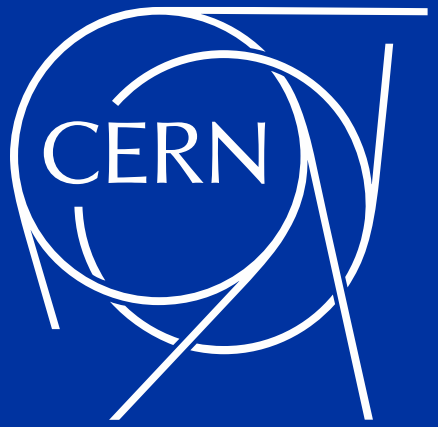
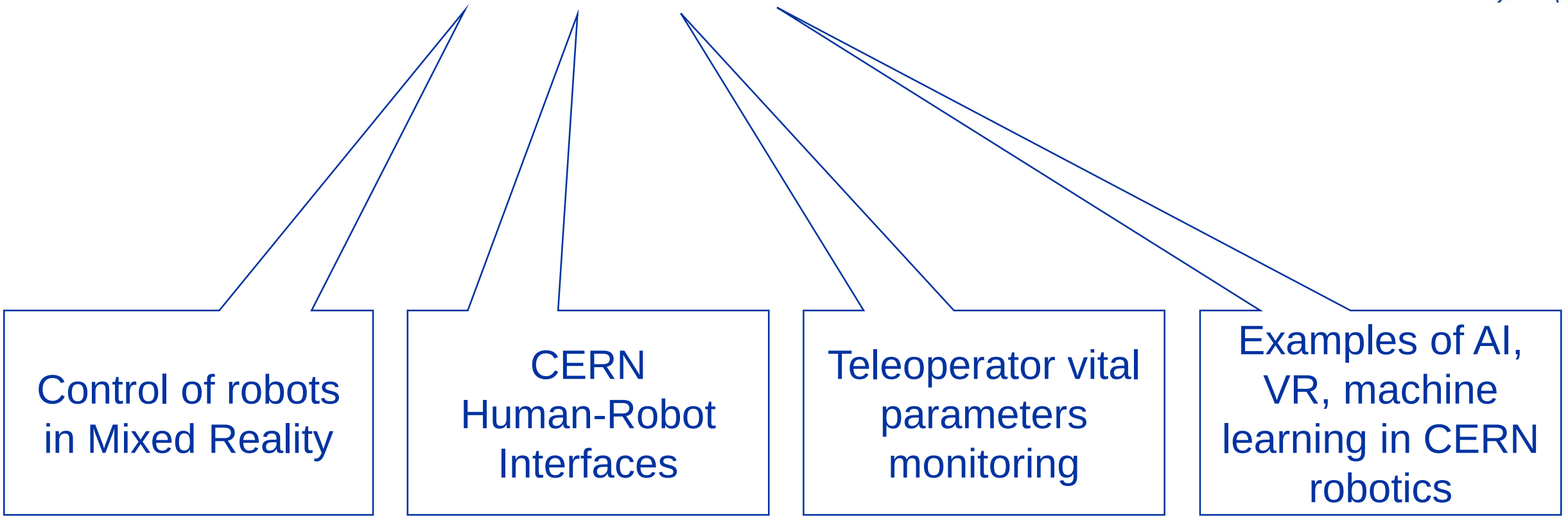


Enhanced reality, user interfaces and artificial intelligence

Krzysztof Adam Szczurek

CERN Academic Training: Robotics

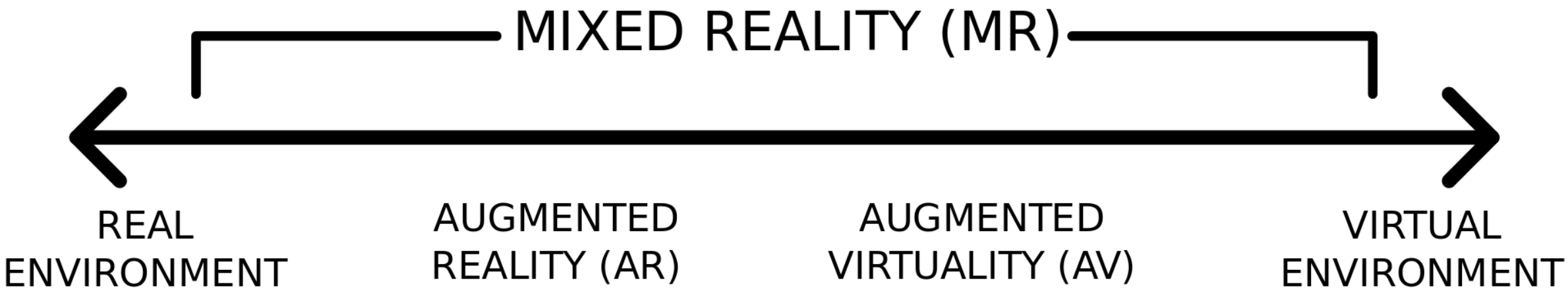
Contents of this lecture



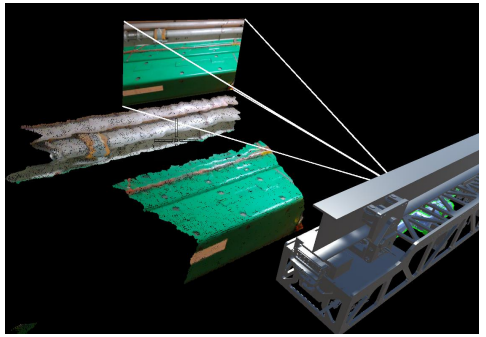
Acknowledgements

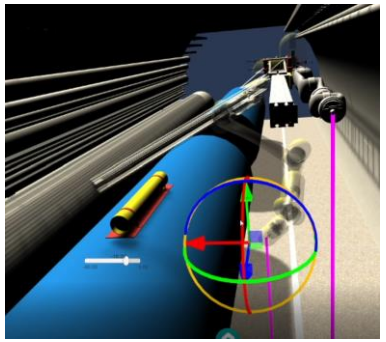
Control of robots in Mixed Reality

Reality-Virtuality Continuum



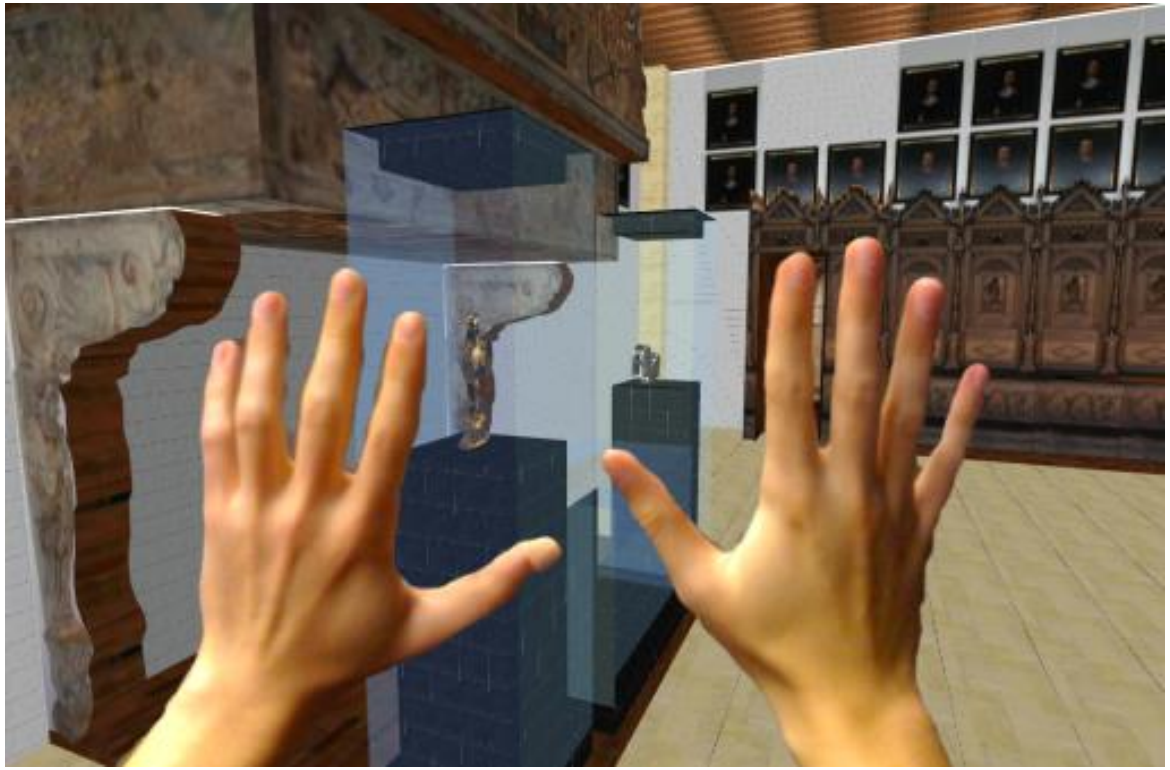
Here Are We





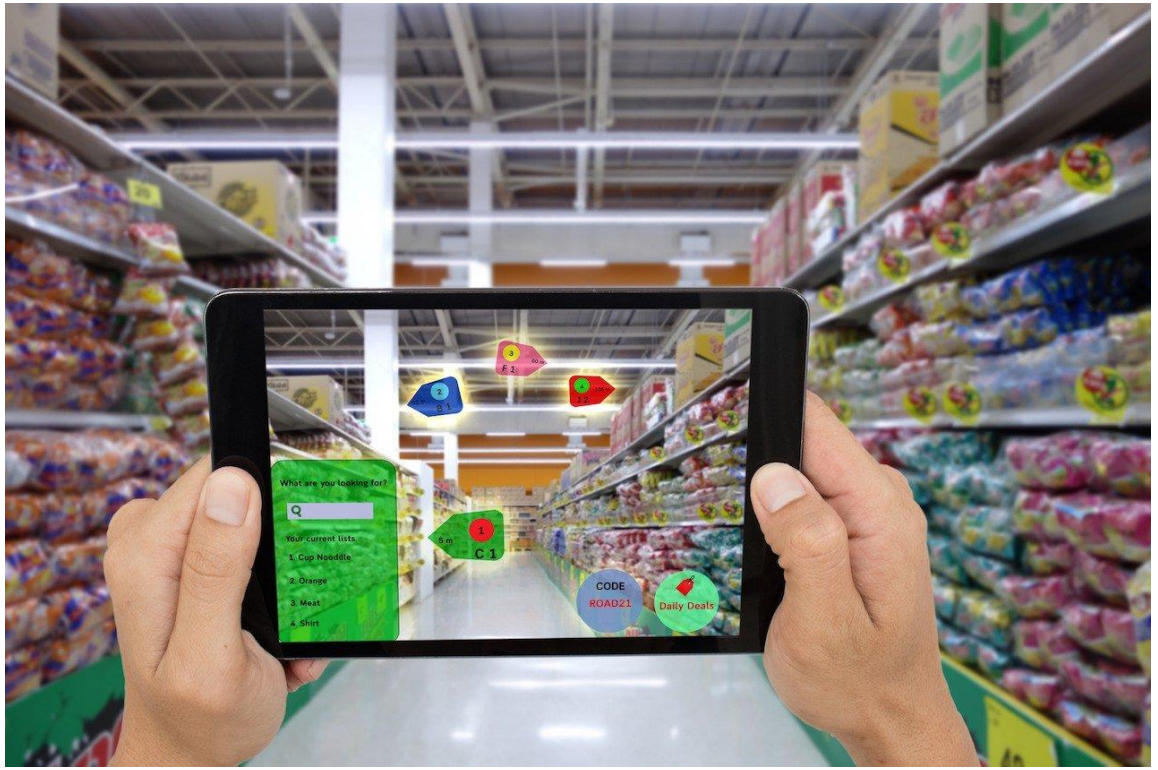
Augmented Virtuality VS Augmented Reality

Reality in Virtuality



https://ichi.pro/pl/co-to-jest-rzeczywistosc-mieszana-106540088967984

Virtuality in Reality



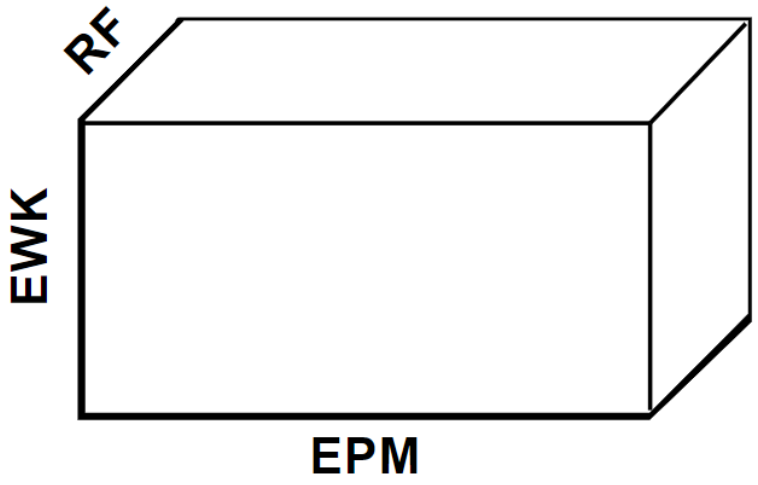
https://industrywired.b-cdn.net/wp-content/uploads/2020/09/AR.jpeg

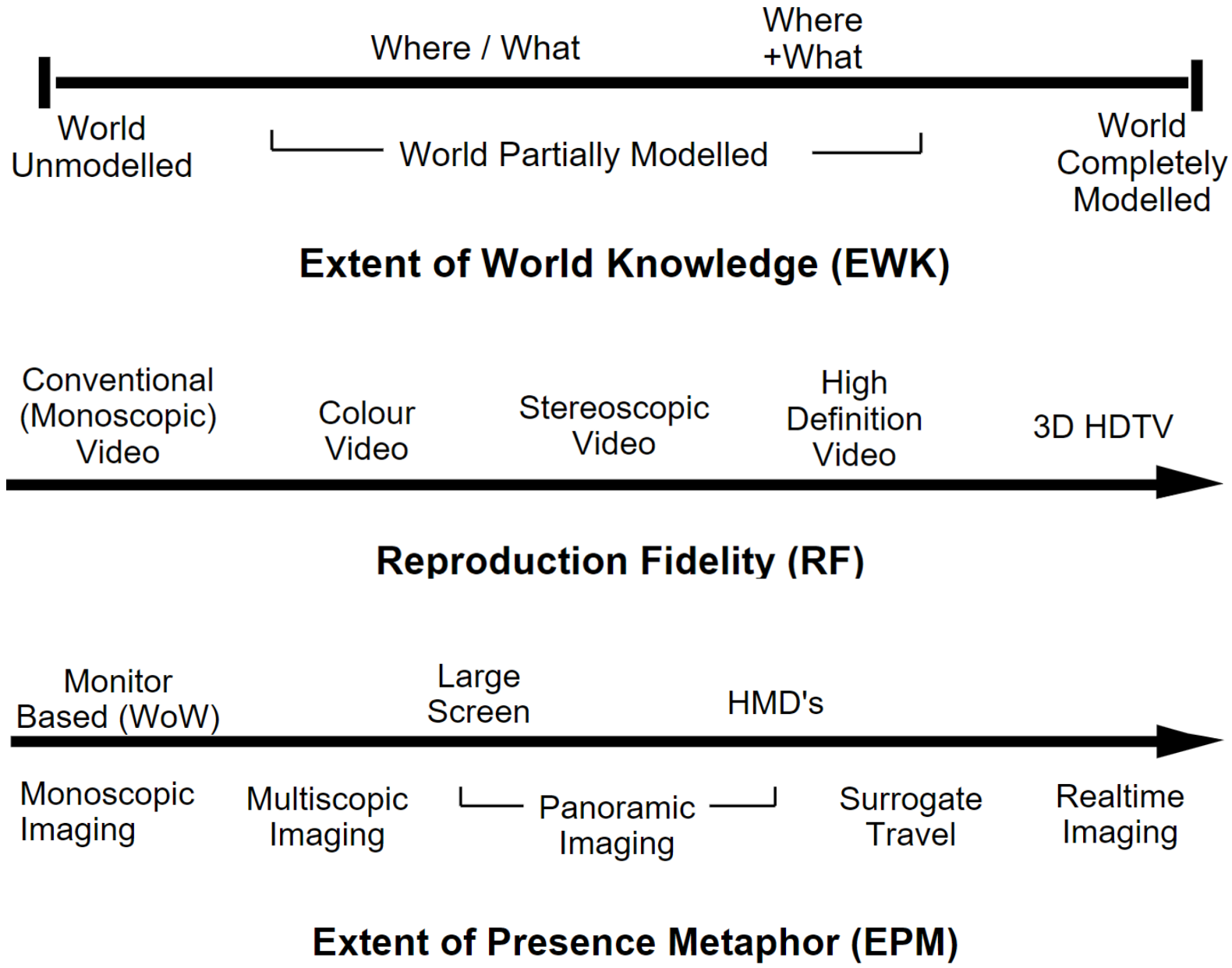
eXtended Reality (XR) VS Mixed Reality (MR)

- The ‘X’ can stand for any letter (M, A, V).
- XR refers to all real and virtual environments.
- It is the broadest term and includes all the computer and hardware XR technologies.

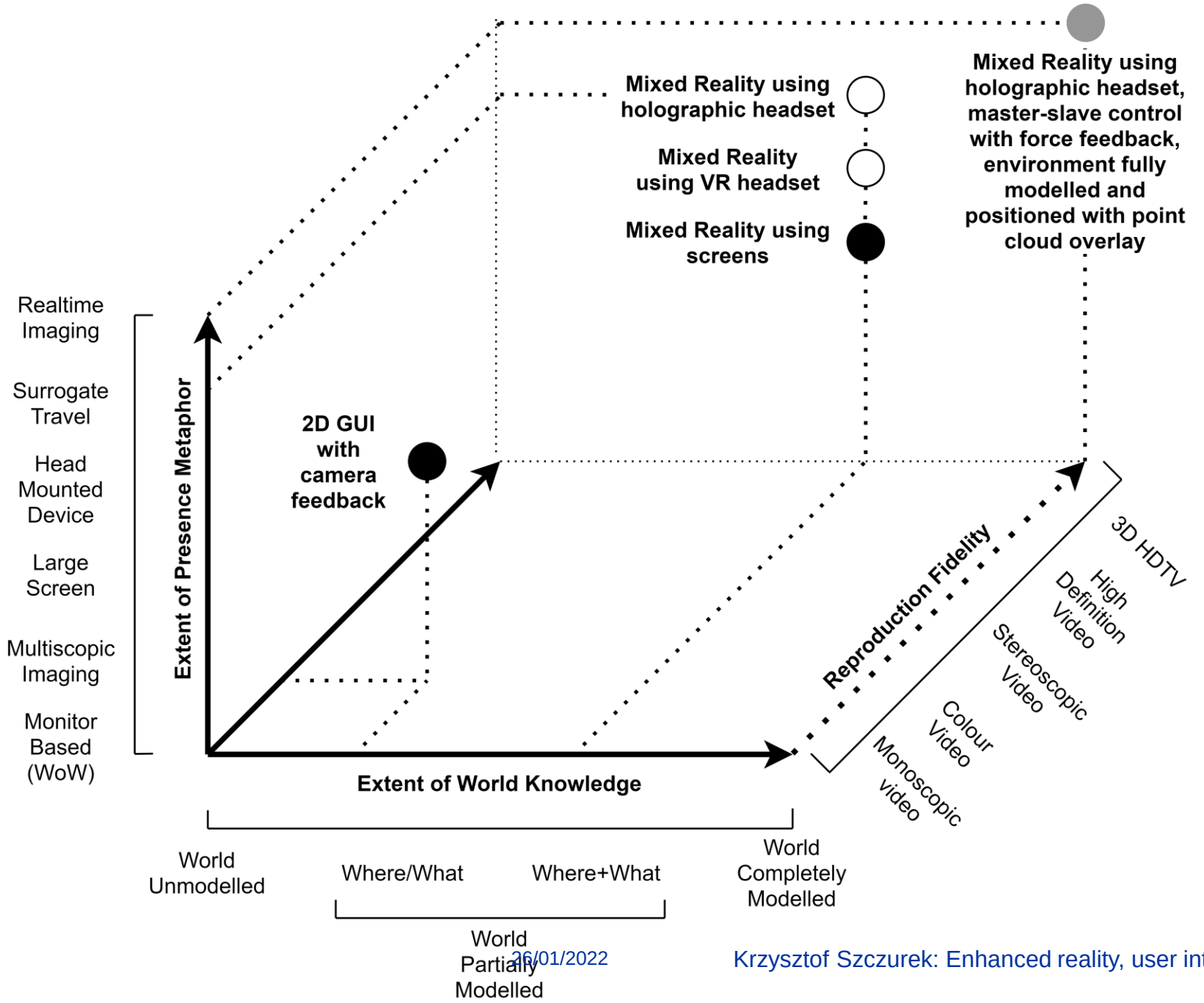
- In Mixed Reality (MR) there is always a part of the real and world shown as the environment or its virtual representation
- The control usually happens in real-time where the user gets feedback in reasonable and deterministic amount of time and acts on real or virtual objects.

Mixed Reality taxonomy





Milgram, P., Takemura, H., Utsumi, A., Kishino, F. (1994). Augmented reality: A class of displays on the reality-virtuality continuum.

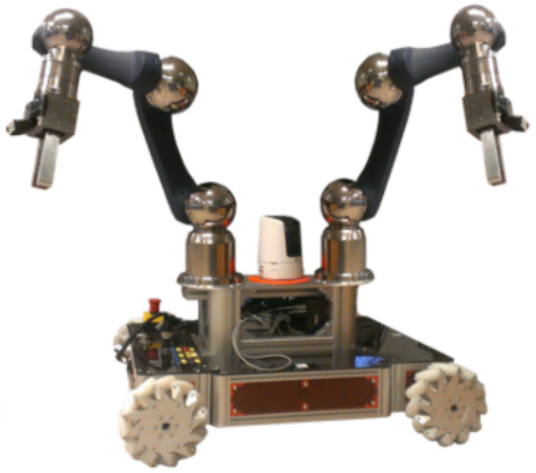


CERN Human-Robot Interfaces

- Currently used
- Currently tested
- Ideal

CERN Human-Robot Interfaces

How the robots are controlled



ROBOT WITH INSTALLED EQUIPMENT AND ITS ON-BOARD COMPUTER

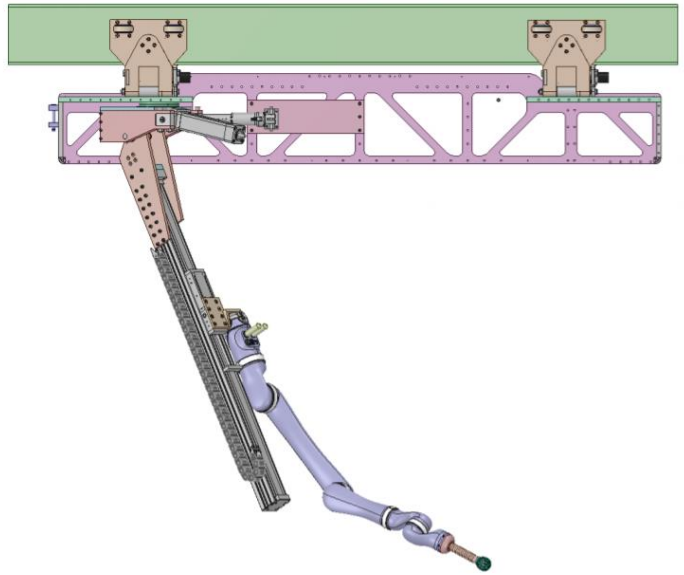
- CERN ROBOTIC FRAMEWORK (C++ framework)
- Communication with devices
- Processing the information from sensors
- Real-time control
- Communication points

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

Challenge – network delay/bandwidth limit

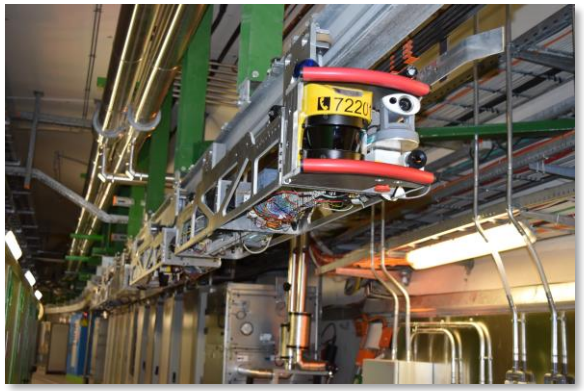


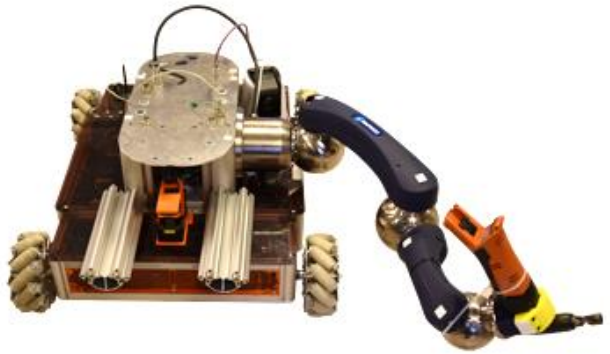
- **Direct Ethernet – Ethernet connection: ~1000 Mbps**
- **WiFi – WiFi over CERN network intrastructure: max ~100 Mbps**
- **4G connection in the LHC tunnel: max ~20 Mbps if connection is good**

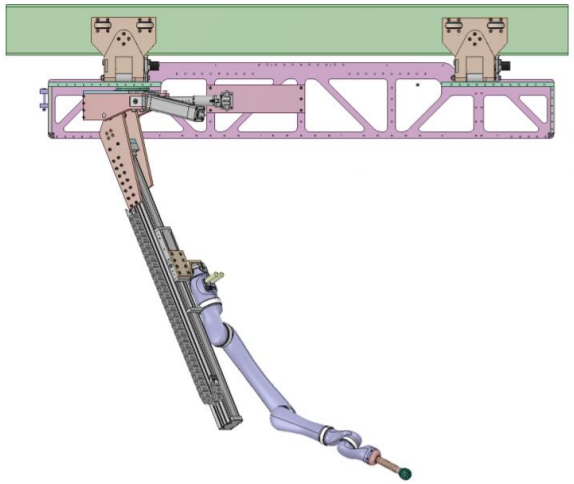
Network constrains and their consequences: Round-trip time

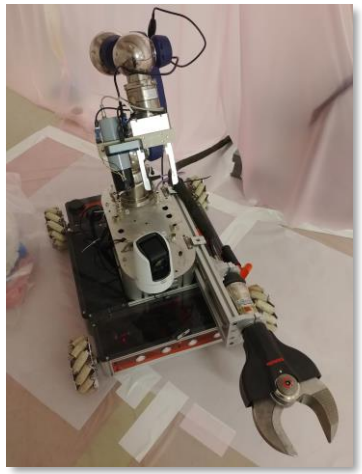
Network connection type	Downlink bandwidth [Mbps]	Round-trip time [ms]		Jitter [ms]
		Bandwidth usage = 0%	Bandwidth usage = 100%	
VPN with 4G modem	11.99	43.4	131.5	26.00
Wi-Fi over CERN GPN	73.95	20.33	30.3	5.64
Ethernet over CERN GPN	885.8	0.04	1.61	0.19
Ethernet cable directly	941.8	0.24	1.47	0.28

Need for versatile Human-Robot Interface for CERN robots

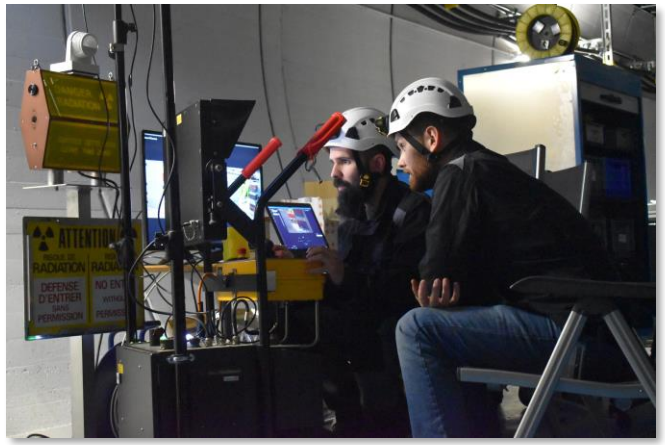




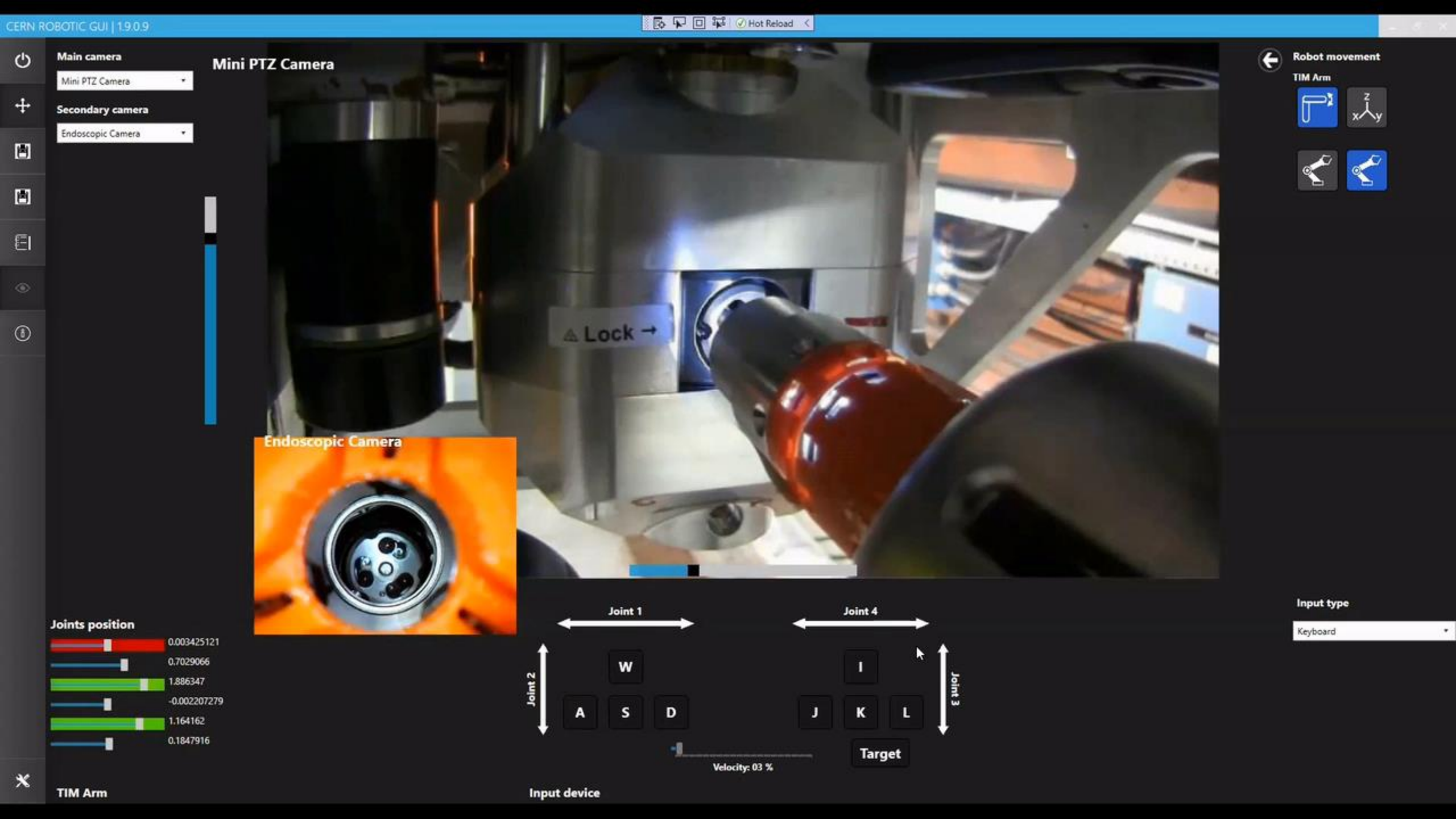




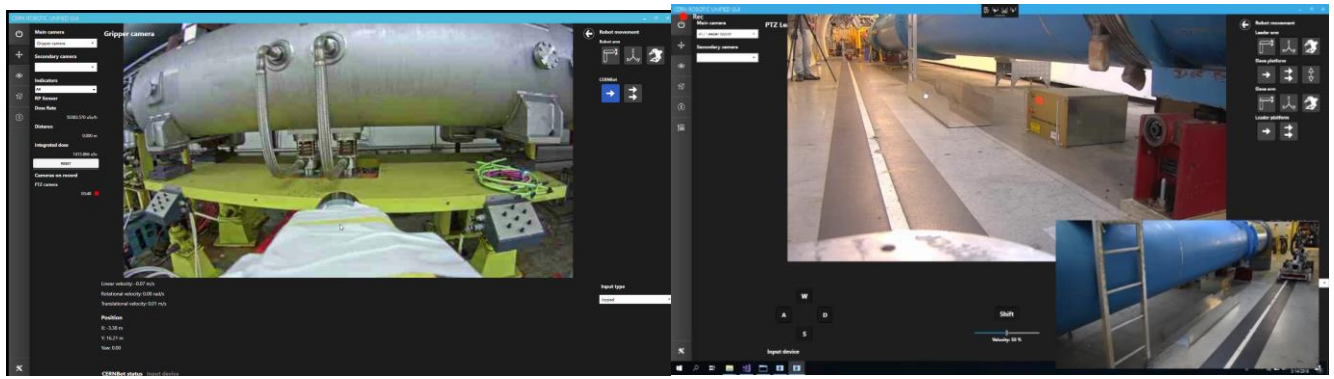
Robots controlled often from the field

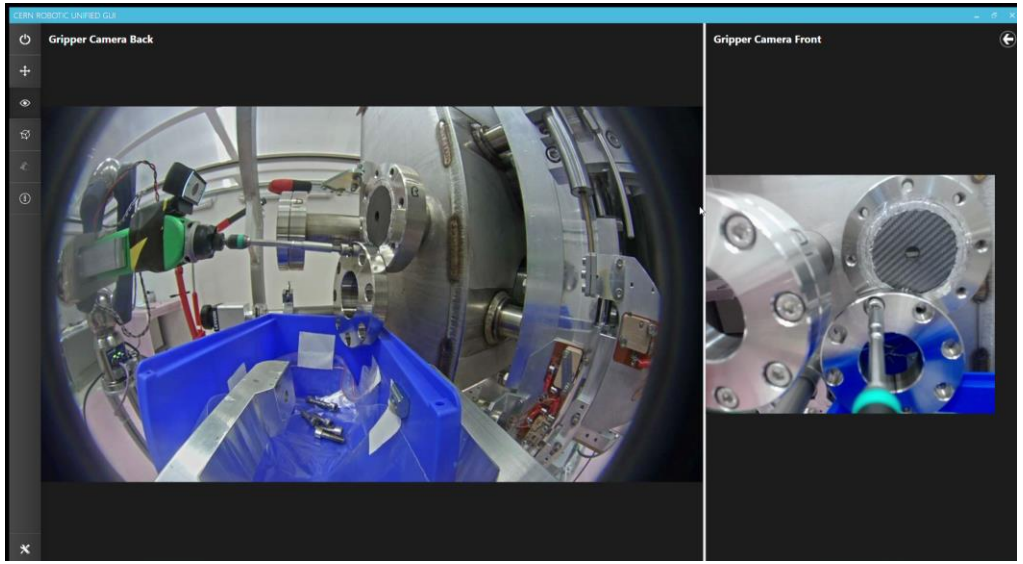


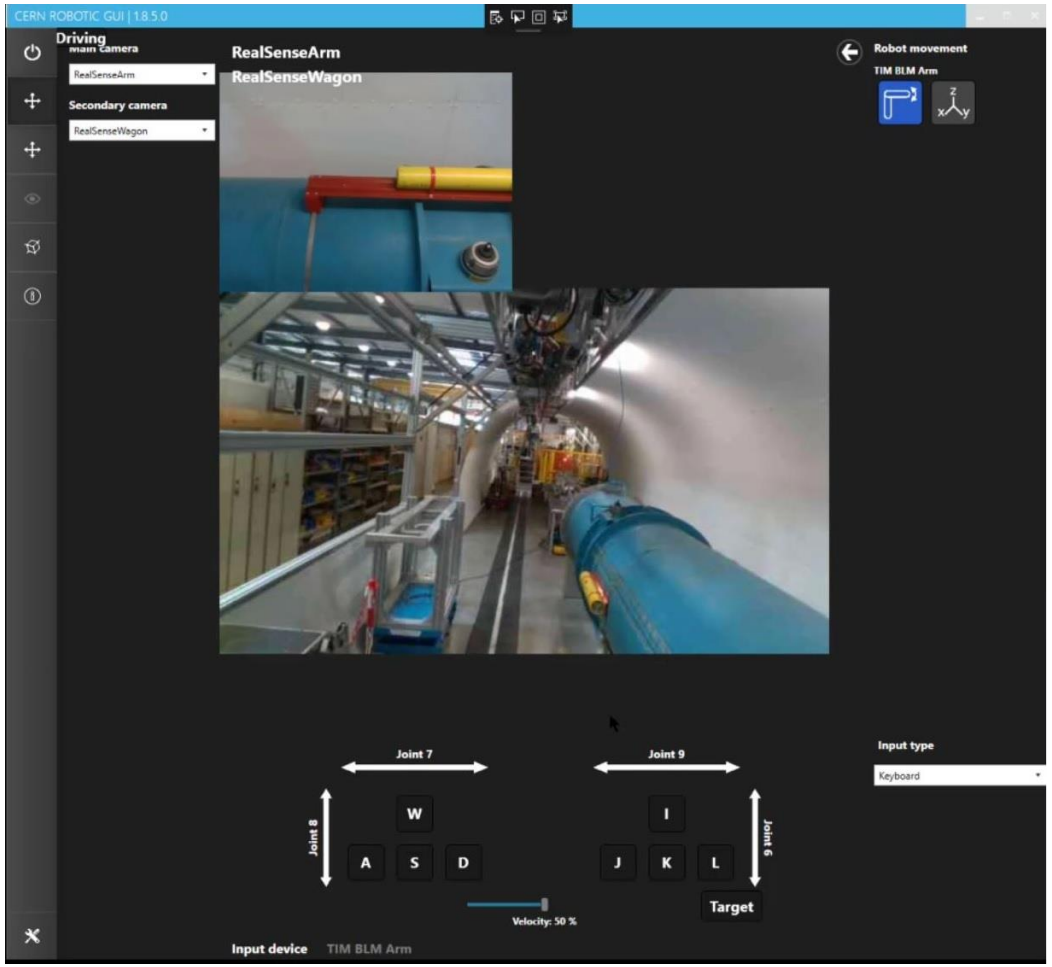
2D Human-Robot Interface


CERN ROBOTIC GUI | 1.9.0.9
Hot Reload
Main camera
Mini PTZ Camera
Secondary camera
Endoscopic Camera
Mini PTZ Camera
Lock
Endoscopic Camera
Robot movement
TIM Arm
Joints position
0.003425121
0.7029066
1.886347
-0.002207279
1.164162
0.1847916
Joint 1
Joint 2
Joint 3
Joint 4
W
A
S
D
I
J
K
L
Target
Velocity: 03 %
Input type
Keyboard
TIM Arm
Input device

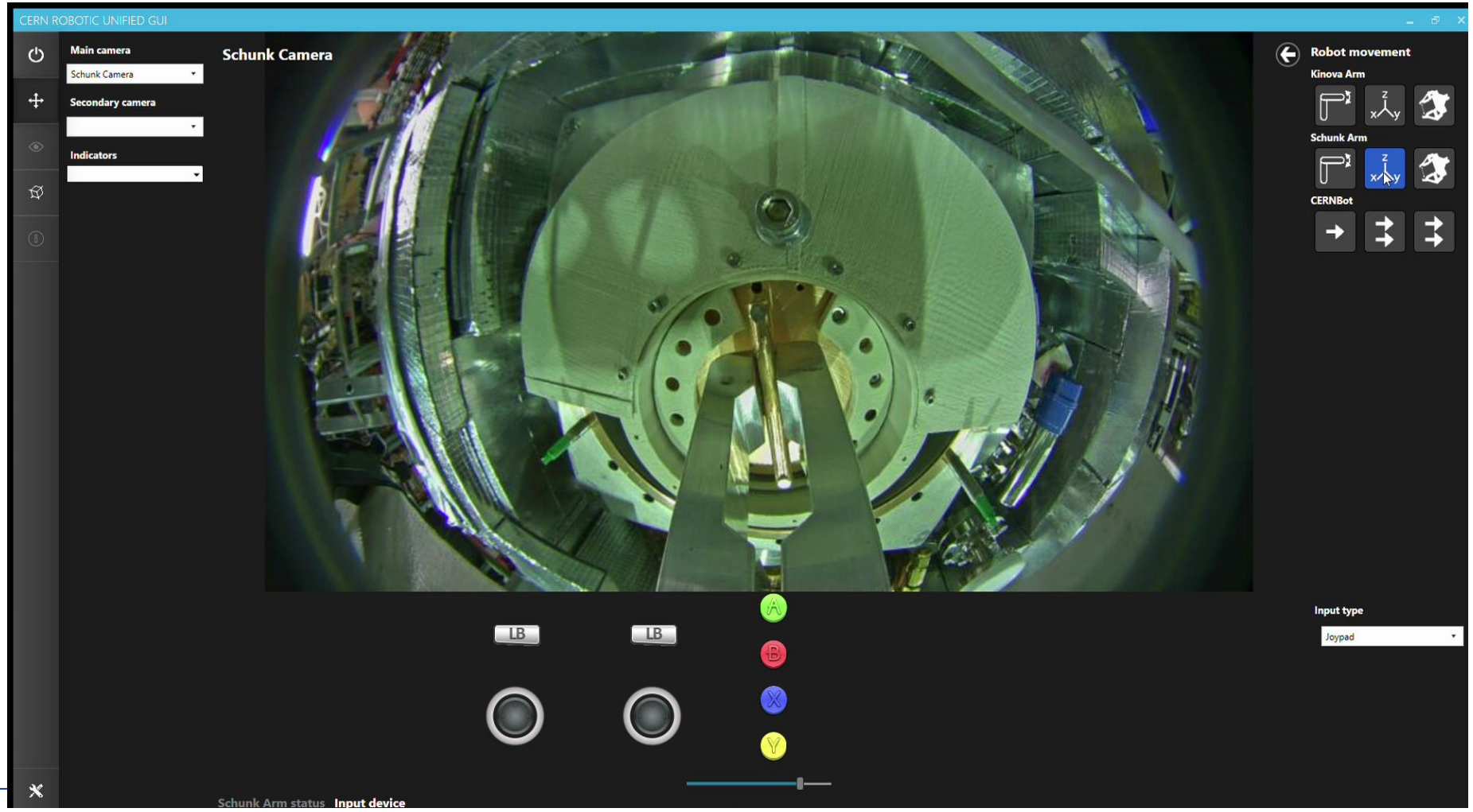
2D Human-Robot Interface: Modularity and multimodality



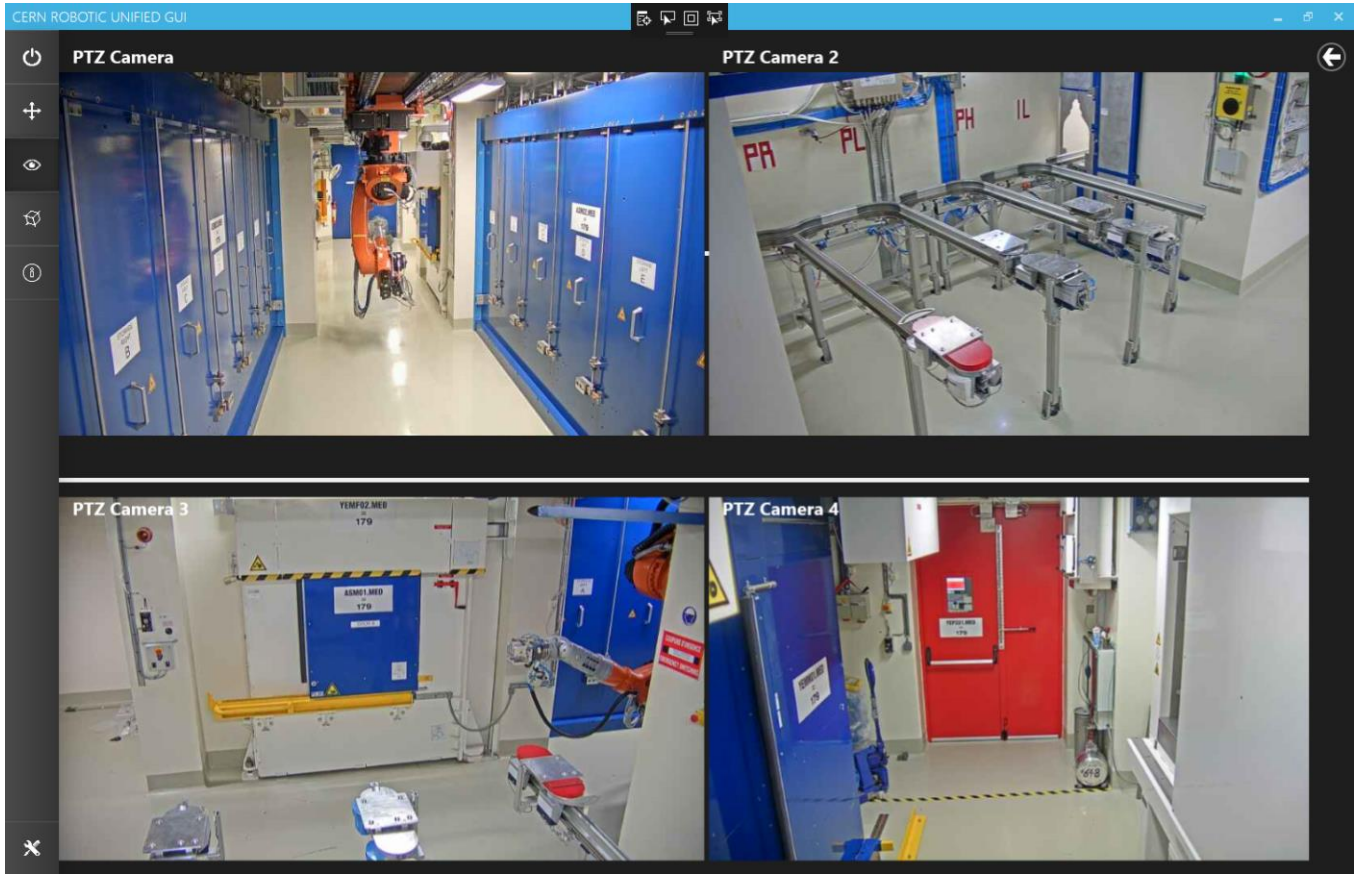


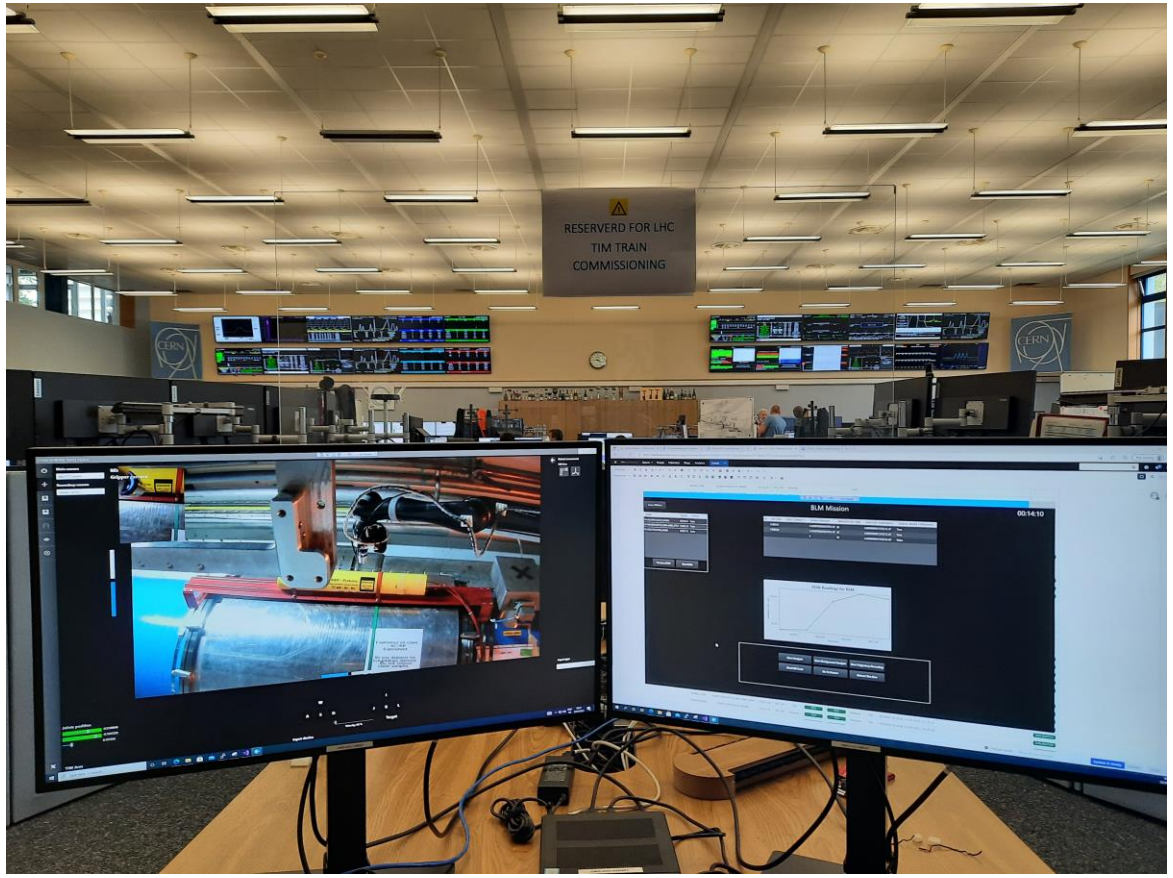


2D Human-Robot Interface: Manipulator control devices



2D Human-Robot Interface: Camera feedback





Main camera

Mini PTZ Camera

Secondary camera

Mini PTZ Camera

Battery

Current: 16.7 A

Voltage: 25.2 V

Movement

Current Position: 13,061.9 m

Current Velocity: 0.0 m/s

Maximum Velocity: 2.5 m/s

Tools

Stabilizer: Inactive

Shielding: unknown

Warnings

VelocityEncoderReadingError

Ack Alarms

Camera options

Quality

Medium

Save Image

Record video

Orientation

Zoom

Focus

Auto focus on

Jog

Backward

Forward

Velocity: 0.3 m/s

DCUM

50

Move

Enable

Emergency STOP

STOP

Charge

Stabilizer

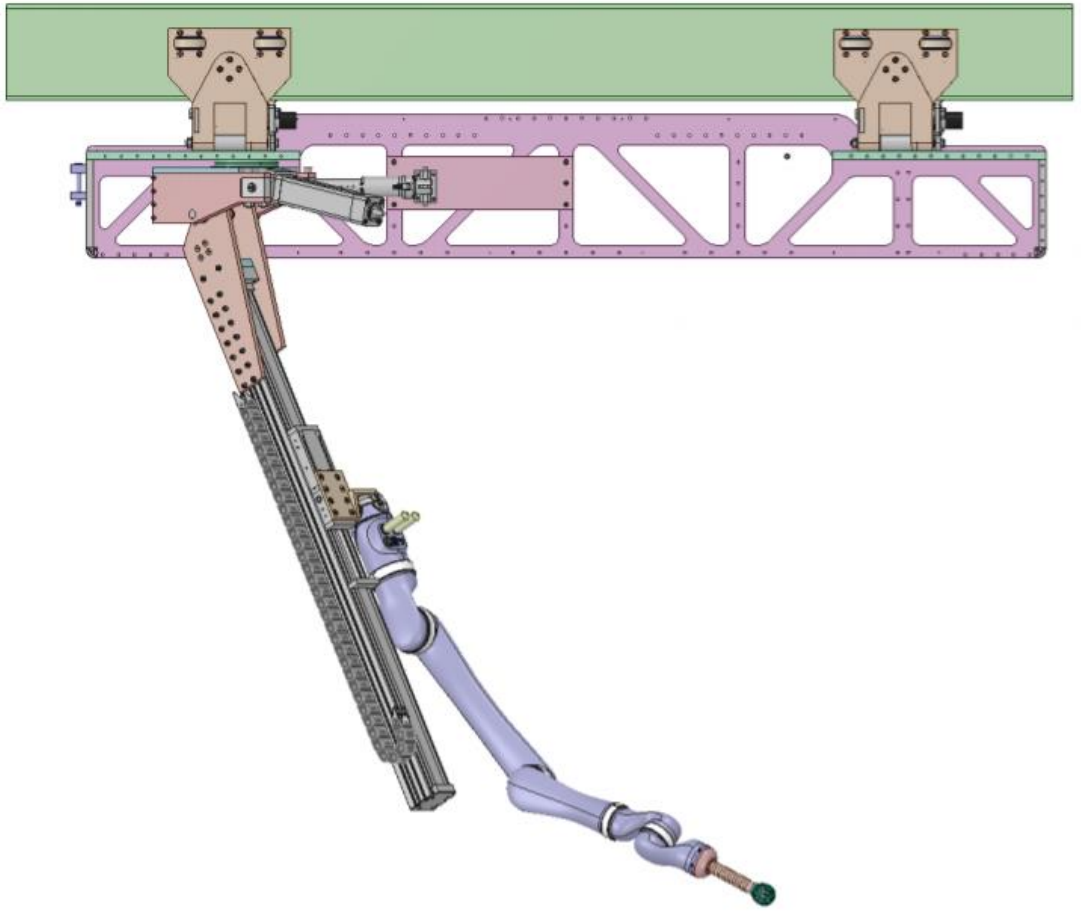
Shielding

14:43

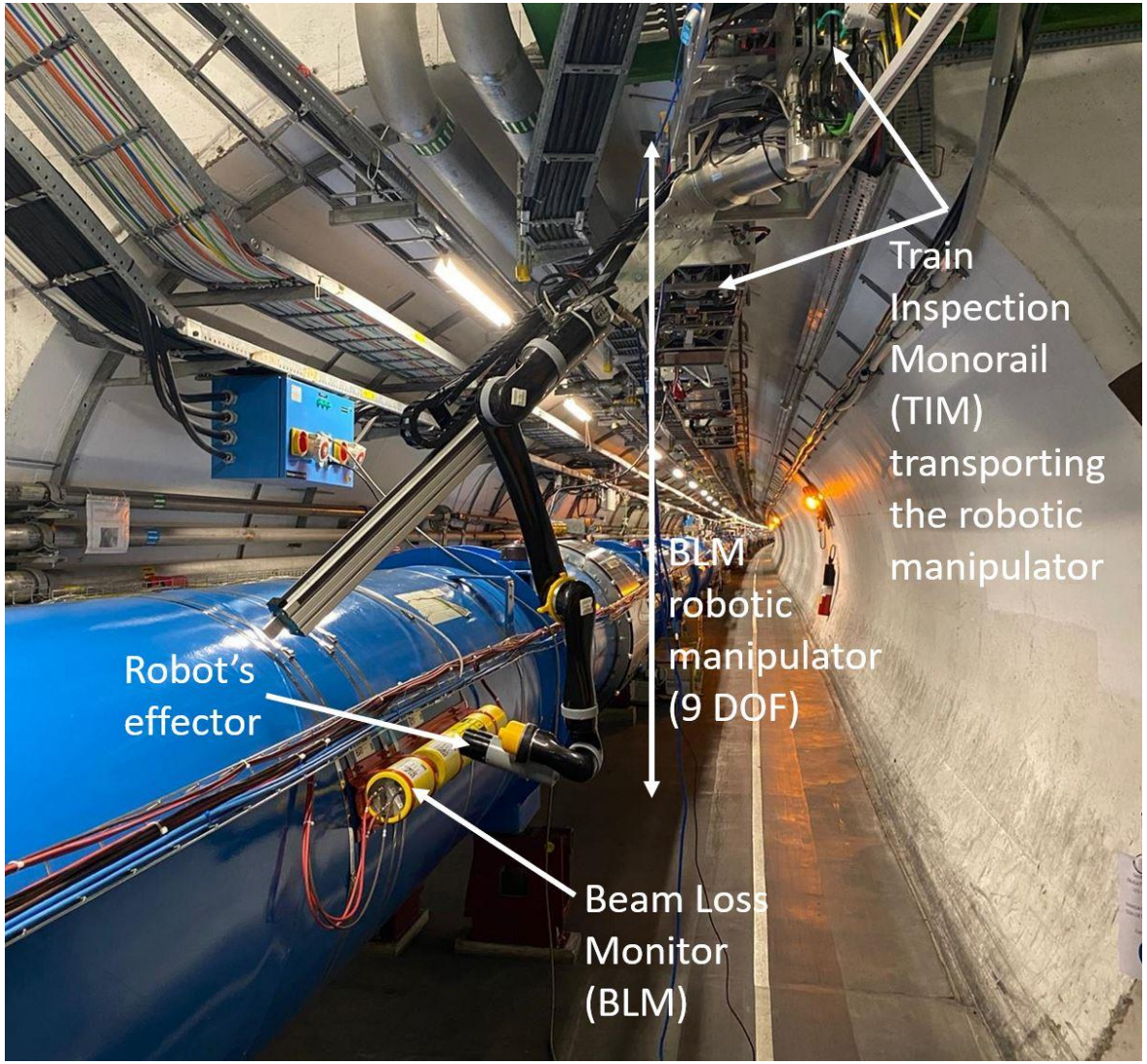
21/09/2021

3D Mixed Reality Human-Robot Interface

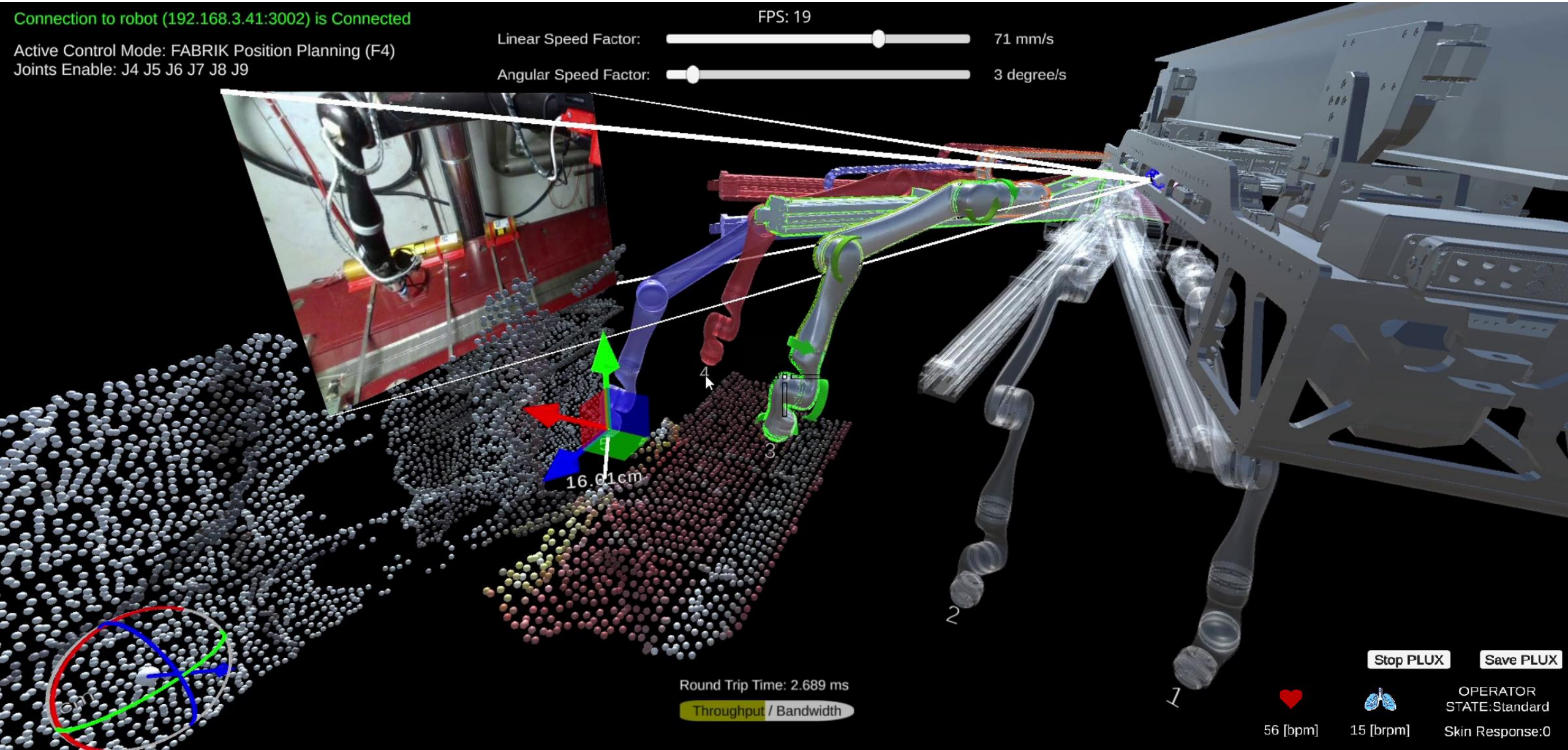
Redundant manipulator = need for easier control



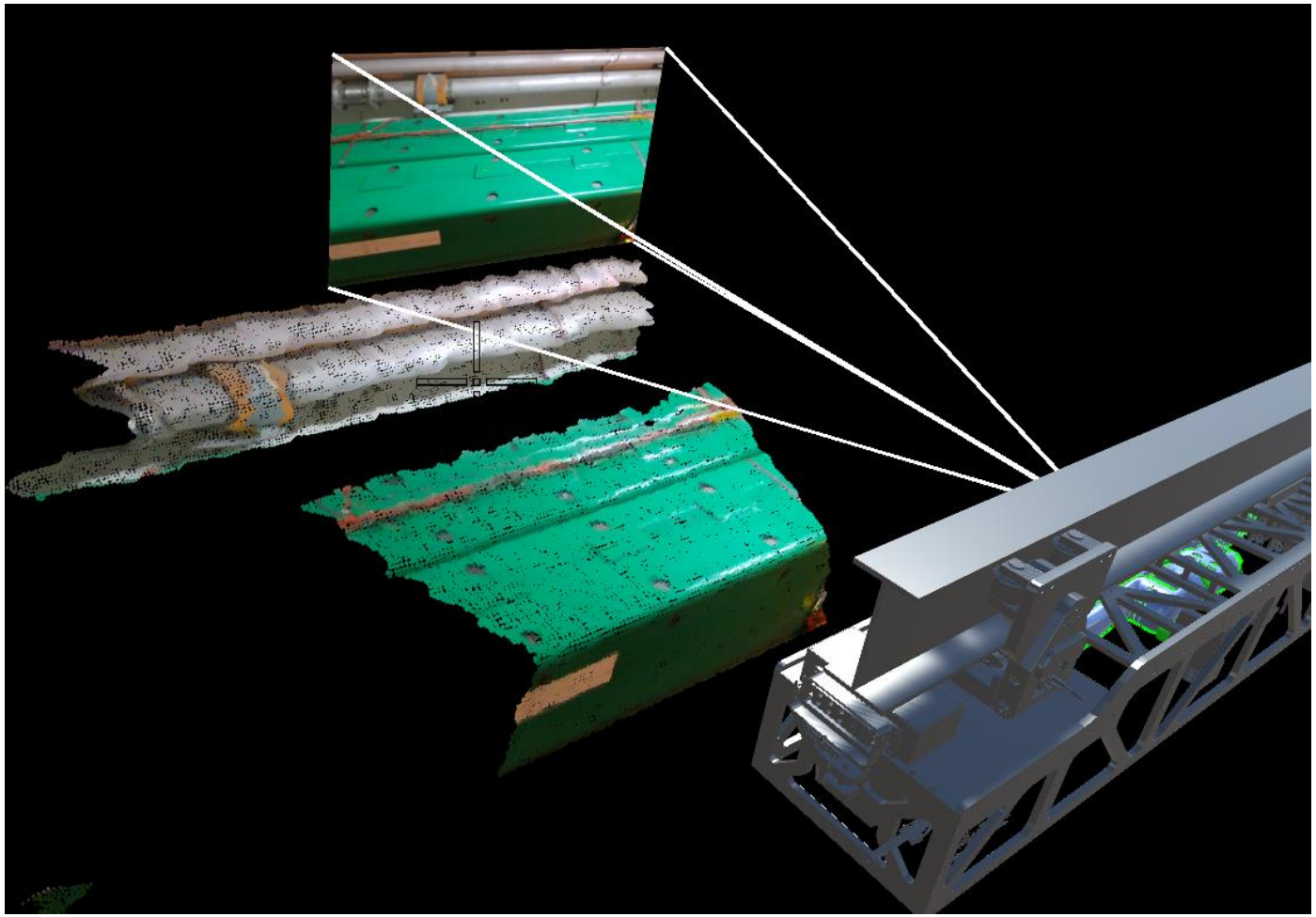
LHC Beam Loss Monitors robotic measurements

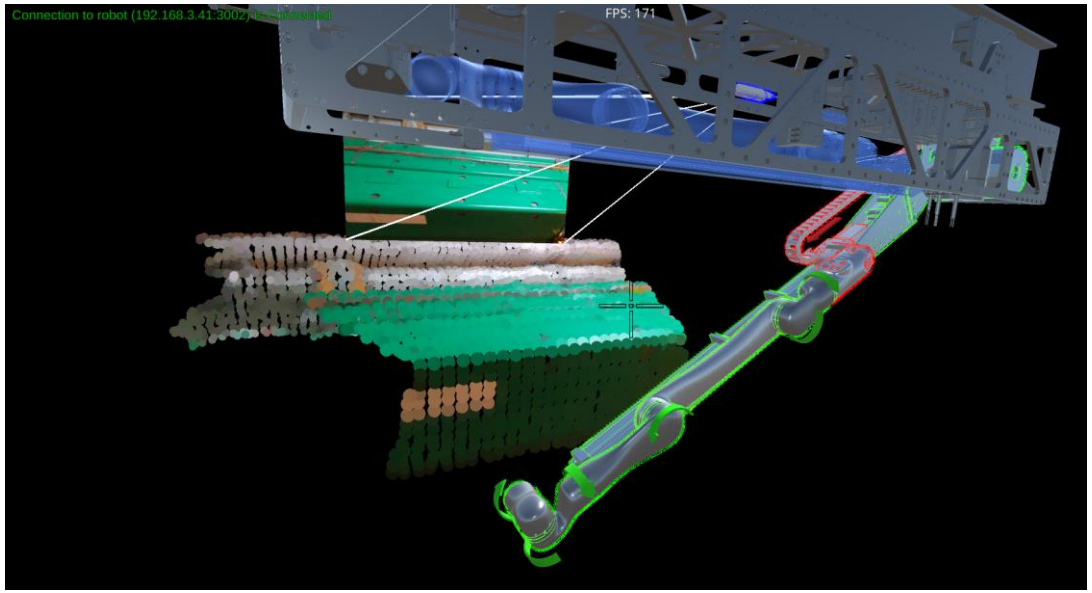


Mixed Reality Human-Robot Interface

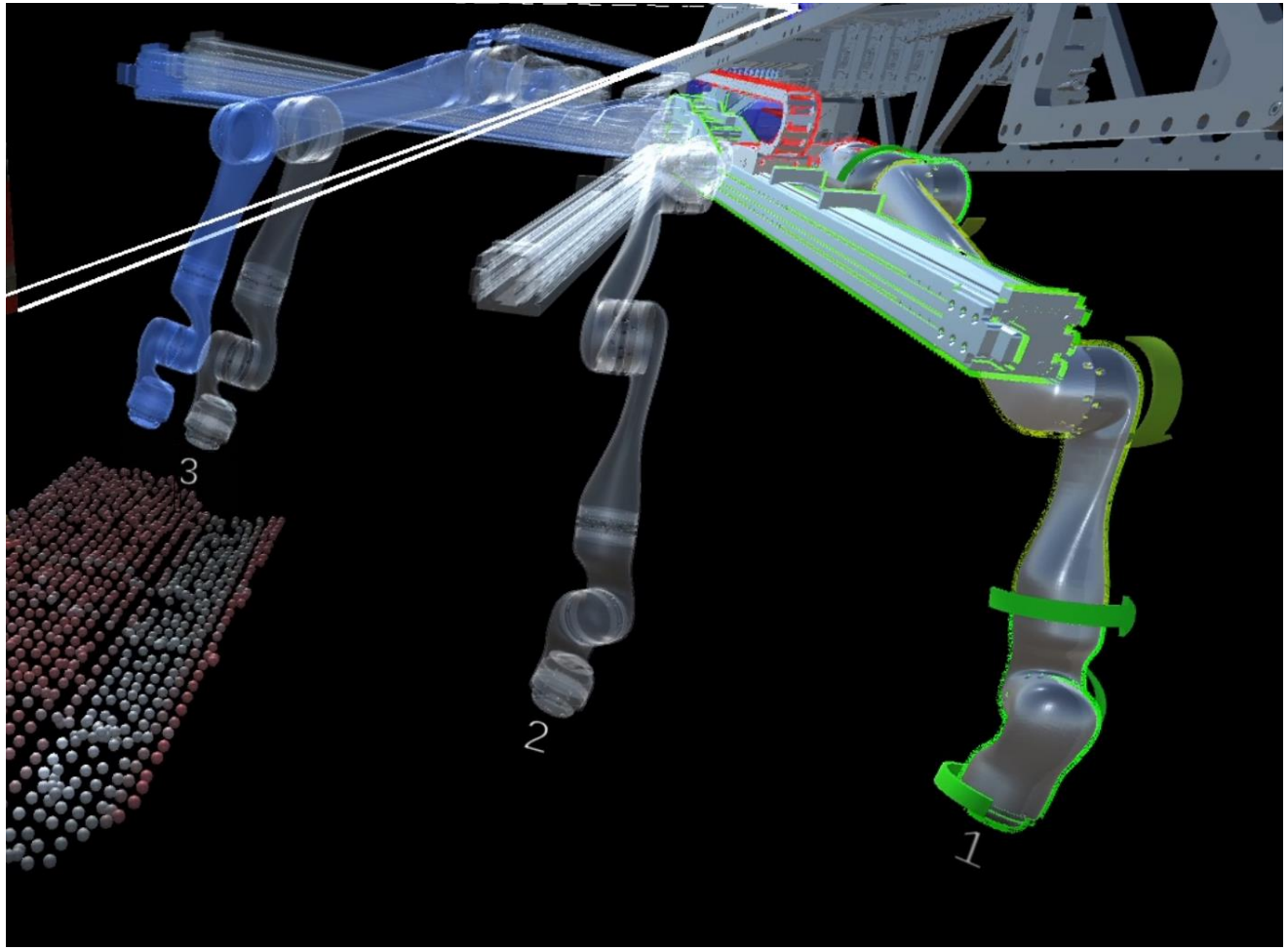


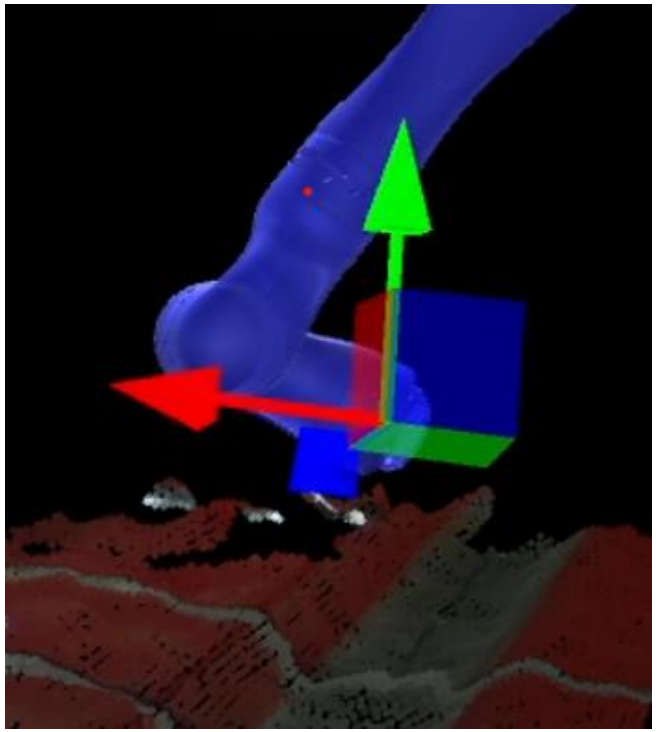
Point cloud feedback



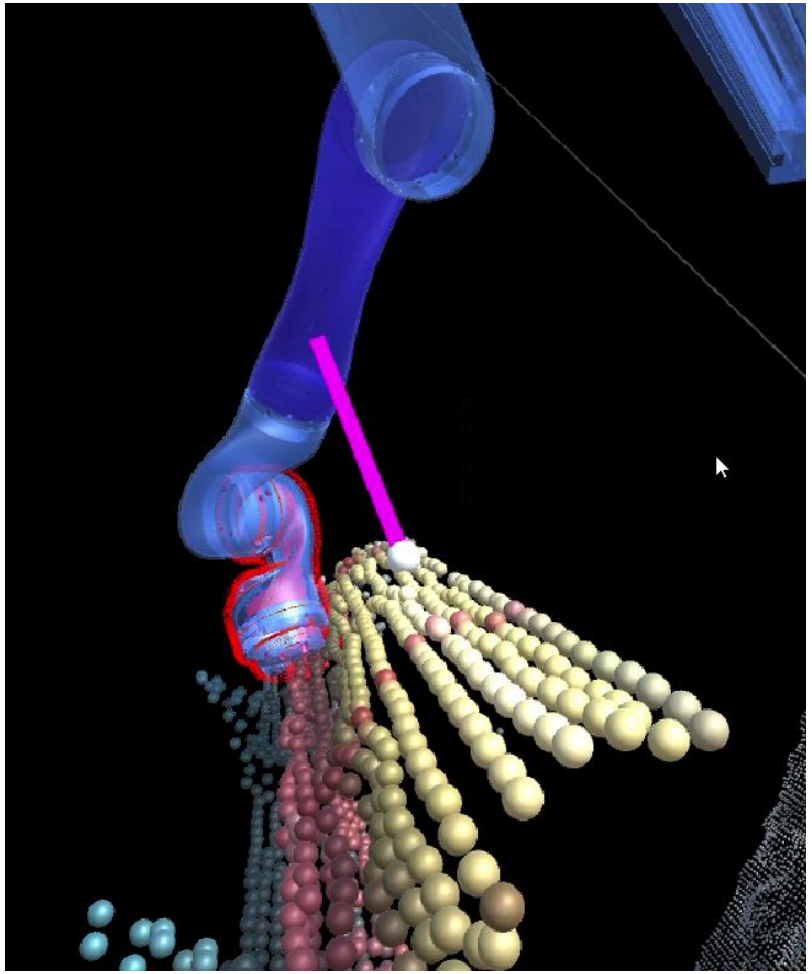


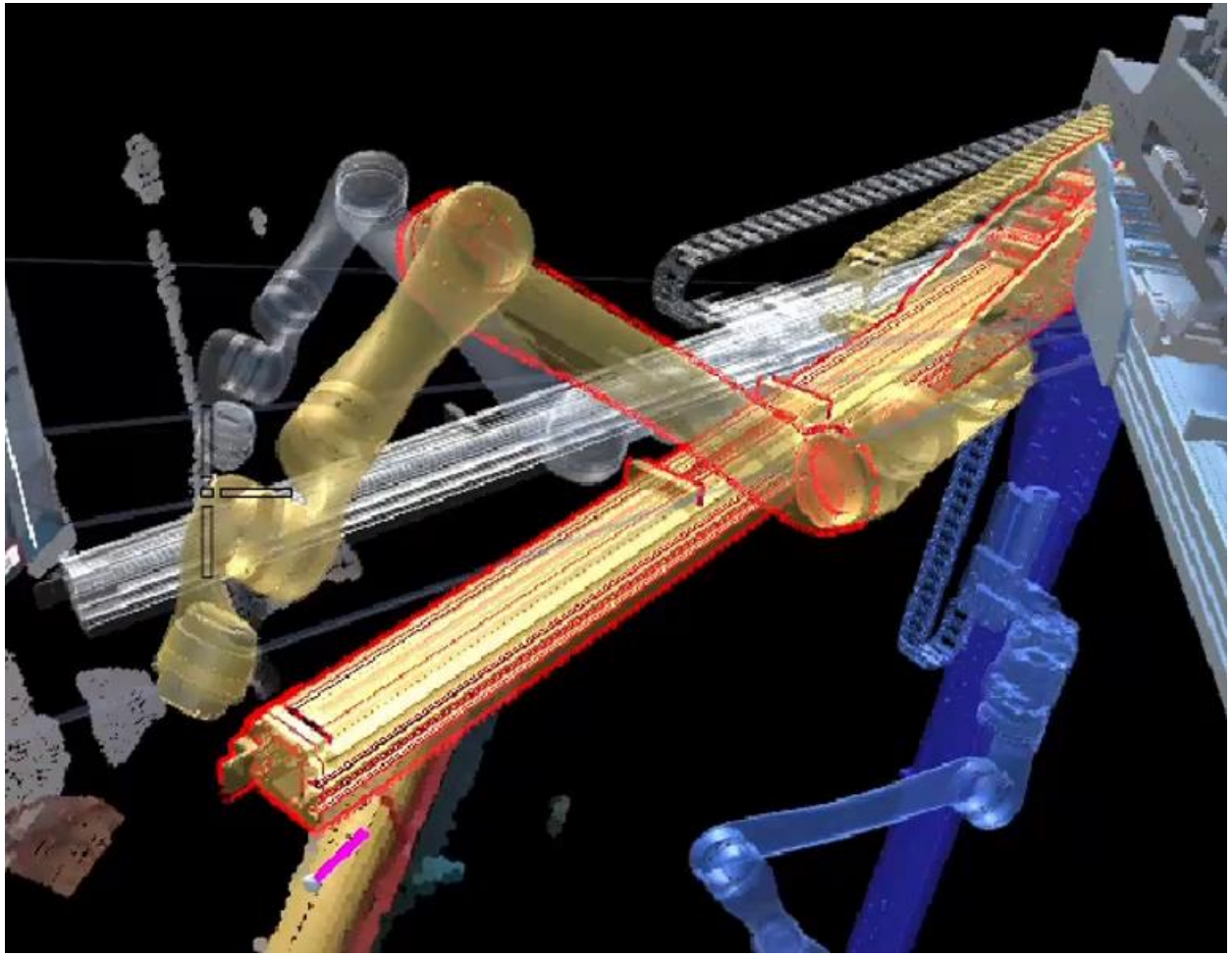
3D control, trajectories planning



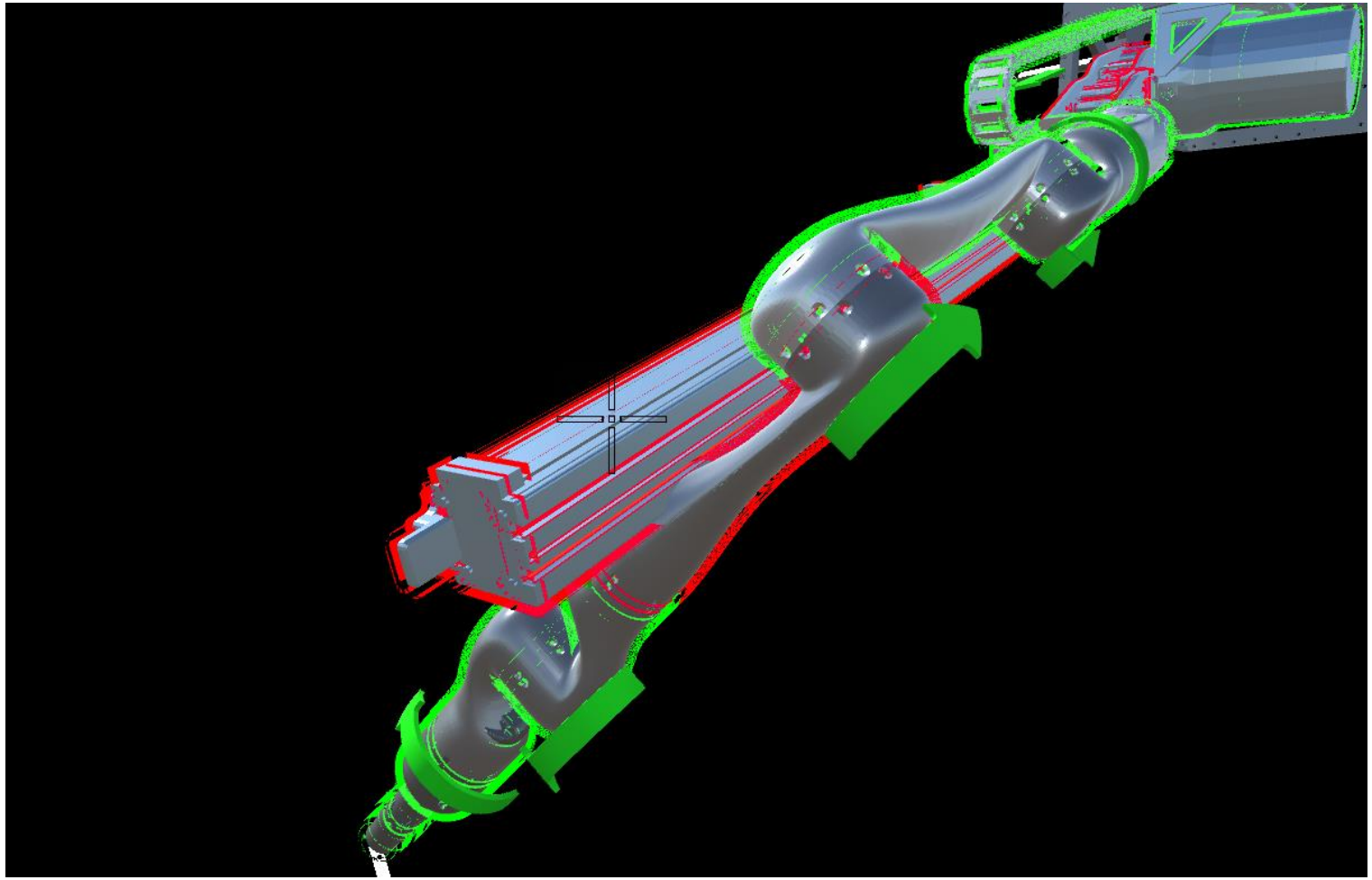


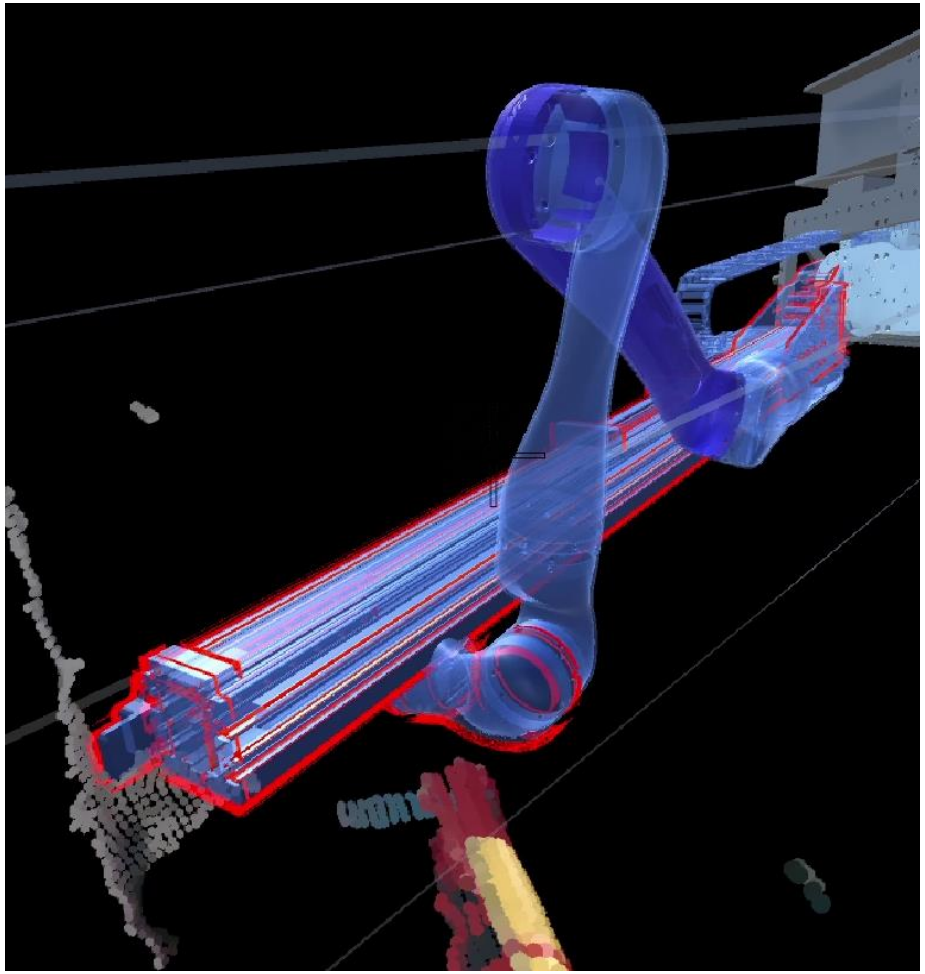
Collision avoidance





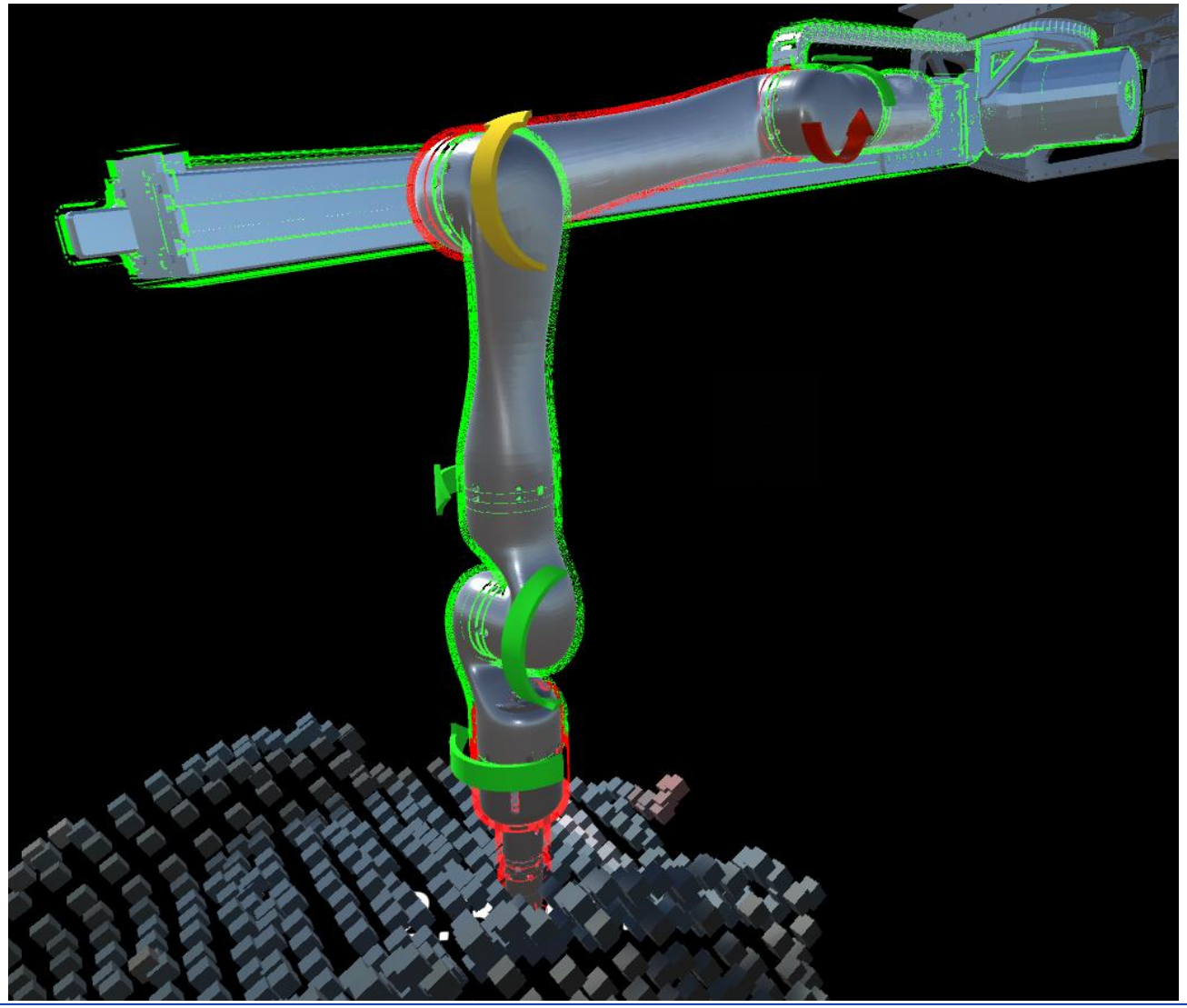
Collision detection: self-collision





PREVIEW TO CHECK COLLISIONS

Collision detection: torques



Why network parameters are important in Mixed Reality control

Round Trip Time: 99.00001 ms

TCP Estimated RTT: 65.714 ms

TCP Estimated Dev RTT: 42.015 ms

TCP Estimated Time Out Interval: 233.776 ms

Throughput Downlink: 6.952 Mbps

Throughput Uplink: 0.102 Mbps

Throughput Point Cloud: 1.522 Mbps

Throughput Video: 2.427 Mbps

Throughput: 3.949 Mbps

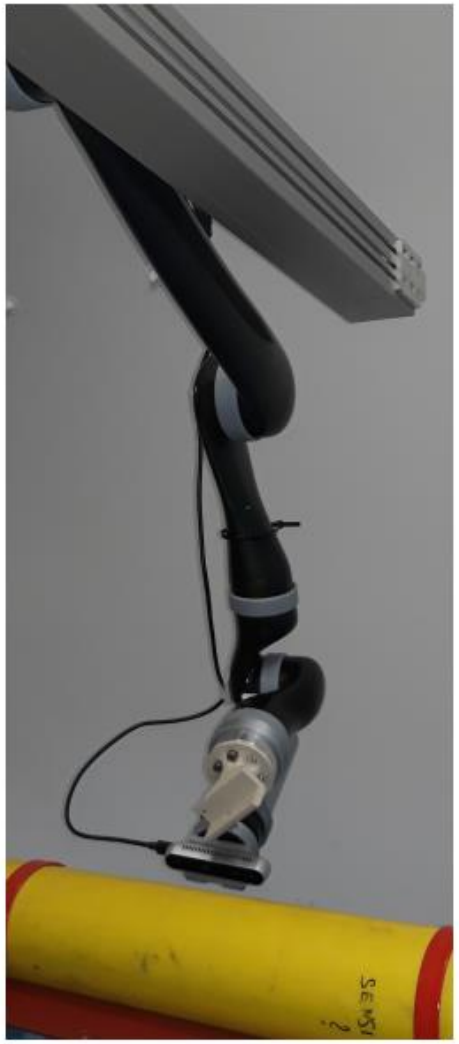
Running Bandwidth Measurement

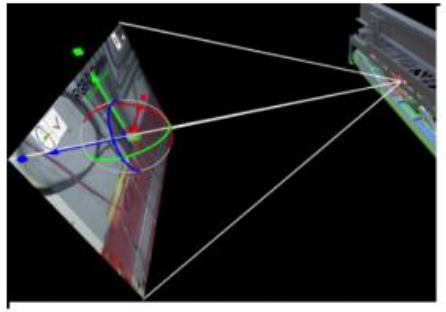
Receiver Bandwidth: 8.15 Mbps

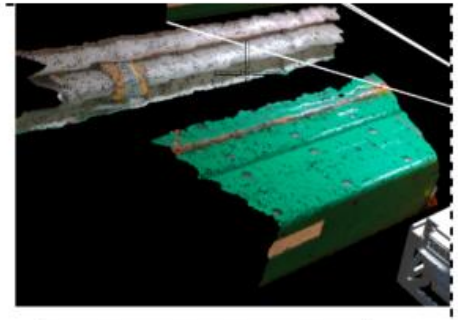
Sender Bandwidth: 2.51 Mbps

Uplink/Downlink: 0.308

RGB-D camera control







Video

Point Cloud

Requested Resolution

Real Video FPS

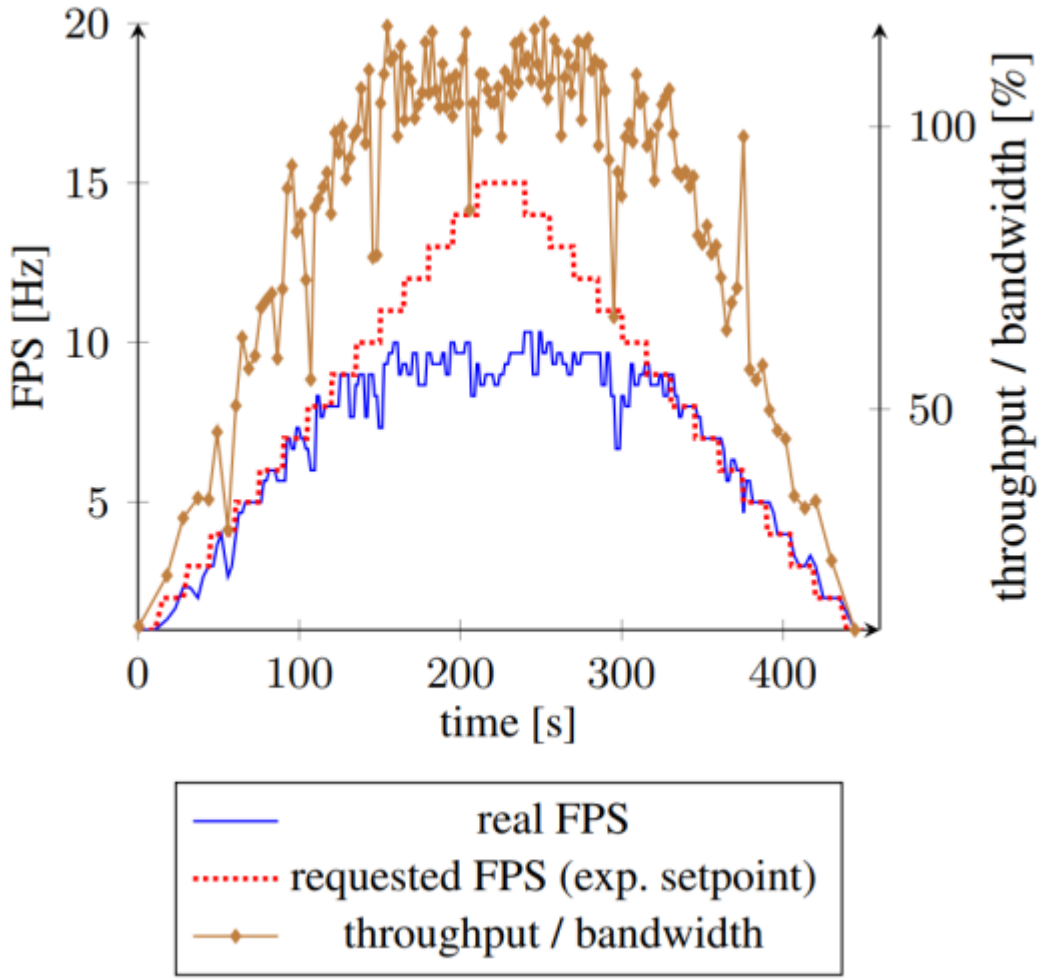
Resolution Feedback

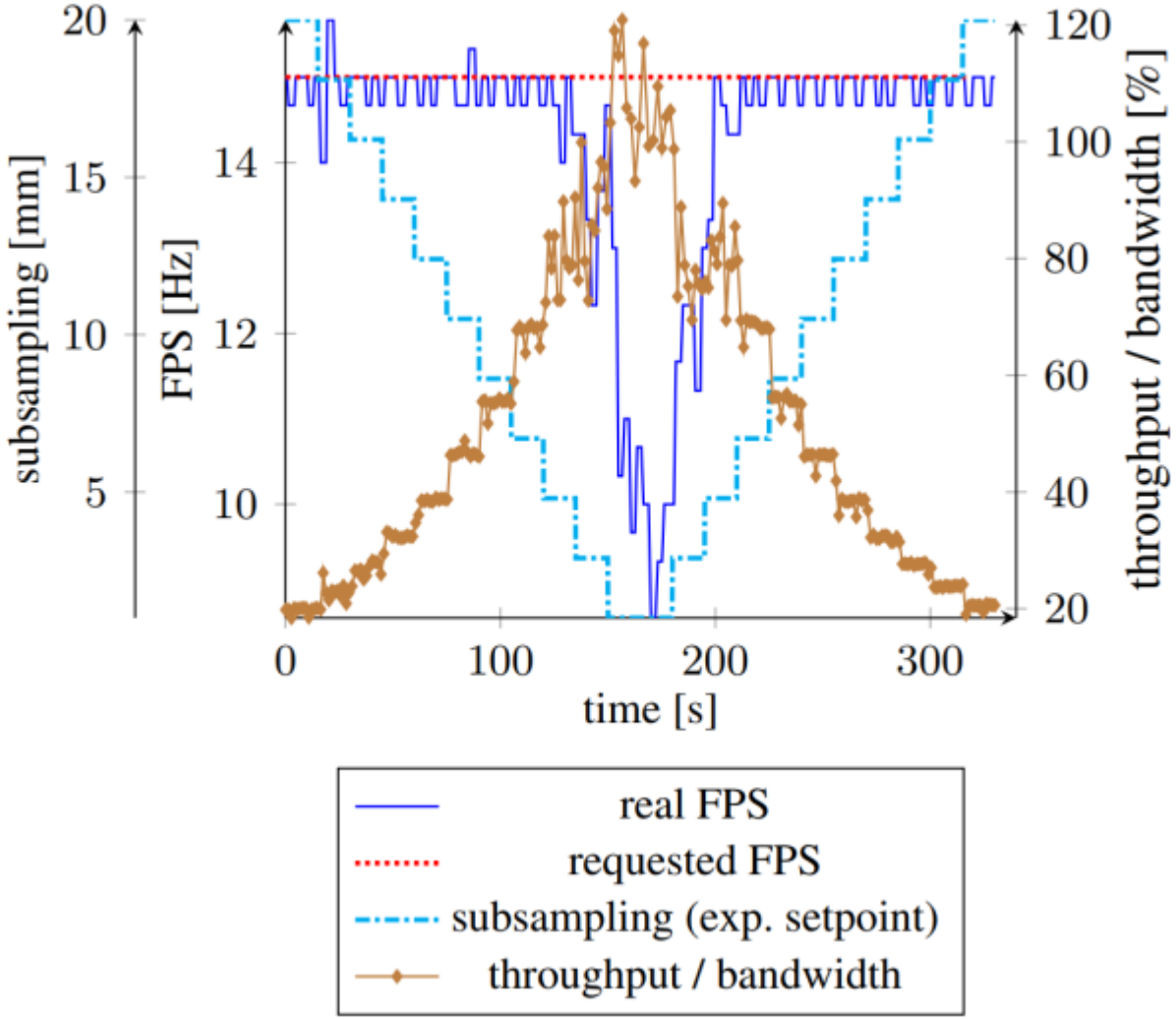
Real Point Cloud FPS

Requested FPS

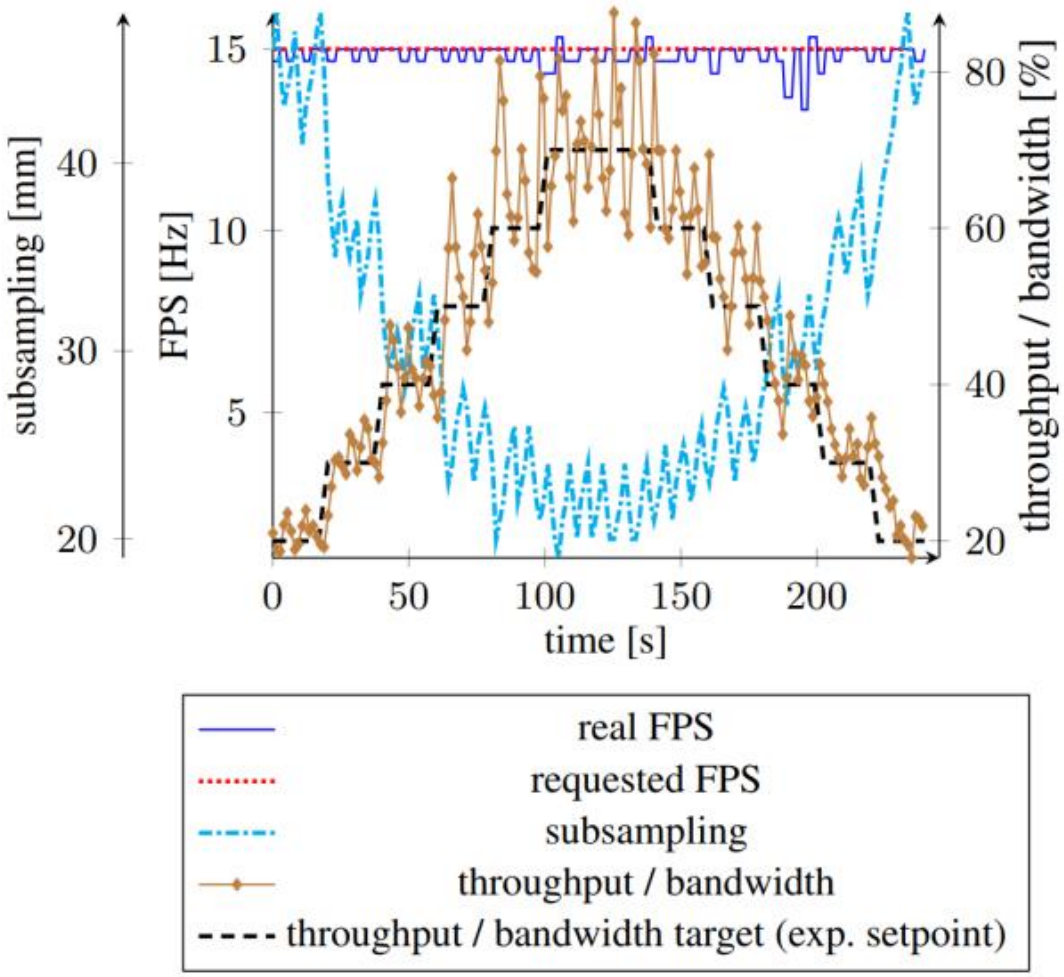
Subsampling Unit Size

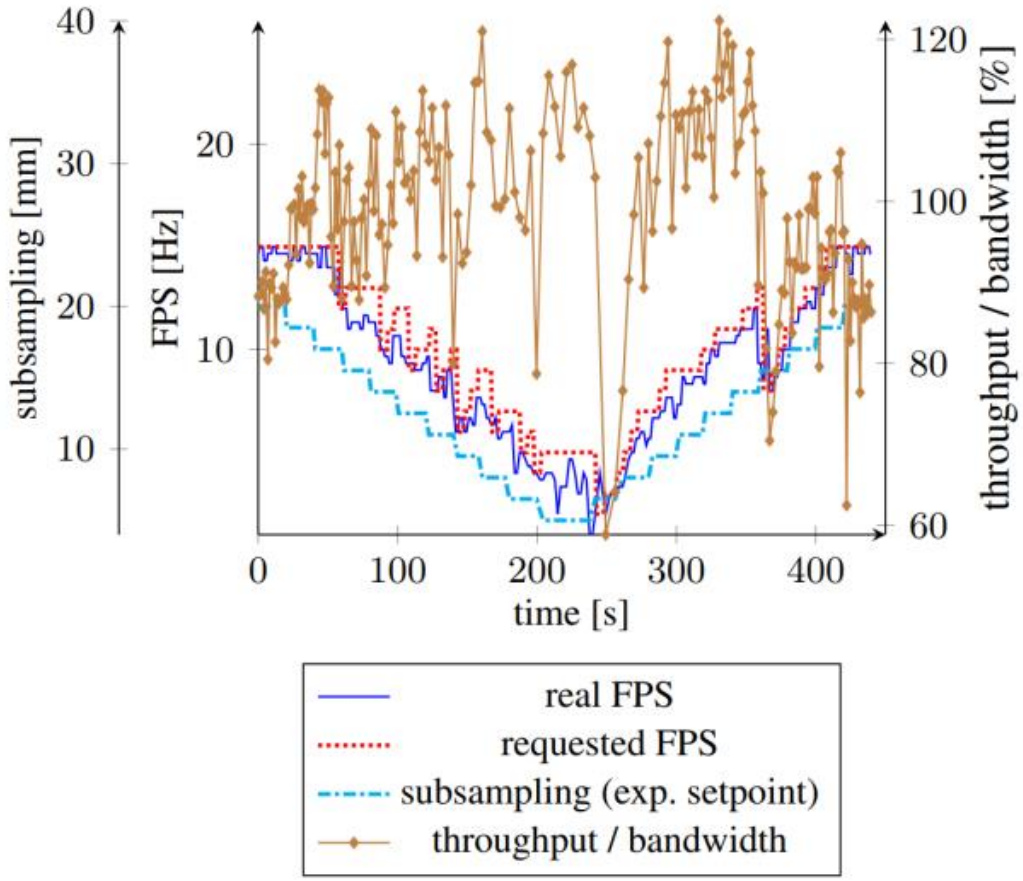
Automatic settings of point cloud and video acquisition: manual control



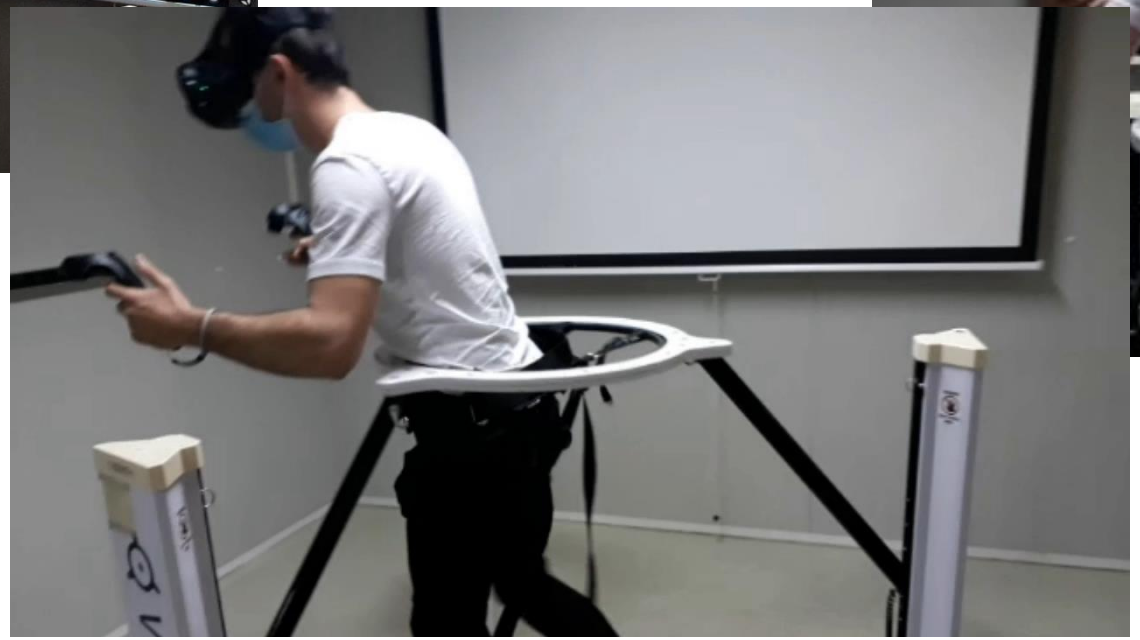


Automatic settings of point cloud and video acquisition: automatic control





VR robot control

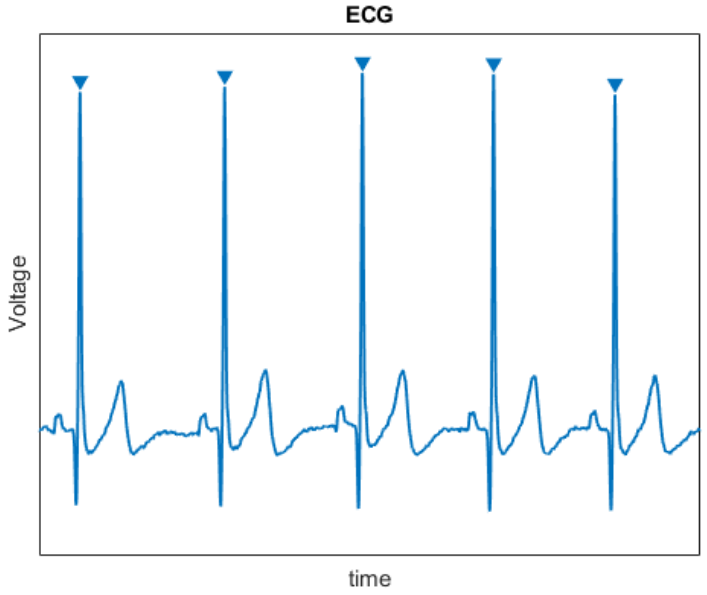


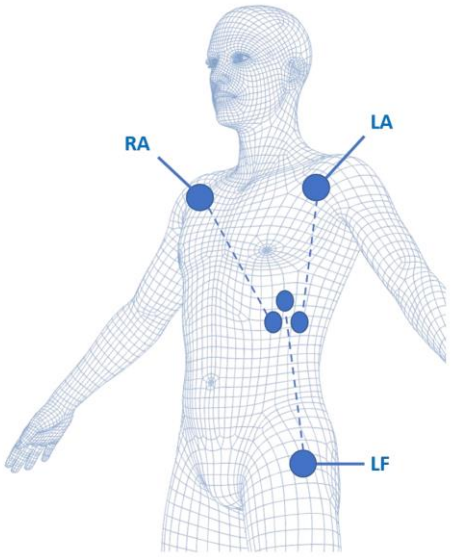
VR robot control

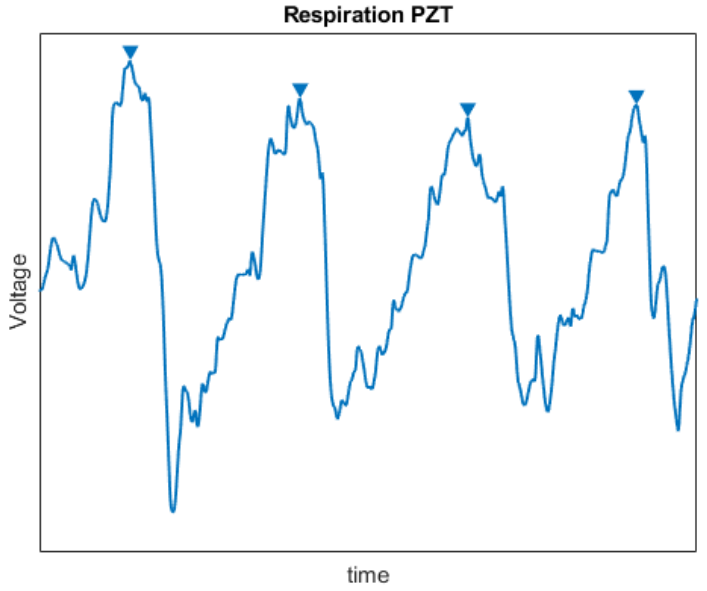
Augmented Reality

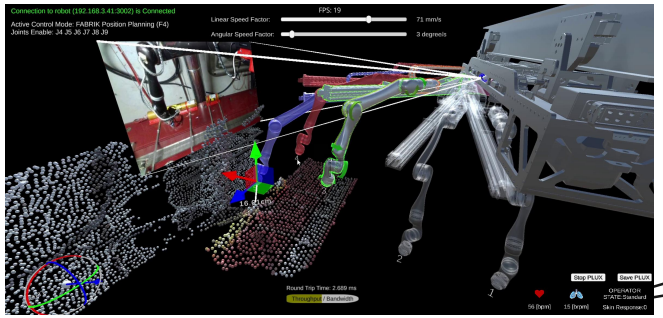
Teleoperator vital parameters monitoring

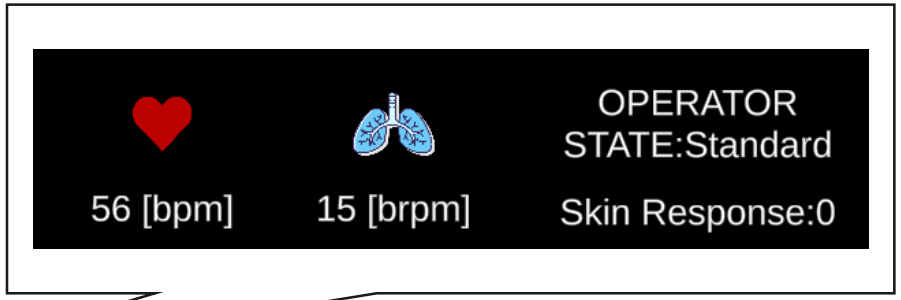
Operator vital parameters monitoring



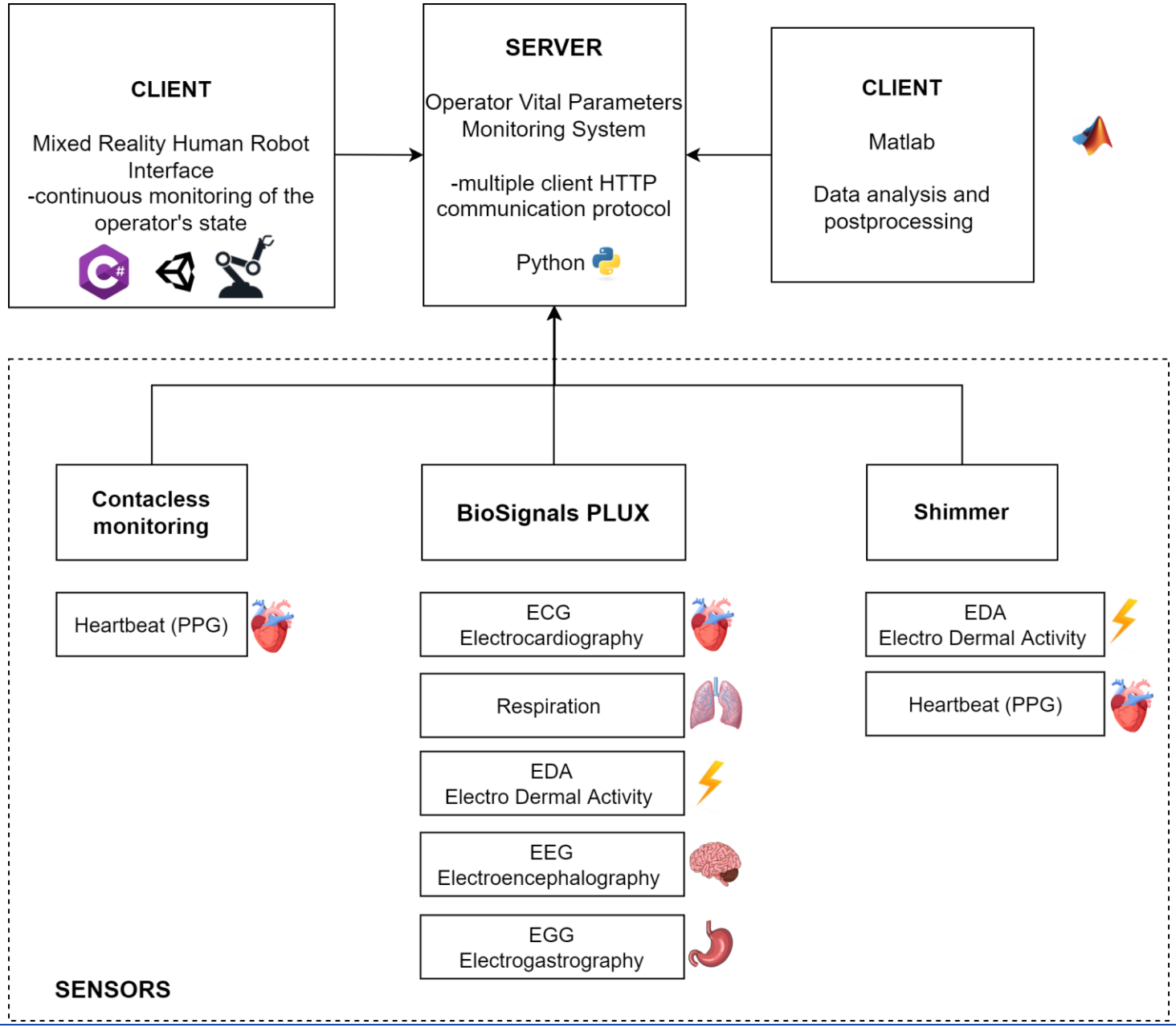




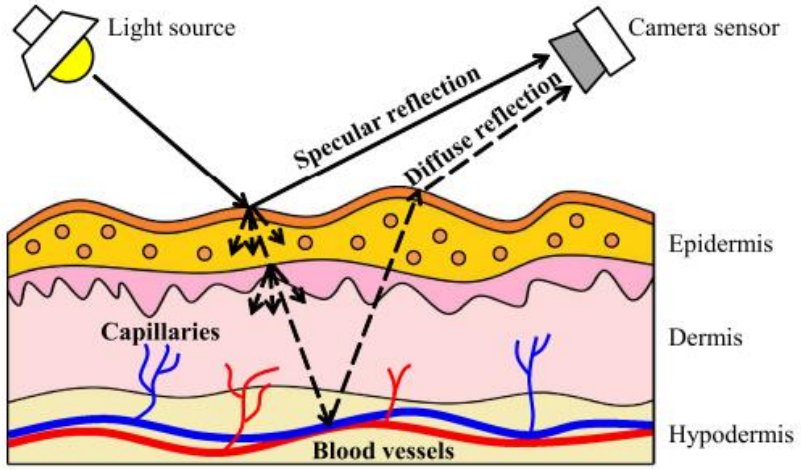


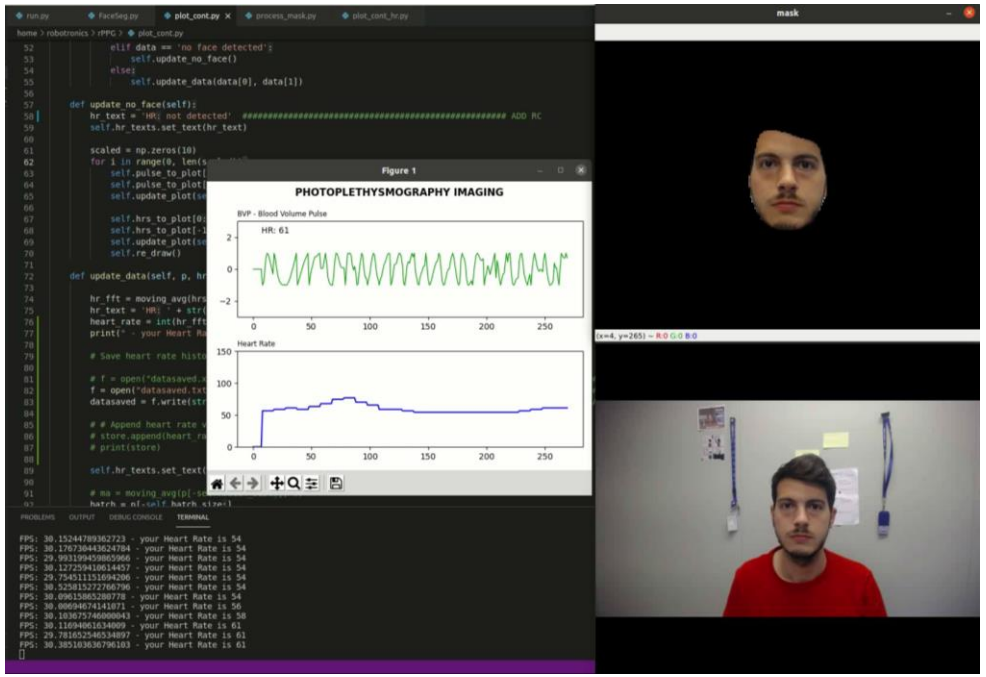


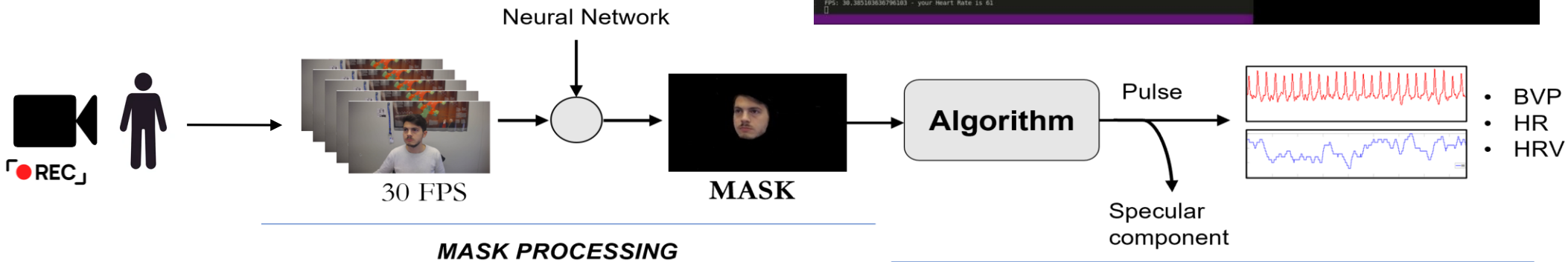
Operator vital parameters monitoring system



Contactless operator vital parameters monitoring





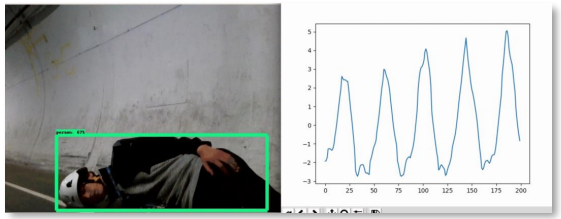


Artificial and virtual environment intelligence, and machine learning in CERN robotics: other examples

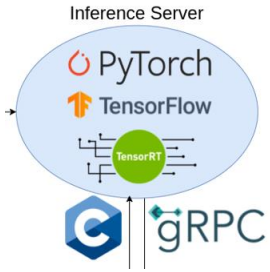
- **Online Tunnel Structure Monitoring, cracks detection**

- **SPS autonomous gate passage**

- **People Recognition and Vital Life Signals Monitoring**



- **Framework for Remote Deep Learning Inference**



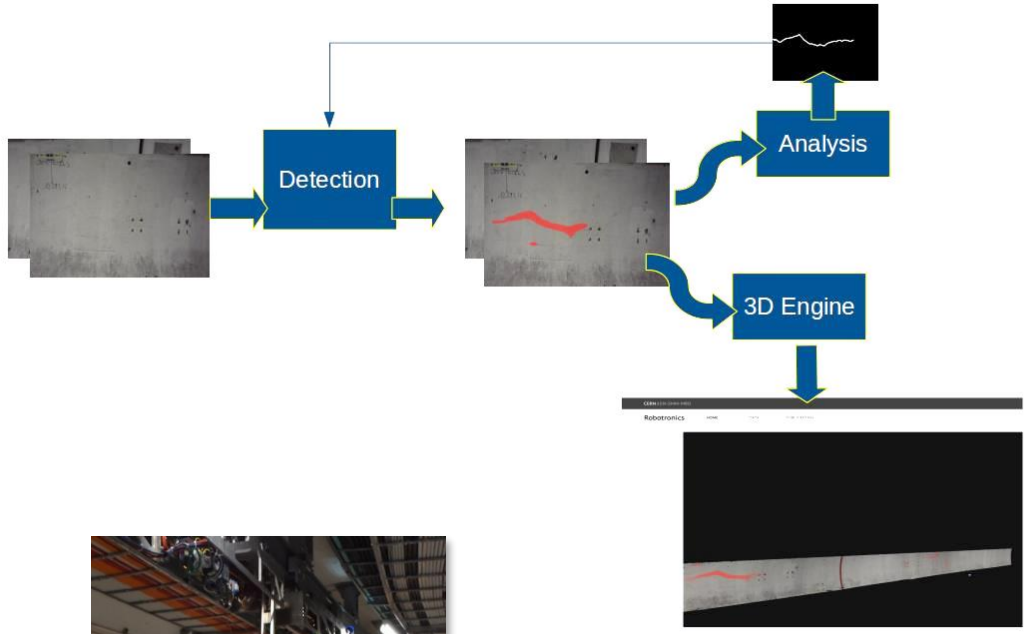
- **BLM 3D recognition**

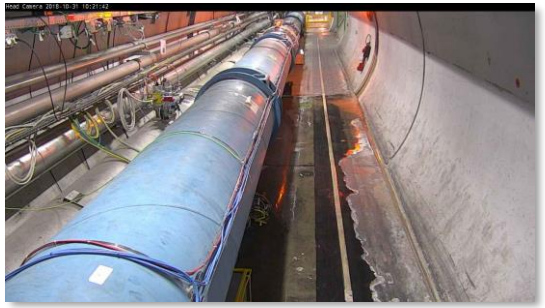
- **Virtual Environment for intelligent Robotic Operations**

- **Vision Based Object Tracking System + Depth Estimation**

Online Tunnel Structure Monitoring, cracks detection

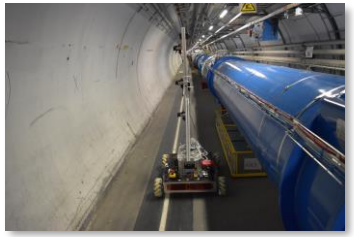
- Detects defects (cracks, water leaks, changes) using a Mask-RCNN network.
- High-definition picture collection using TIM and CERNBot.
- 3D reconstruction of wall using structure from motion techniques to compare time evolution of defects (available on web browser or virtual reality headset).
- **HL-LHC condition survey of existing infrastructure carried out with TIM to monitor impact of new civil works.**



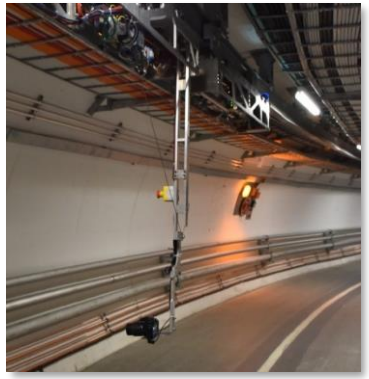


Example of water leak found by TIM2 during TS3 2018

HD camera system for tunnel dome view



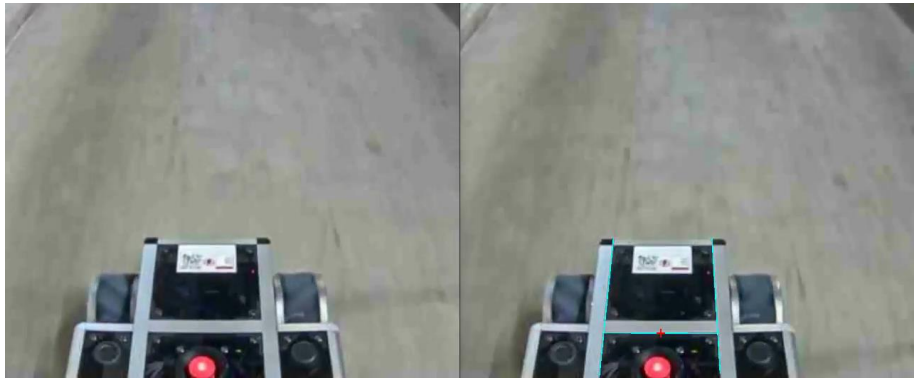
System integrated also on other robots



HD cameras mounted on TIM

Attard, L., Debono, C. J., Valentino, G., di Castro, M., Masi, A., & Scibile, L. (2019). Automatic Crack Detection using Mask R-CNN. *2019 11th International Symposium on Image and Signal Processing and Analysis (ISPA)*, 152–157. https://doi.org/10.1109/ISPA.2019.8868619

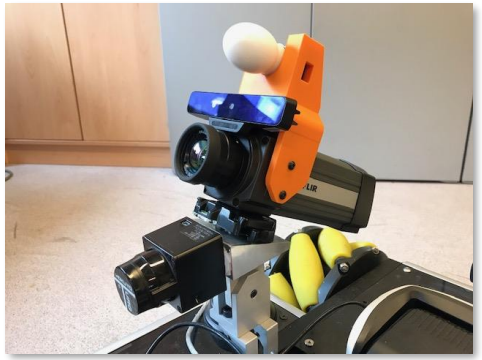
SPS Autonomous navigation and gate passage



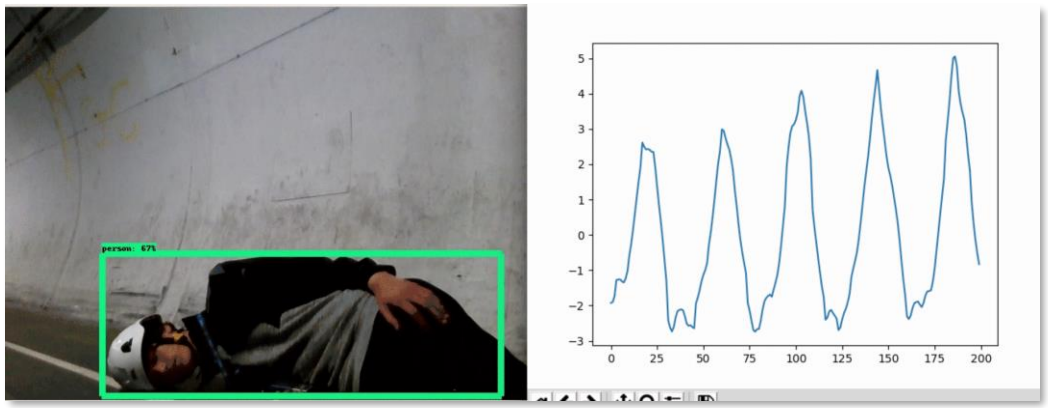
- Autonomous sector door detection, recognition and passage – heavily relies on vision
- Research into optical flow and deep learning to detect and perform pose estimation of the door – CNN-based dense pixel correspondence estimation
- Target Image + Source Image -> Aligned source image

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.



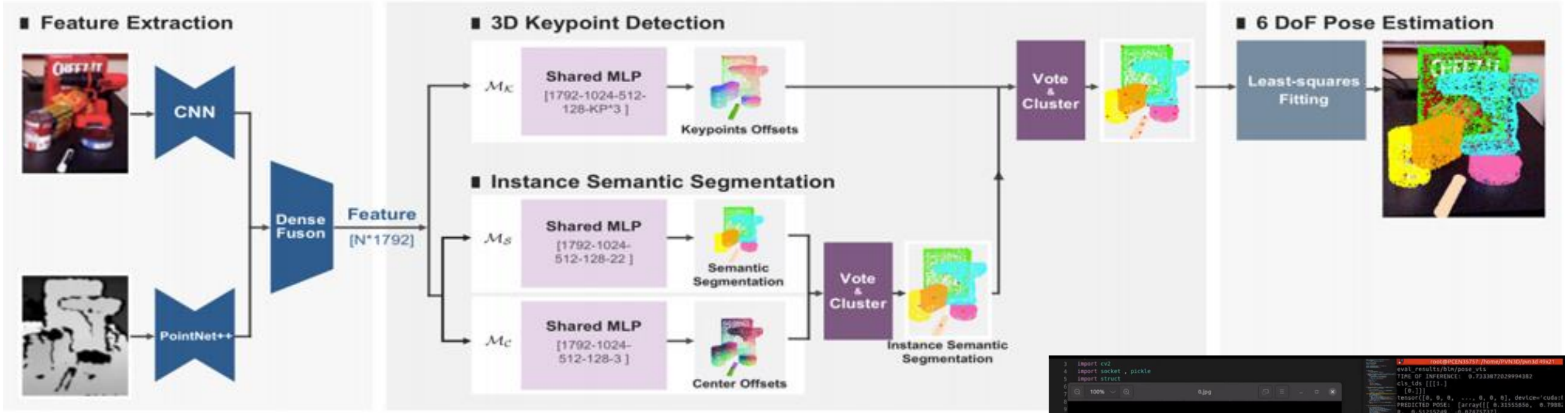
Vision system (2D Laser, radar, thermal and 2D-3D camera)

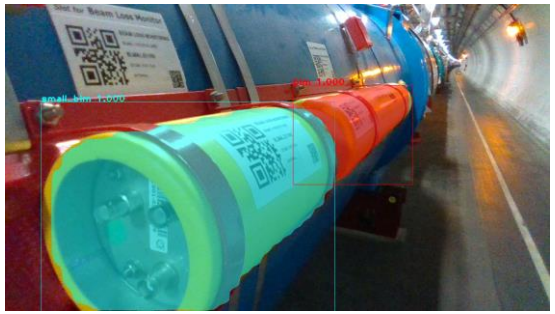


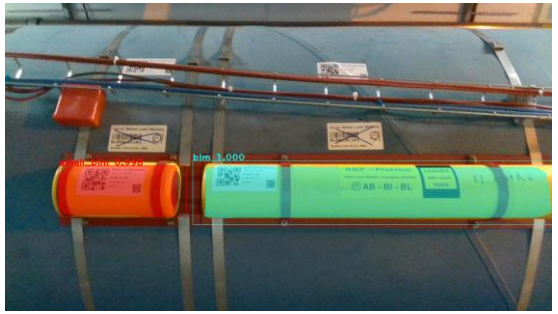
Online respiration monitoring

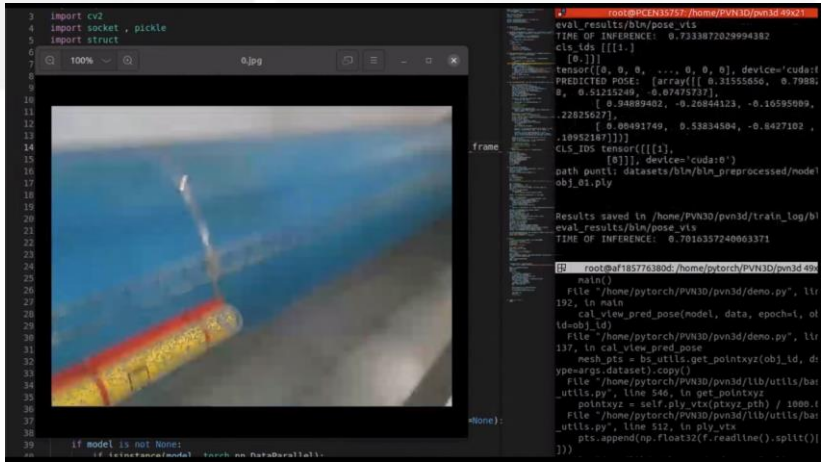
Online people recognition and tracking

BLMs detection and 6 DoF pose estimation using ML

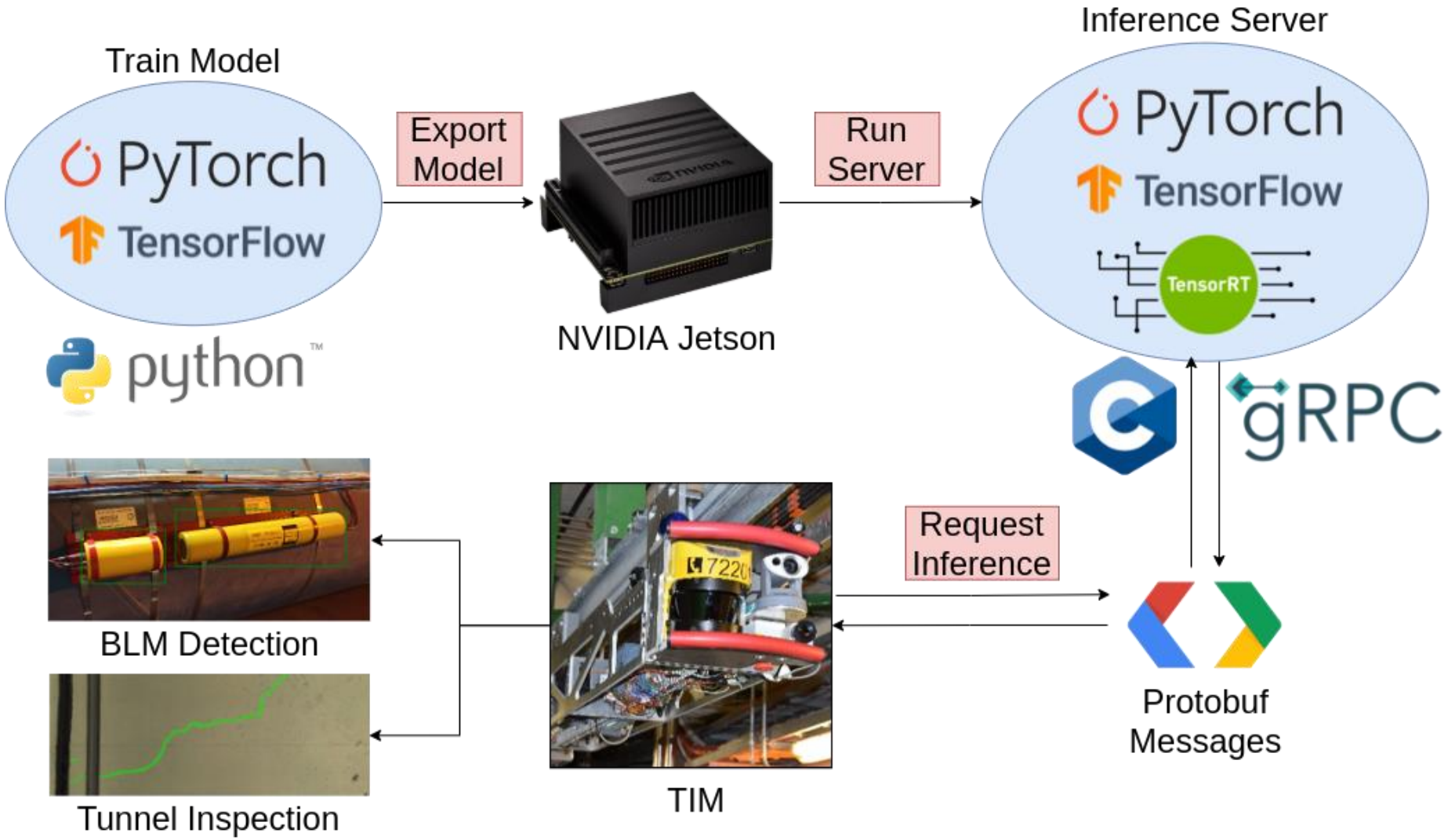






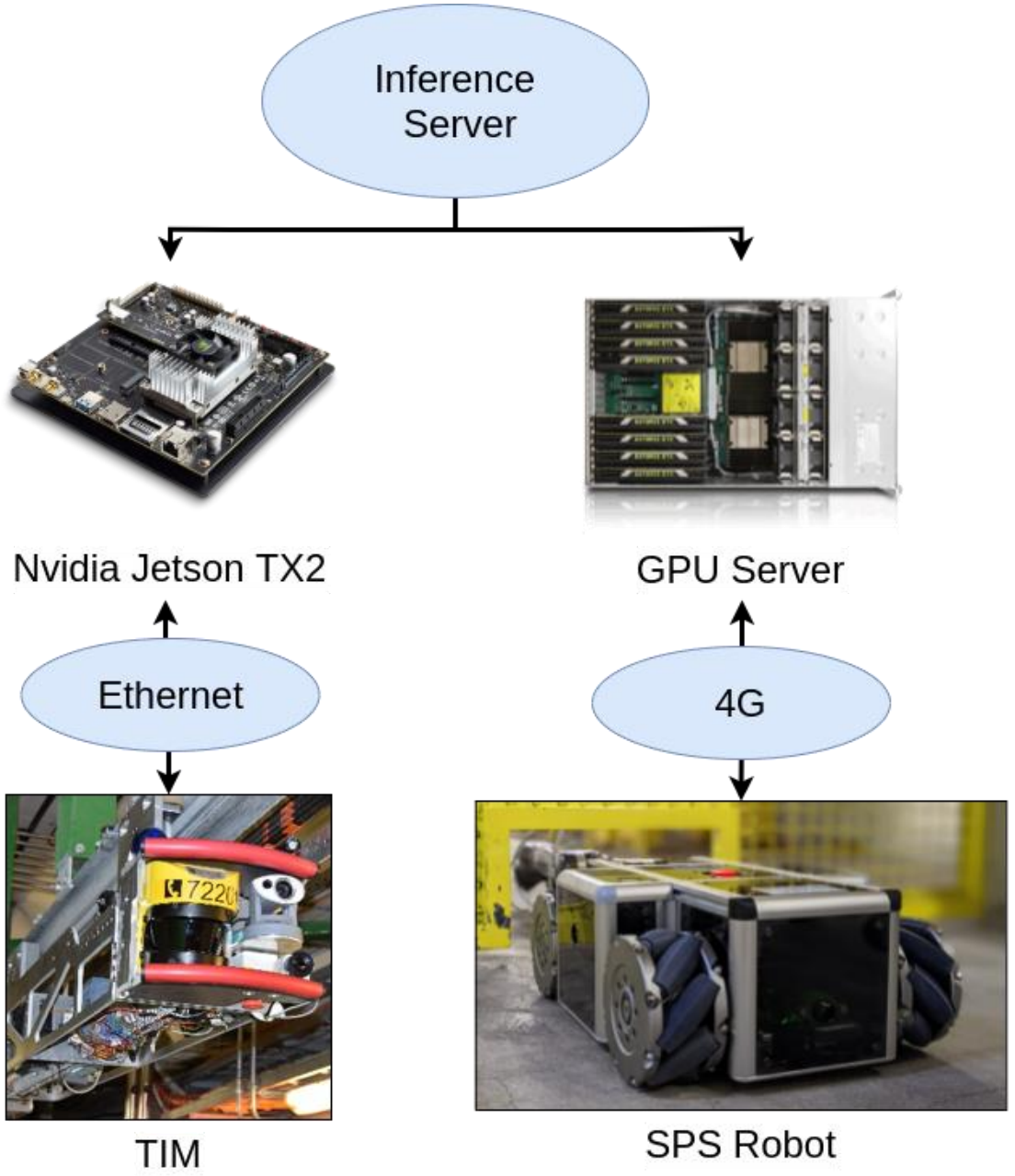


Framework for Remote Deep Learning Inference



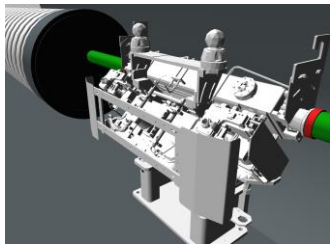
Framework for Remote Deep Learning Inference

Use example



Virtual Environment for intelligent Robotic Operations

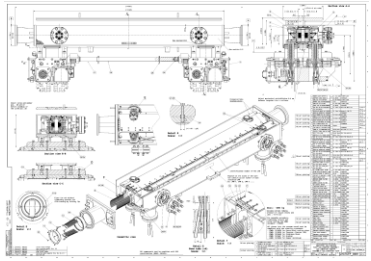
Sketches



CAD models (stp, VOLT or SMARTEAM)

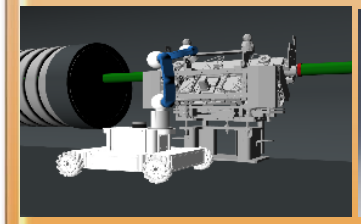
photogrammetry

Laser scanning

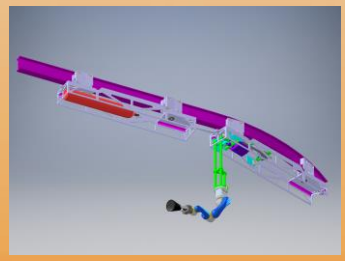


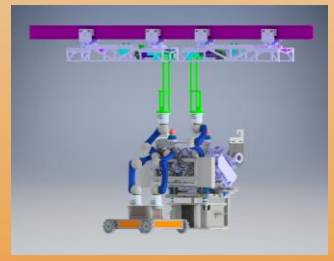
2D plans

INPUT DATA

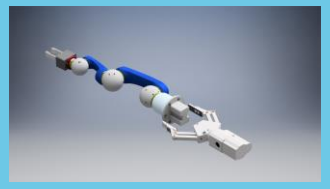


Virtual Reality mockup



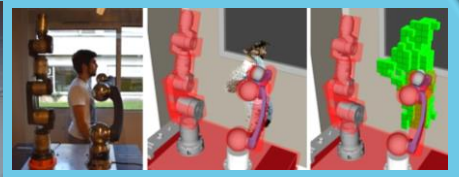


Studies



New equipment design

Whole scenario simulation



Anti-collision and Virtual fixtures

Implementation

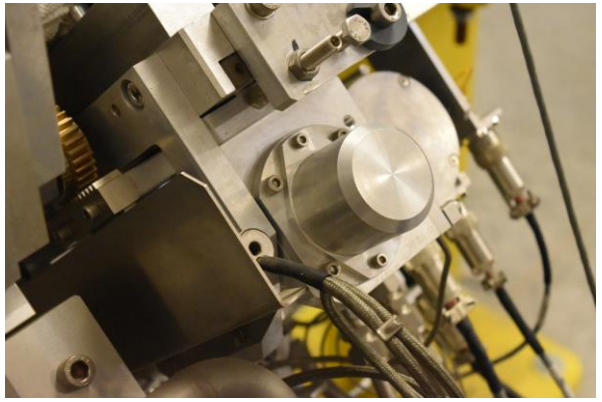
Operator training in VR.
Force feedbacks

Assistance for real operations

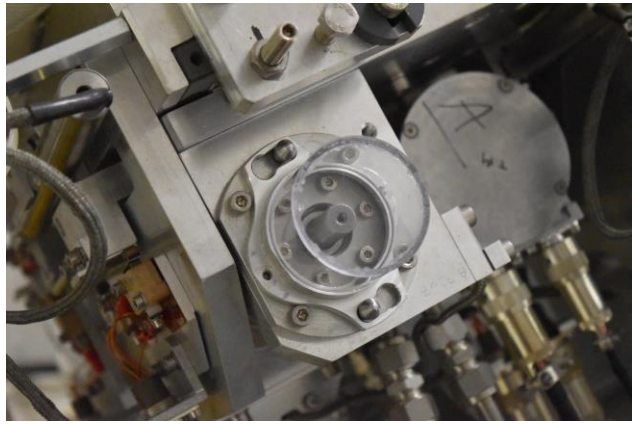
Steering New Machines Design

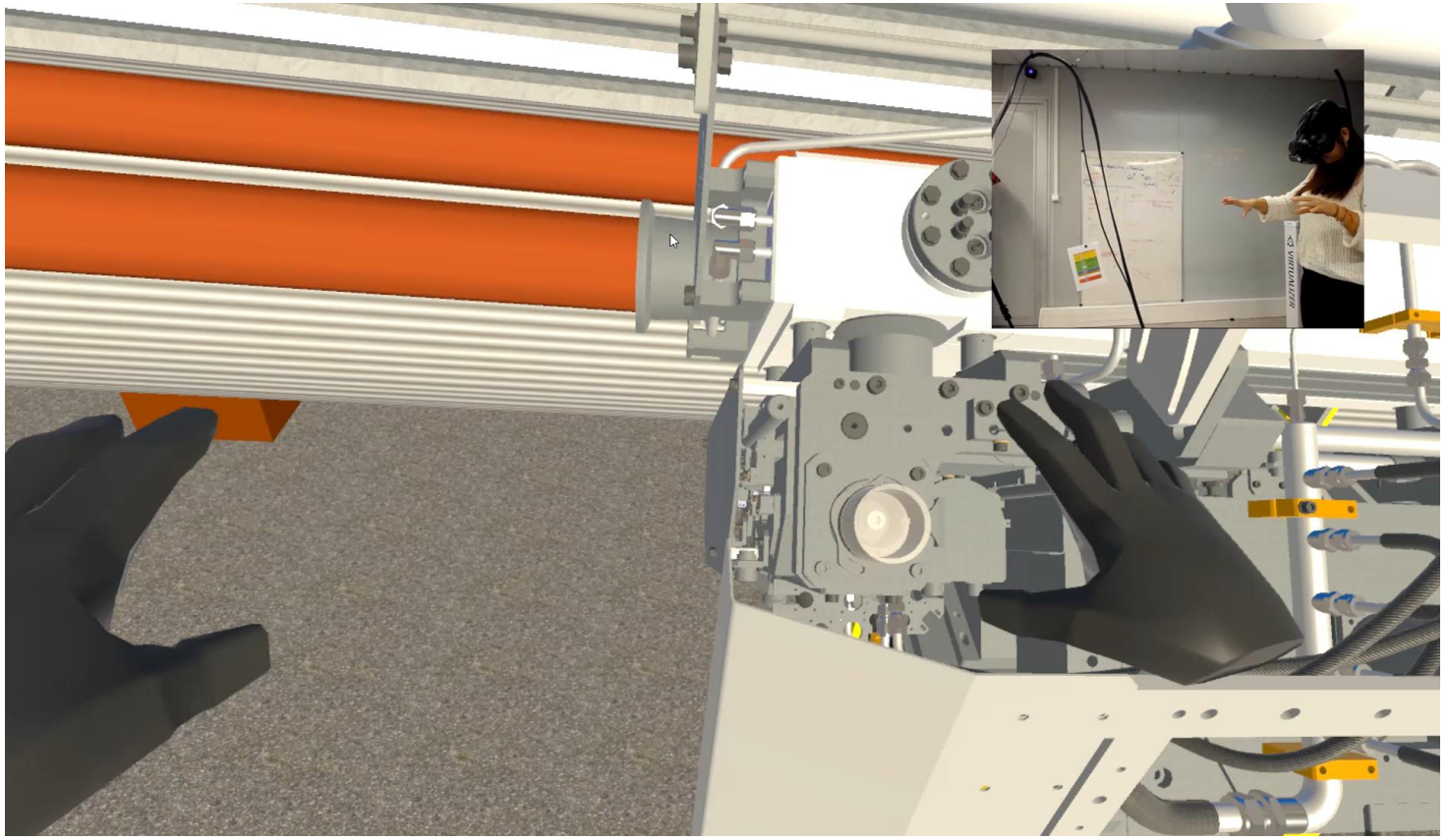
- For example, design of the new LHC Collimators motor screw cap
  - ✓ Simulation in VR to check hands on handling and “robot friendliness”

Current solution

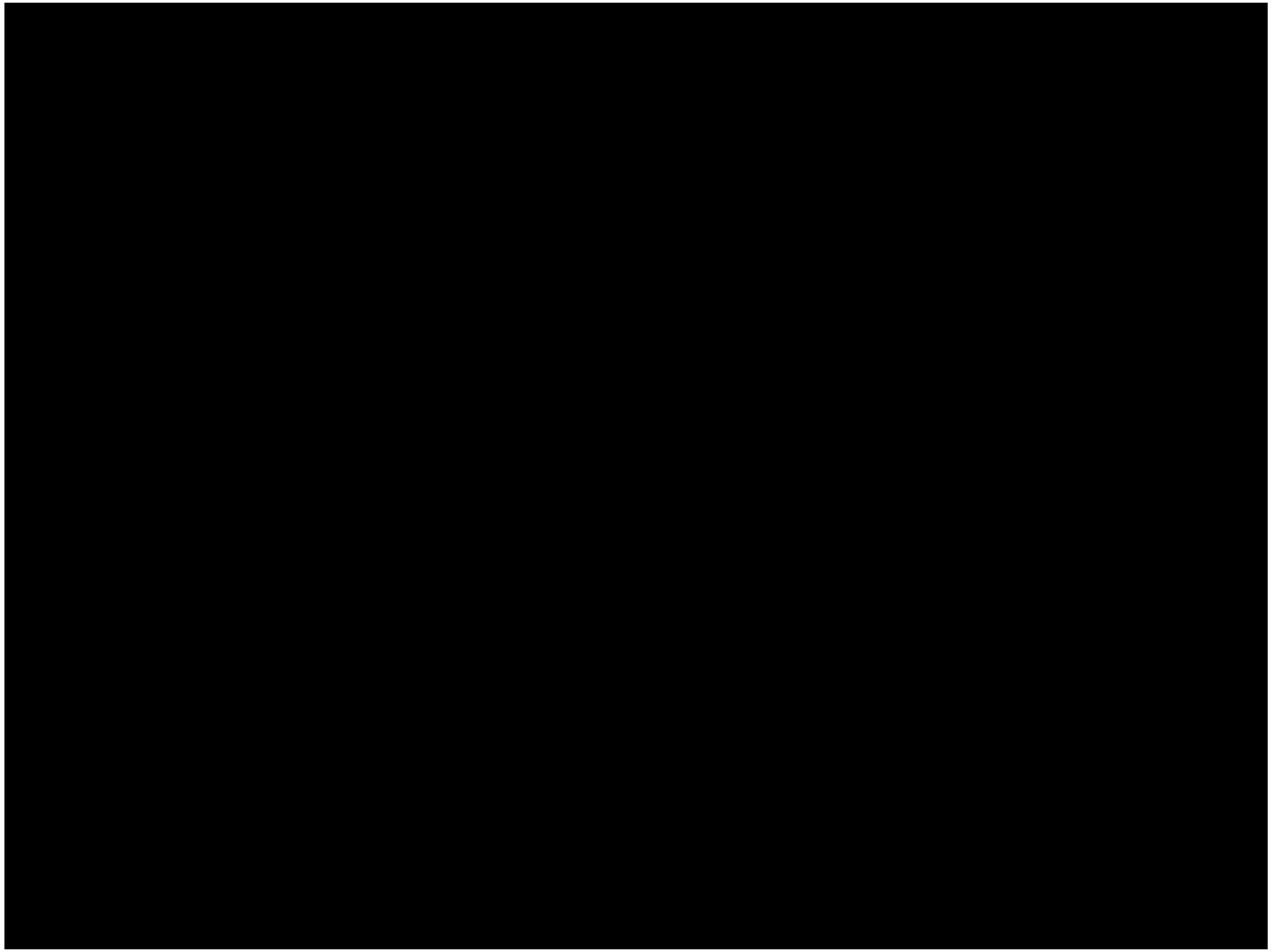


New solution





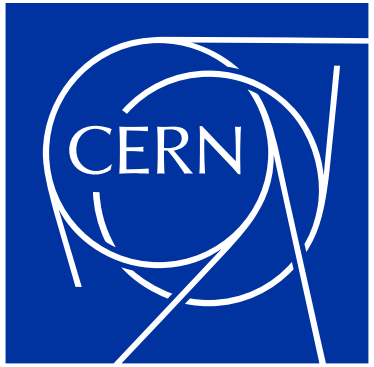
Vision Based Object Tracking System + Depth Estimation



Conclusions

- **The Human-Robot Interface is an important part of telerobotic system that play a big role in the success of an intervention.**
- **By using advanced technologies such as the immersive control in Mixed Reality, the safety and efficiency of the operation can be improved.**
- **The artificial intelligence, machine learning, autonomous behaviors become indispensable in complex and challenging projects where robots and their reliability, flexibility and adaptability are key factors.**

Thanks!



beams.cern