~300	~ 350	**~ 690**	**~7000**

* Calculated on estimated human intervention time

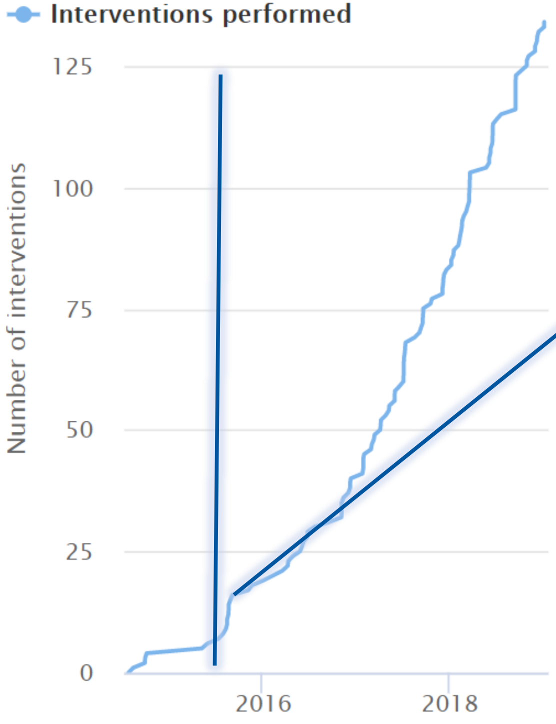




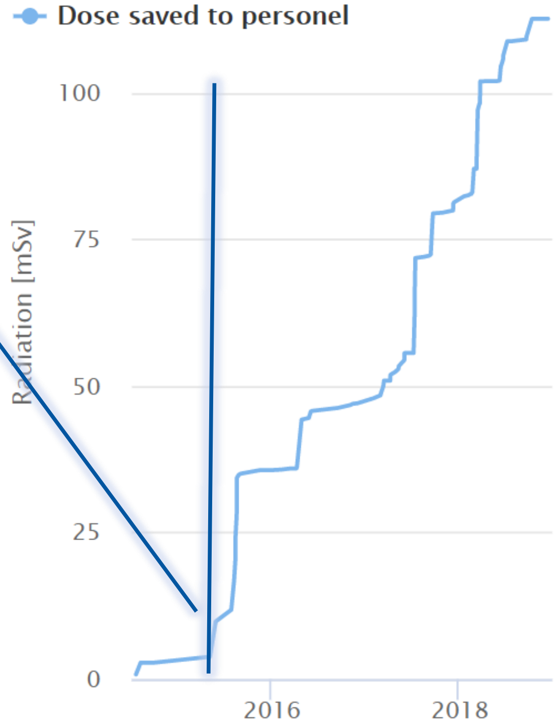
Remote maintenance test facility (b927)

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

Robotic Support at CERN

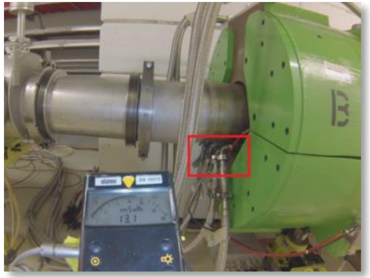


Started to apply CERN custom made robotic solutions. Remote handling capabilities and modularity strongly increased!



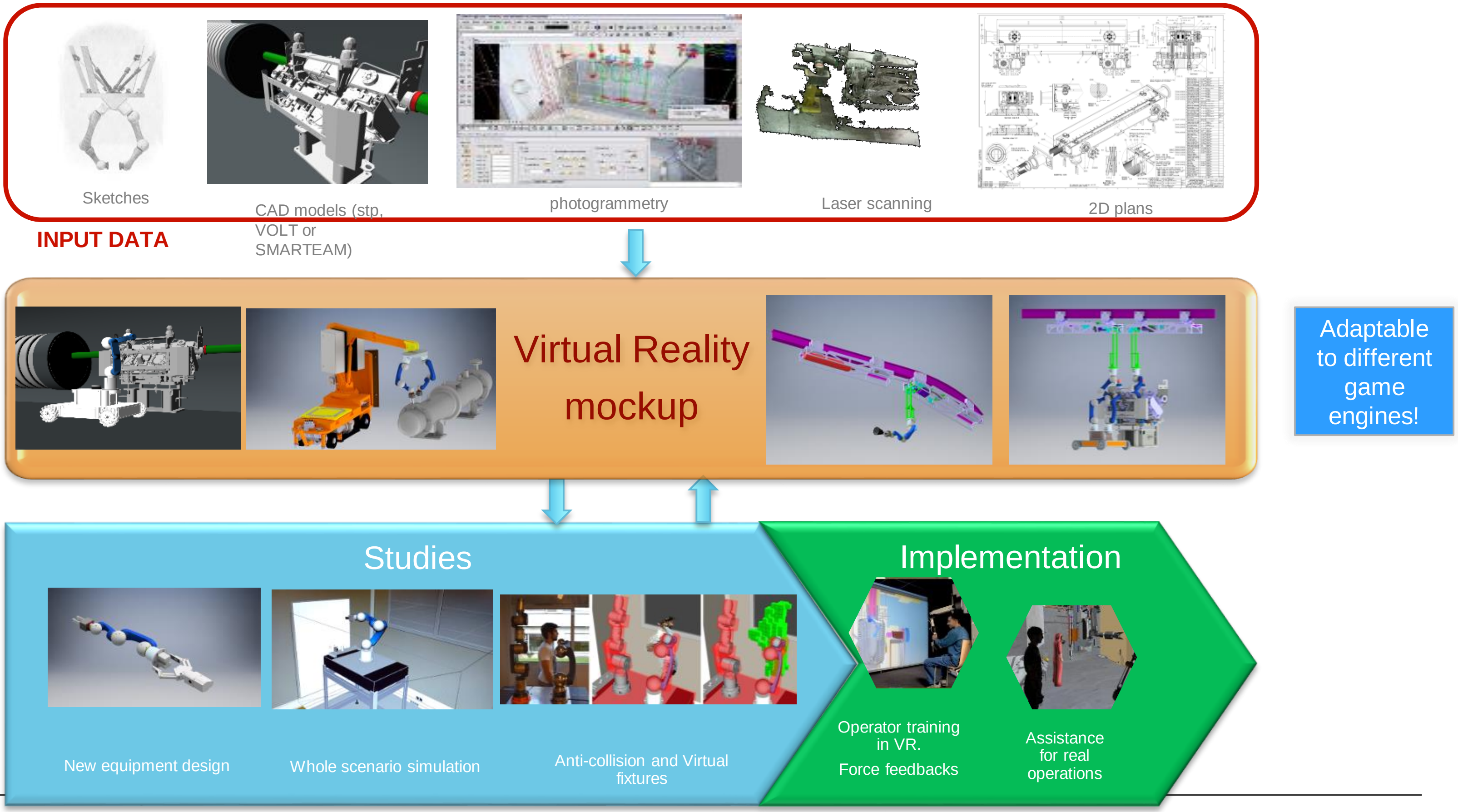
Importance of the design phase, procedures and tools

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



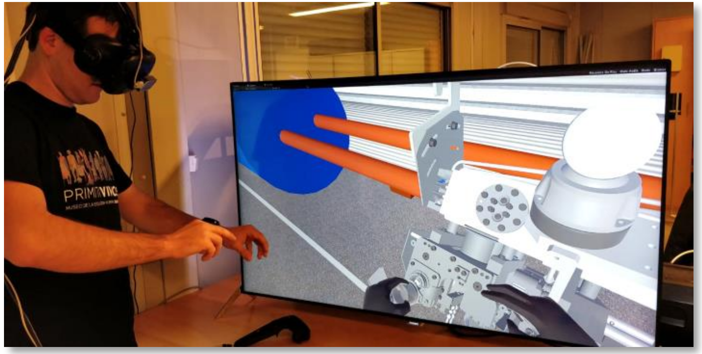
Easier remote or hands-on manipulation than chain-type connection

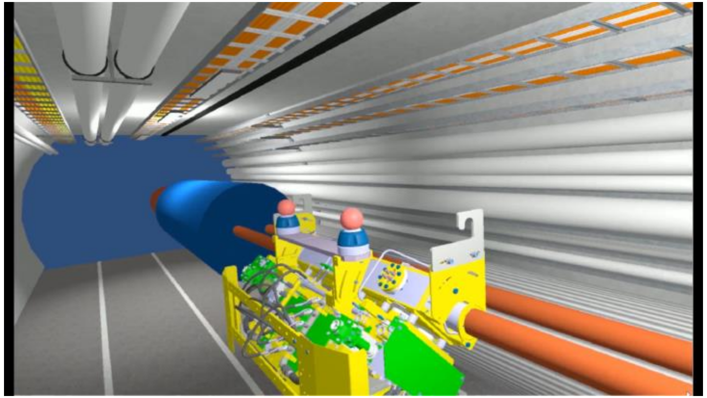
Custom made VERO framework: Virtual Environment for intelligent Robotic Operations



Current use of Enhanced Reality in BE-CEM

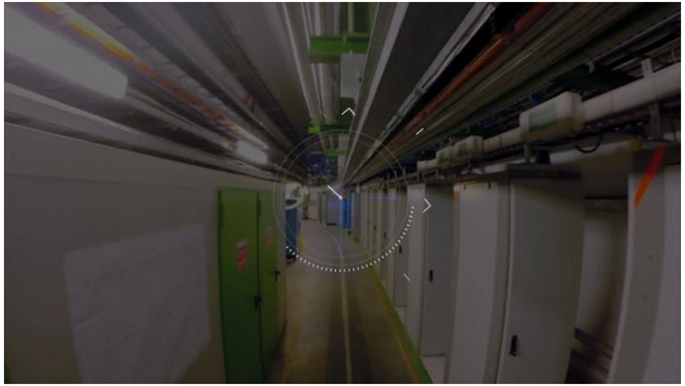
- Simulation of robotic interventions
  - ✓ Integration of robots in the environment and choice of robots
  - ✓ Intervention procedures
  - ✓ Tools design and test
  - ✓ Machines risk assessment
  - ✓ Robots training by demonstration
  - ✓ Operators training and teleoperations
  - ✓ Risk analysis
  - ✓ 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



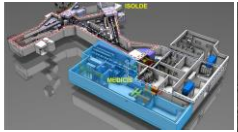


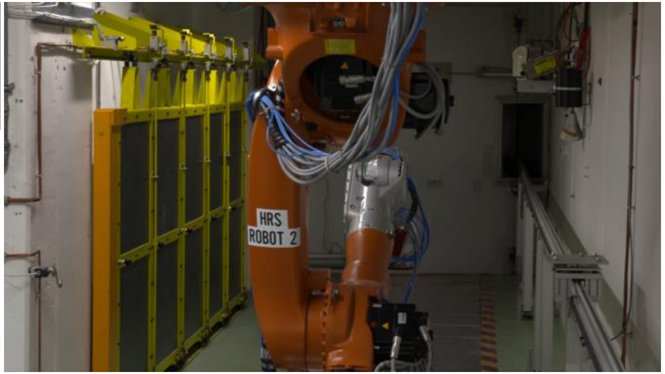
Main Robotics Interventions in 2020

Main Robots integrated/controlled within facilities at CERN

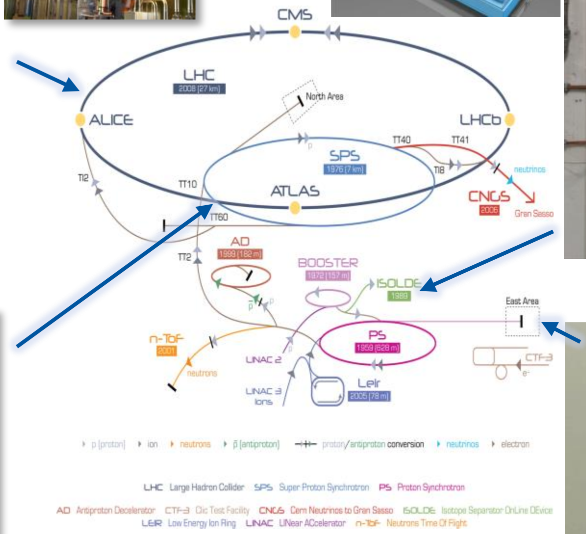


TIM (x5)





Kuka Robots (x3)



CERNbot

CHARMbot

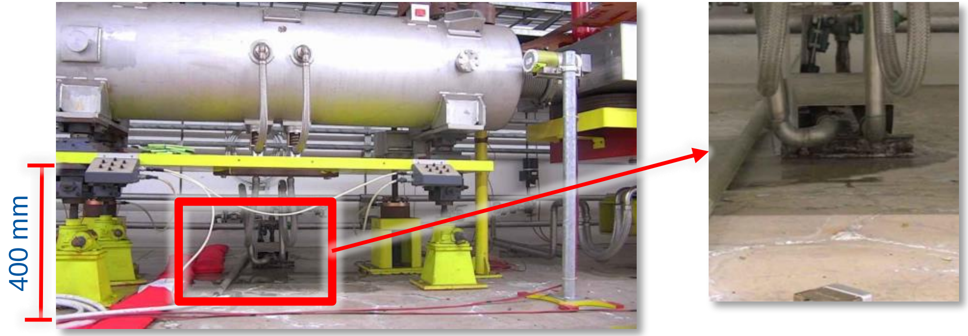
Novel SPS robot designed, produced and installed during LS2

MIRA

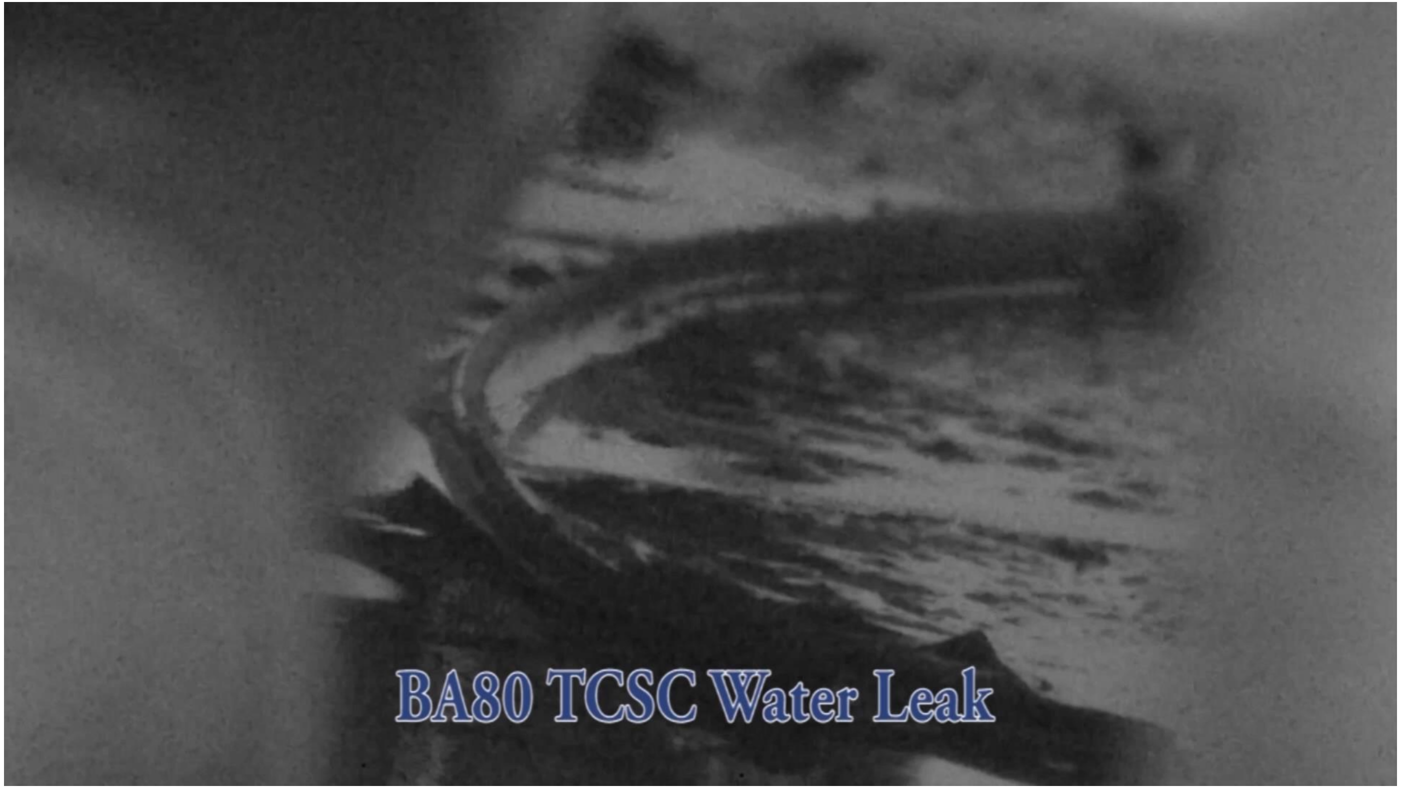
Measurement and Inspection Robot for Accelerators

Challenging Teleoperation Example#1

- Water leak inspection and fix in extremely radioactive area
  - ✓ **Access particularly difficult**
  - ✓ 1 km inside 1st 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**

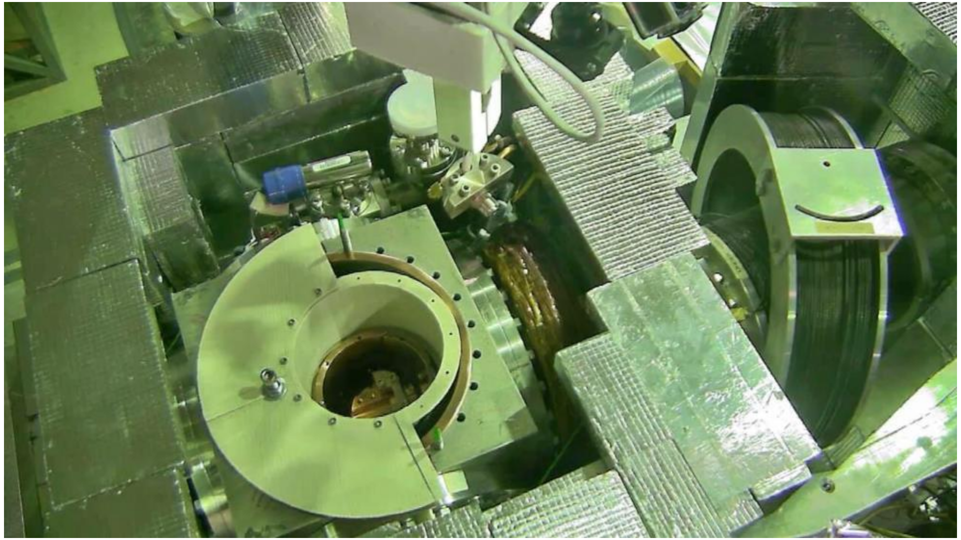


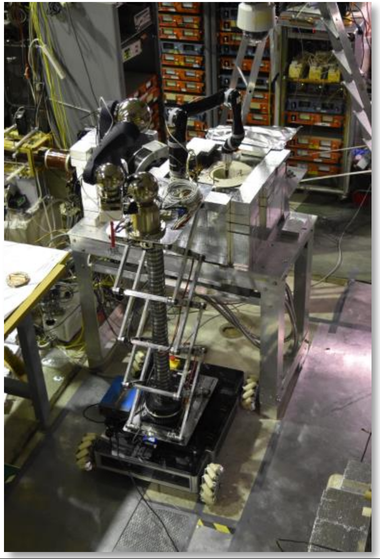
Challenging Teleoperation Example#1

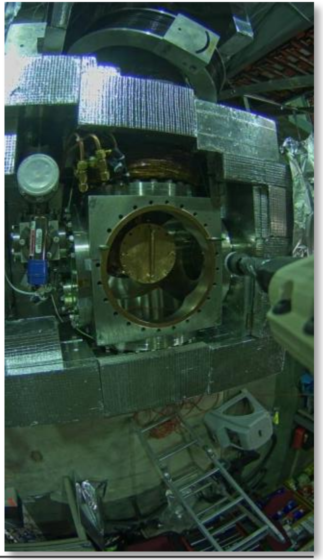


Challenging Teleoperation Example#2

- 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#3
Dismantling of n_ToF target

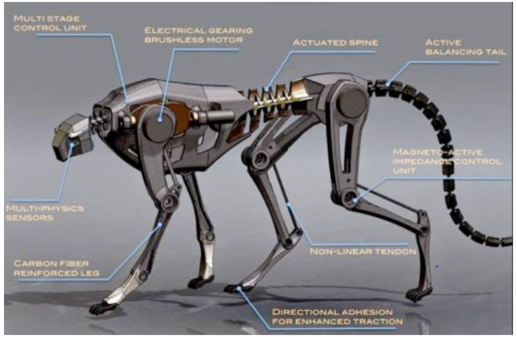
Contents

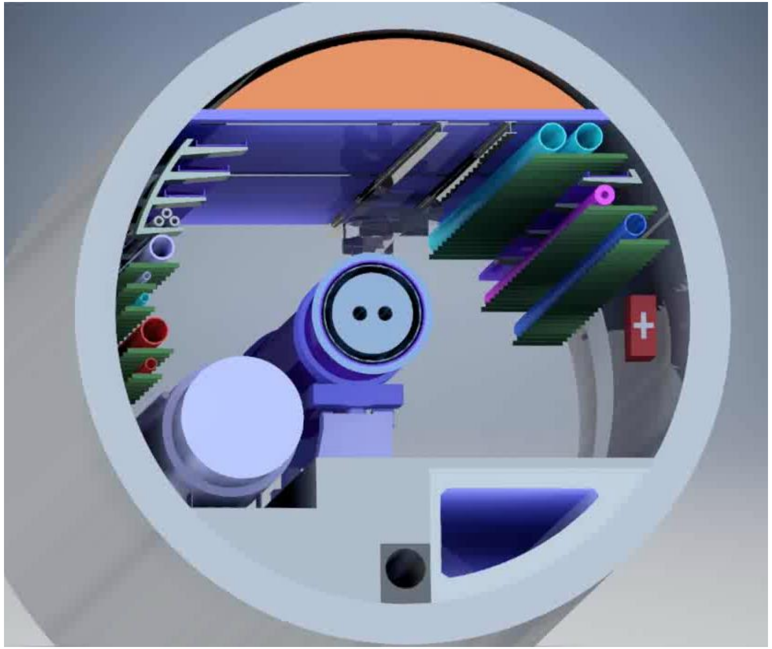
User-friendly teleoperation system

- 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

Robots for Future Accelerators (FCC)

- Novel robotics platforms and controls for remote maintenance and interventions





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

References

[1] Petriu, E. M., and M. Krieger. "Robotic Sensing and Perception as the AI Frontier of the I&M." Instrumentation and Measurement Technology Conference, 19Revisiting92. IMTC'92., 9th IEEE. IEEE, 1992.
[2] Bajcsy, Ruzena, Yiannis Aloimonos, and John K. Tsotsos. " active perception." Autonomous Robots 42.2 (2018): 177-196.
[3] Asaro, Peter M. "What should we want from a robot ethic." International Review of Information Ethics 6.12 (2006): 9-16.
[4] Winfield, Alan. "Roboethics–for humans." New Scientist210.2811 (2011): 32-33.
[5] Buehler, Martin, Karl Iagnemma, and Sanjiv Singh, eds. The 2005 DARPA grand challenge: the great robot race. Vol. 36. Springer, 2007.
[6] Kawatsuma, Shinji, Mineo Fukushima, and Takashi Okada. "Emergency response by robots to Fukushima-Daiichi accident: summary and lessons learned." Industrial Robot: An International Journal 39.5 (2012): 428-435.
[7] Di Castro, Mario, Manuel Ferre, and Alessandro Masi. "CERNTAURO: A Modular Architecture for Robotic Inspection and Telemanipulation in Harsh and Semi-Structured Environments." IEEE Access 6 (2018): 37506-37522.
[8] L. Joseph, "Mastering ROS for robotics programming", Packt Publishing Ltd, 2015.
[9] G. Lunghi, R. M. Prades and M. Di Castro, "An Advanced, Adaptive and Multimodal Graphical User Interface for Human-robot Teleoperation in Radioactive Scenarios," in Proceedings of the 13th International Conference on Informatics in Control, Automation and Robotics, SCITEPRESS-Science and Technology Publications, Lda, 2016.
[10] M. Di Castro e. al., i-TIM: A Robotic System for Safety, Measurements, Inspection and Maintenance in Harsh Environments, presented at SSRR18.
[11] M. Di Castro et al. "A Dual Arms Robotic Platform Control for Navigation, Inspection and Telemanipulation," ICALEPCS2017, 2018.
[12] A. Holmes-Siedle and L. Adams, "RADFET: A review of the use of metal-oxide-silicon devices as integrating dosimeters," Int. J. Radiat. Appl. Instrum. Part C Radiat. Phys. Chem., vol. 28, no. 2, pp. 235–244, Jan. 1986
[13] J. Mekki, M. Brugger, S. Danzeca, L. Dusseau, K. Røed, and G. Spiezia, "Mixed Particle Field Influence on RadFET Responses Using Co-60 Calibration," IEEE Trans. Nucl. Sci., vol. 60, no. 4, pp. 2435–2443, Aug. 2013.
[14] R. Harboe-Sorensen, F.-X. Guerre, and A. Roseng, "Design, Testing and Calibration of a 'Reference SEU Monitor' System," in 8th European Conference on Radiation and Its Effects on Components and Systems, 2005. RADECS 2005, Sept., pp. B3-1-B3-7.
[15] S. Danzeca et al., "Qualification and Characterization of SRAM Memories Used as Radiation Sensors in the LHC," IEEE Transactions on Nuclear Science, vol. 61, no. 6, pp. 3458–3465, Dec. 2014.
[16] T. Granlund and N. Olsson, "SEUs Induced by Thermal to High-Energy Neutrons in SRAMs," in 8th European Conference on Radiation and Its Effects on Components and Systems, 2005. RADECS 2005, Sept., pp. E1-1-E1-4.
[17] M. Di Castro et al, "An incremental slam algorithm for indoor autonomous navigation", presented at IMEKO 2014.
[18] Ruffo, M., et al. "New infrared time of-flight measurement sensor for robotic platforms." (2014).
[19] Nick, Mostafa, Rachid Cherkaoui, and Mario Paolone. "Optimal allocation of dispersed energy storage systems in active distribution networks for energy balance and grid support." IEEE Trans. Power Syst 29.5 (2014): 2300-2310.
[20] G. Welch, G. Bishop, An introduction to the kalman lter. department of computer science, university of north carolina, ed: Chapel Hill, NC, unpublished manuscript.
[21] J. Blair, Sine- tting software for ieee standards 1057 and 1241, in: Instrumentation and MeasurementTechnology Conference, 1999. IMTC/99. Proceedings of the 16th IEEE, Vol. 3, IEEE, 1999, pp. 1504-1506
[22] N. B. Priyantha, A. K. Miu, H. Balakrishnan, S. Teller, The cricket compass for context-aware mobile applications, in: Proceedings of the 7th annual international conference on Mobile computing and networking, ACM, 2001, pp. 1-14.
[23] Ramadan, Rabie A., and Athanasios V. Vasilakos. "Brain computer interface: control signals review." Neurocomputing223 (2017): 26-44.
[24] Wang, Meng, et al. "A Wearable SSVEP-Based BCI System for Quadcopter Control Using Head-Mounted Device." IEEE Access 6 (2018): 26789-26798.
[25] Pacchierotti, Claudio, et al. "Cutaneous haptic feedback to ensure the stability of robotic teleoperation systems." The International Journal of Robotics Research 34.14 (2015): 1773-1787.
[26] M. Ferre et al., eds, "Advances in telerobotics", Heidelberg: Springer, vol. 31, 2007.
[27] H. C. Longuet-Higgins, "A computer algorithm for reconstructing a scene from two projections," Nature, vol. 293, no. 5828, p. 133, 1981.
[28] H. Bay, A. Ess, T. Tuytelaars, and L. Van Gool, "Speeded-up robust features (surf)," Computer vision and image understanding, vol. 110, no. 3, pp. 346–359, 2008.
[29] J. F. Henriques, R. Caseiro, P. Martins, and J. Batista, "High-speed tracking with kernelized correlation filters," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 37, no. 3, pp. 583–596, 2015
[30] L. Attard, C. J. Debono, G. Valentino and M. Di Castro, Image mosaicing of tunnel wall images using high level features, Proceedings of the 10th International Symposium on Image and Signal Processing and Analysis, Ljubljana, 2017, pp. 141-146. doi: https://doi.org/doi: 10.1109/ISPA.2017.8073585
[31] Leanne Attard, Carl James Debono, Gianluca Valentino, Mario Di Castro, Vision-based change detection for inspection of tunnel liners, Automation in Construction, Volume 91, 2018, pp. 142-154.
doi: https://doi.org/10.1016/j.autcon.2018.03.020
[32] Dag T. Wisland, et.al. "Remote Monitoring of Vital Signs Using a CMOS UWB Radar Transceiver," 14th IEEE International NEWCAS Conference, NEWCAS 2016.
[33] Nakata, Robert H., et.al "Motion Compensation for an Unmanned Aerial Vehicle Remote Radar Life Sensor", 2018, IEEE
X. Hu, T. Jin "Preliminary results of noncontact respiration and heartbeat detection using IR-UWB radar", 2016, IEEE
[34] Fritsche, P., et.al "Fusion of radar, LiDAR and thermal information for hazard detection in low visibility environments", 2017, IEEE
[35]) MITCHELL, Harvey B. Multi-sensor data fusion: an introduction. Springer Science & Business Media, 2007
[36] Rudolph Emil. A new approach to linear filtering and prediction problems. Journal of basic Engineering, 1960, vol. 82, no 1, p. 35-45.
[37] Tingxiang Fan, Pinxin Long, Wenxi Liu and Jia Pan. Fully Distributed Multi-Robot Collision Avoidance via Deep Reinforcement Learning for Safe and Efficient Navigation in Complex Scenarios. Arxiv.
[38] M. di castro et. Al, Object Detection and 6D Pose Estimation for Precise Robotic Manipulation in Unstructured Environments, Lecture Notes in Electrical Engineering, Springer, Volume 495, Chapter 20
[39] Lunghi, G., Marin, R., Di Castro, M., Masi, A., & Sanz, P. J. (2019). Multimodal Human-Robot Interface for Accessible Remote Robotic Interventions in Hazardous Environments. IEEE Access, 7, 127290-127319.
[40] Veiga Almagro, C., Di Castro, M., Lunghi, G., Marín Prades, R., Sanz Valero, P. J., Pérez, M. F., & Masi, A. (2019). Monocular Robust Depth Estimation Vision System for Robotic Tasks Interventions in Metallic Targets. Sensors, 19(14), 3220.
[41] Saliba, C., Bugeja, M. K., Fabri, S. G., Di Castro, M., Mosca, A., & Ferre, M. (2018). A Training Simulator for Teleoperated Robots Deployed at CERN. In ICINCO (2) (pp. 293-300).

Thank you for your attention

Robotics technologies 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
- And others…

Main Motivations for Custom Robotic Development

- 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** unstructured and harsh environments

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