OPERATIONAL CONTROLS FOR ROBOTS INTEGRATED IN ACCELERATOR COMPLEXES

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Abstract: The fourth industrial revolution, the current trend of automation and data interconnection in industrial technologies, is becoming an essential tool to boost maintenance and availability for space applications, warehouse logistics, particle accelerators and for harsh environments in general. The main pillars of Industry 4.0 are Internet of Things (IoT), Wireless Sensors, Cloud Computing, Artificial Intelligence (AI), Machine Learning and Robotics. We are finding more and more way to interconnect existing processes using technology as a connector between machines, operations, equipment and people. Facility maintenance and operation is becoming more streamlined with earlier notifications, simplifying the control and monitor of the operations. Core to success and future growth in this field is the use of robots to perform various tasks, particularly those that are repetitive, unplanned or dangerous, which humans either prefer to avoid or are unable to carry out due to hazards, size constraints, or the extreme environments in which they take place. To be operated in a reliable way within particle accelerator complexes, robot controls and interfaces need to be included in the accelerator control frameworks, which is not obvious when movable systems are operating within a harsh environment. In this paper, the operational controls for robots, integrated in accelerator complexes at the European Organization for Nuclear Research (CERN), is presented. Current robot controls at CERN will be detailed and the use case of the Train Inspection Monorail (TIM) robot control will be presented.

Robotic Service at CERN: Remote interventions in particle accelerators are mainly needed for safety and availability increase. At constant machine reliability, to increase availability, the only way is to improve the maintainability, and this can be done improving human intervention procedures or using efficient remote systems. At CERN, robots for remote inspection and maintenance are designed and controlled using a framework named CERNTAURO a novel in-house robotic control solution. he robotic service at CERN has enabled more than 1000 robotic operations over the last 8 years, operating robots for more than 1500 hours. Many in-situ challenging tasks like cutting, screwing, sewing etc. have been performed, saving a significant amount of dose to personnel and improving accelerator availability


Telemax robot

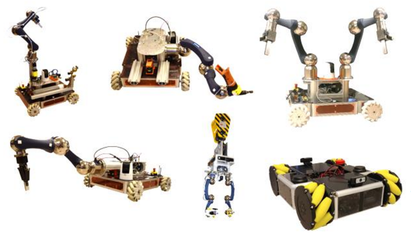

Train Inspection Monorail (CERN made)

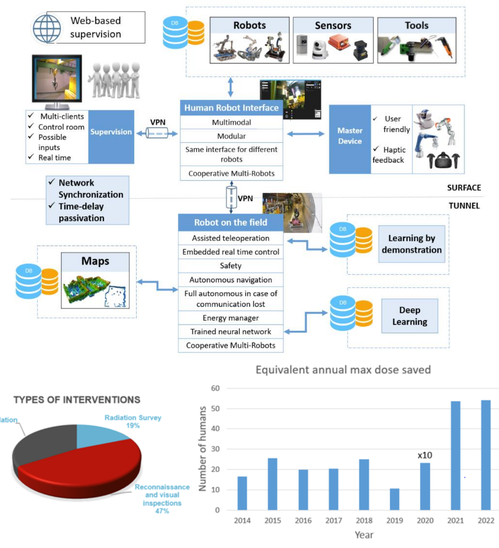

Teodor robot


EXTRM robot (CERN controls)


Drone for tele-operation support

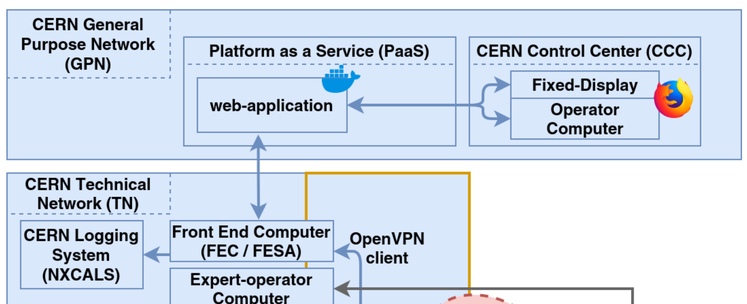

Quadrupeds for "difficult" zones


CERNBot in different configurations (CERN made)



Overview of the different type of robots under the BE-CEM group responsibility at CERN (left), CERNTAURO framework architecture (top right), Main type of interventions that are currently possible using robots (left) and radiation dose saved to personnel (bottom right).

ROBOTIC OPERATIONS AND CONTROLS WITHIN PARTICLE ACCELERATORS:

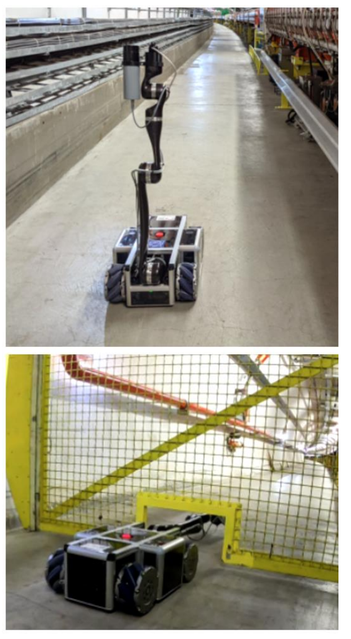


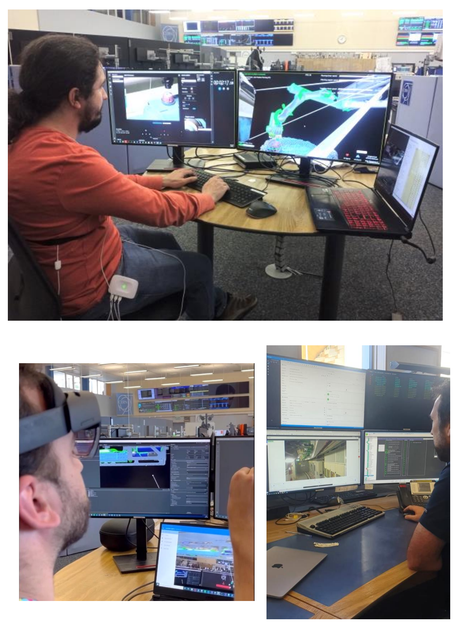
Control scheme for the robots integrated in accelerator controls infrastructure.

Network connection type	Robot side's connection	Interconnection	Operator's computer
Ethernet cable directly	Ethernet cable connector	Single cable	Ethernet cable connector
Ethernet over CERN GPN	Ethernet cable connection to CERN General Purpose Network	CERN General Purpose Network cabled indrastructure	Ethernet cable connection to CERN General Purpose Network
VPN 4G modem in the LHC tunnel	4G modem	Network operator 4G connection in the LHC tunnel, VPN connection to CERN General Purpose Network cabled infrastructure	Ethernet cable connection to CERN General Purpose Network
Wi-Fi over CERN GPN	Wi-Fi connection to CERN General Purpose Network Wi-Fi infrastruture	CERN General Purpose Network cabled infrastructure	Wi-Fi connection to CERN General Purpose Network Wi-Fi infrastruture

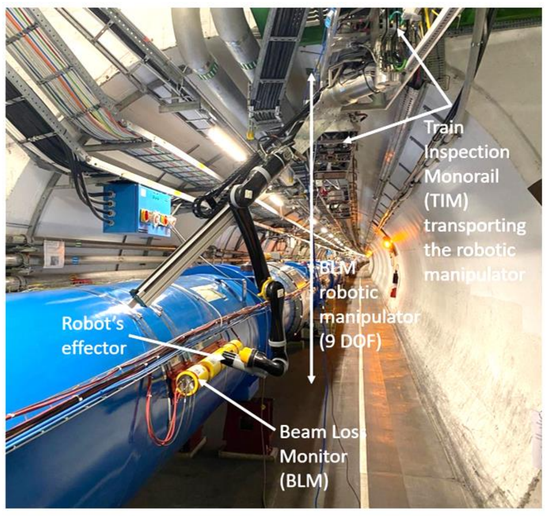
Network connection type	Downlink bandwidth [Mbps]	Round-trip time [ms]		Jitter [ms]	Bandwidth standard deviation [Mbps]
		Bandwidth usage = 0%	Bandwidth usage = 100%		
VPN with 4G modem	11.99	43.4	131.5	26.00	0.61
Wi-Fi over CERN GPN	73.95	20.33	30.3	5.64	17.88
Ethernet over CERN GPN	885.8	0.04	1.61	0.19	38.1
Ethernet cable directly	941.8	0.24	1.47	0.28	0.42

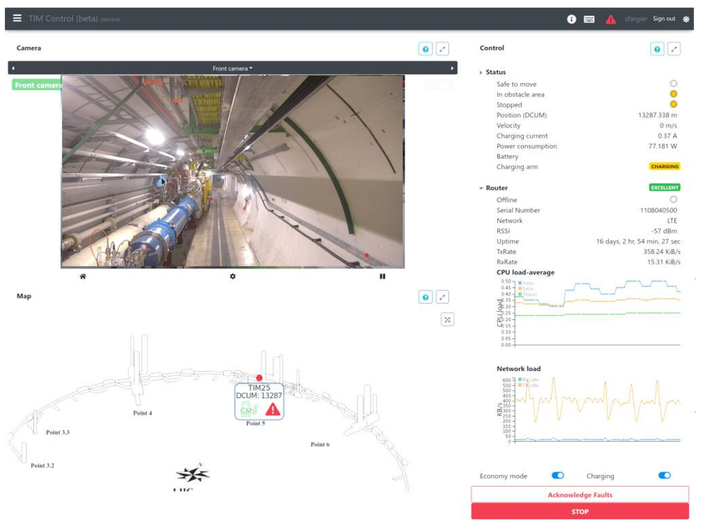
Connection types between a robot and operator (top) and bandwidth and its deviation, round-trip time and its jitter measurements for all connection types (bottom)

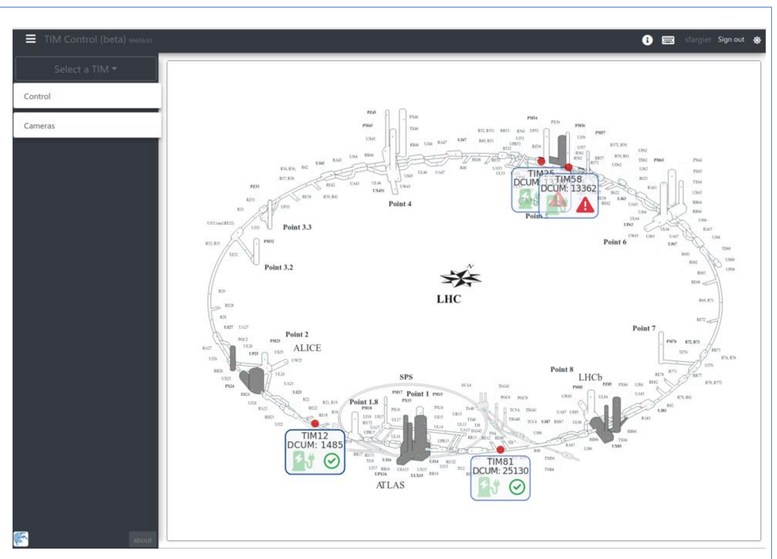

SPS robot operation for remote inspection and RP measurements (top), robot passing the sector doors apertures of 400x200 mm (bottom)


Robots' operation from CERN Control Center

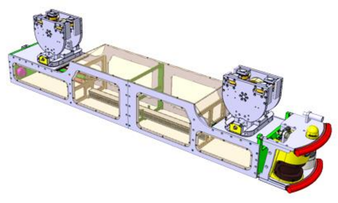
CONTROL DESIGN AND INTEGRATION

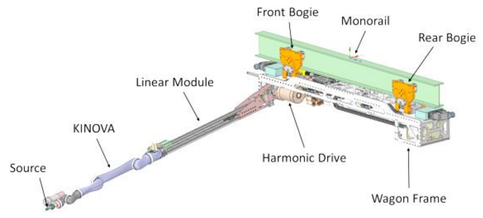




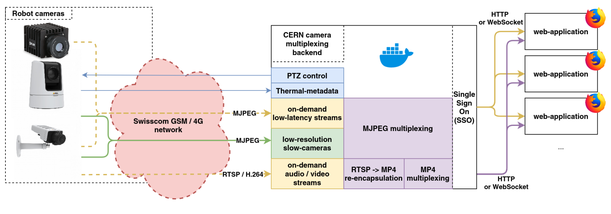


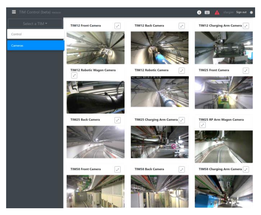
TIM human-robot interface main tab showing one camera, the position within the LHC and some robot live information (left). TIM operators human-robot interface tab showing the position of the four TIM robots operational in the LHC (right)



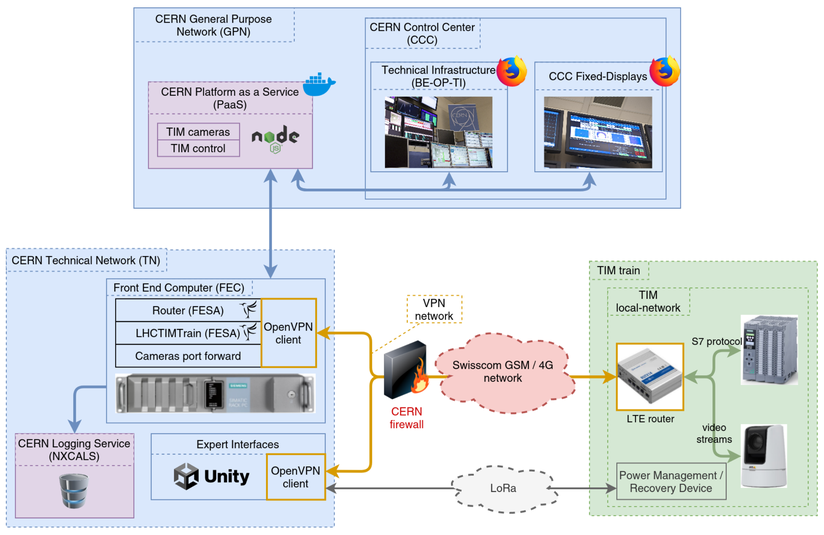


TIM robot passing the LHC sector doors (top left), 3D of a wagon (bottom left), 9 degrees of freedom robotic wagon (top right), 3D of the robotic wagon (bottom right)





Novel framework developed for camera images streaming from the TIM robot (left) and TIM operators human-robot interface tab showing all available cameras on one TIM robot (right)



Overview of the TIM robot control integrated in accelerators controls

Conclusions and outlook: A novel robotic framework integrated within accelerator controls for the inspection and maintenance of particle accelerators has been developed and is currently in operation at CERN on four TIM robots within the LHC. Tele-operation tasks for remote maintenance that are currently performed by expert robotic operators could be driven and/or supervised by accelerator operators, integrating advanced robotic impedance and shared controls. The project will profit from the operators return of experience for the rest of LHC RUN3 to drive possible future robots designs targeted on accelerators maintenance needs

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