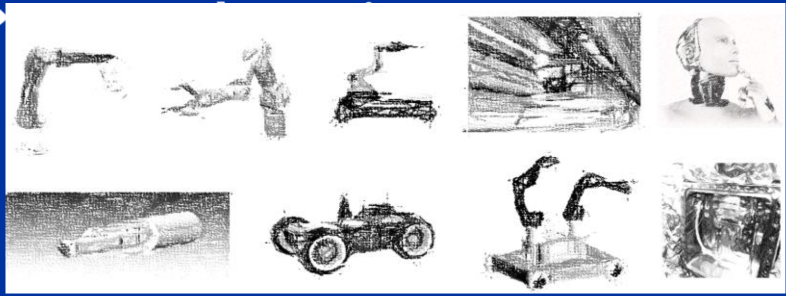
Controls
Electronics &



# Digital Twins for Mechatronics and Robotics in BE-CEM and some other examples at CERN


Mario DI CASTRO

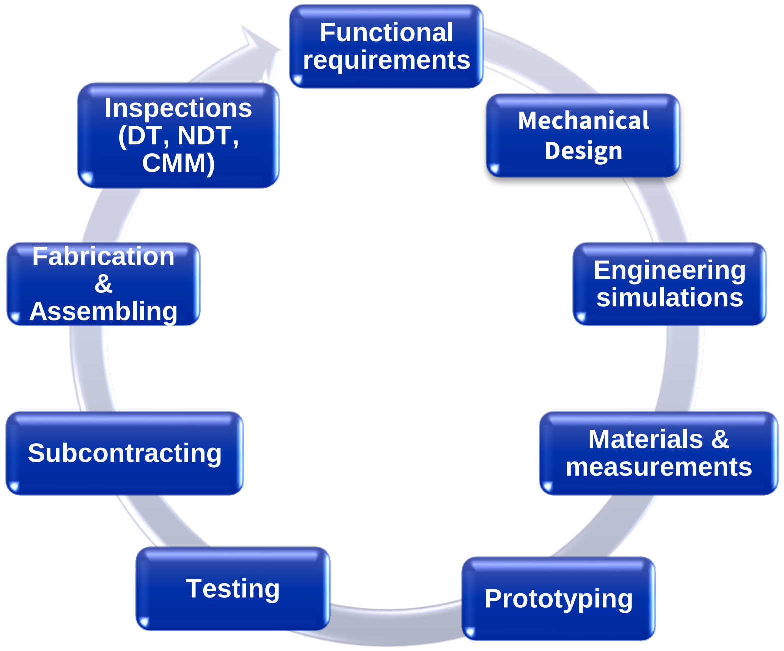
CERN, BE-CEM group

*MOCRAF WORKSHOP, ICALEPCS23, 8th of October 2023, Cape Town*

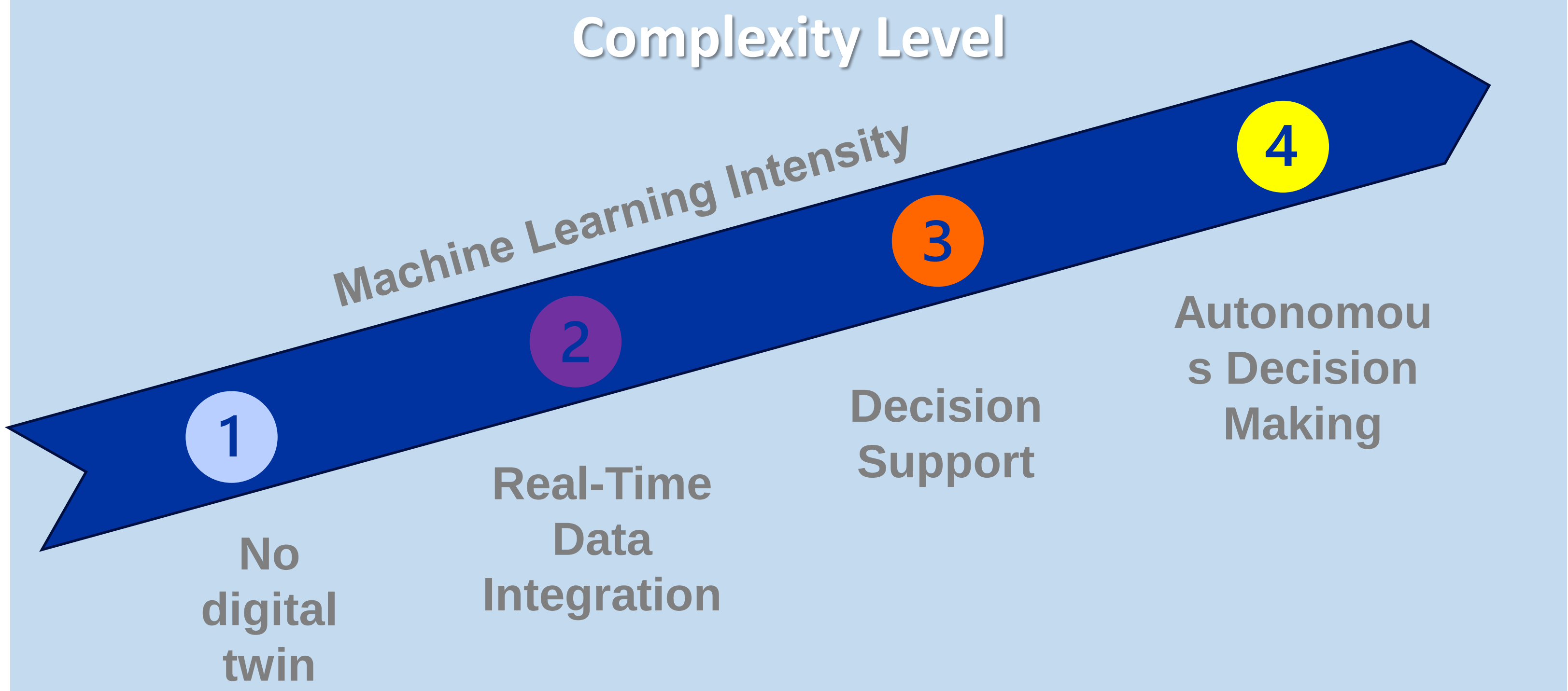
# What is a digital twin?

# What is a digital twin?

"A virtual representation of a physical asset that uses real-time and/or historical data to simulate and describe the behaviour, characteristics, and performance of its physical counterpart."

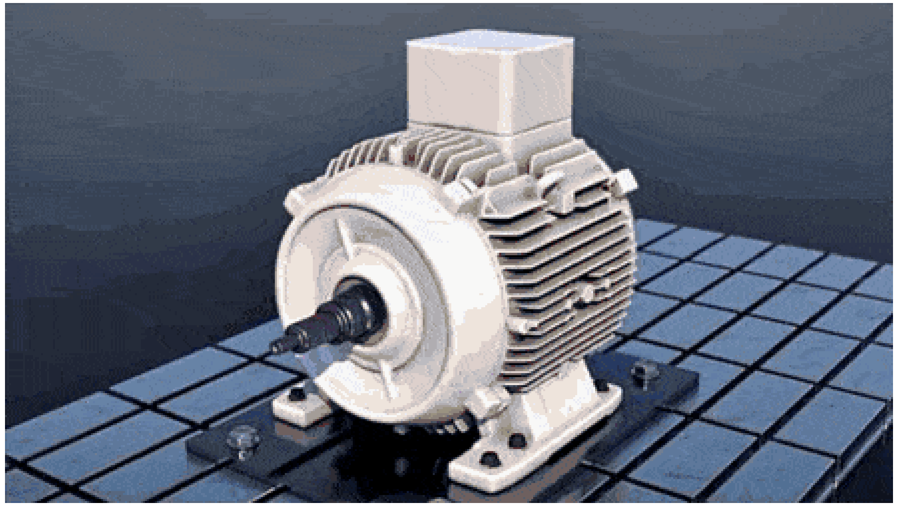


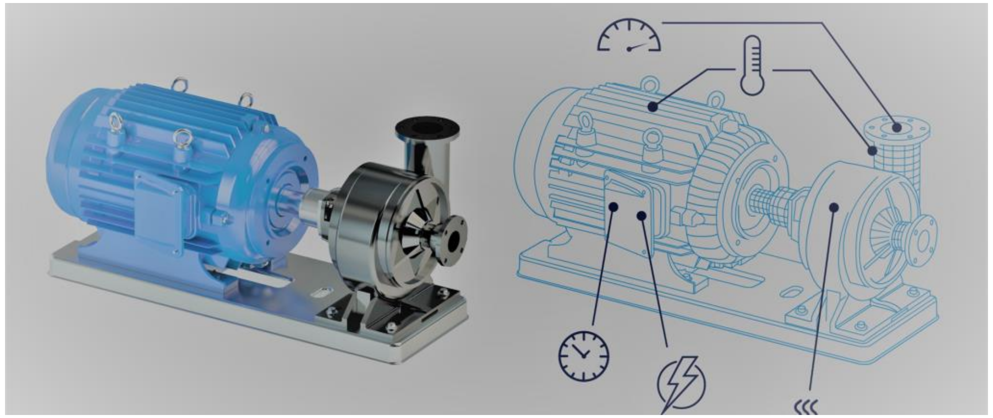

**Pool the existing capabilities of the group to develop a concept of Mechanical Digital Twin**




**Complexity levels represent a progression of capabilities, and not all digital twins need to reach the highest levels of maturity**

# Digital Twin





"A digital twin is a digital clone/replica of a living or non-living physical entity in the virtual world."

It can be a virtual model of an asset, process, product, system or system of systems.

A digital twin can exist simultaneously with its twin in the "real world".

Benefits of a digital twin:

- Quality control
- Improvement & Optimizations of systems
- System diagnostics
- Monitoring
- Prediction of production outcomes

# Google says more…

IBM
https://www.ibm.com › topics › what-is-a-digital-twin

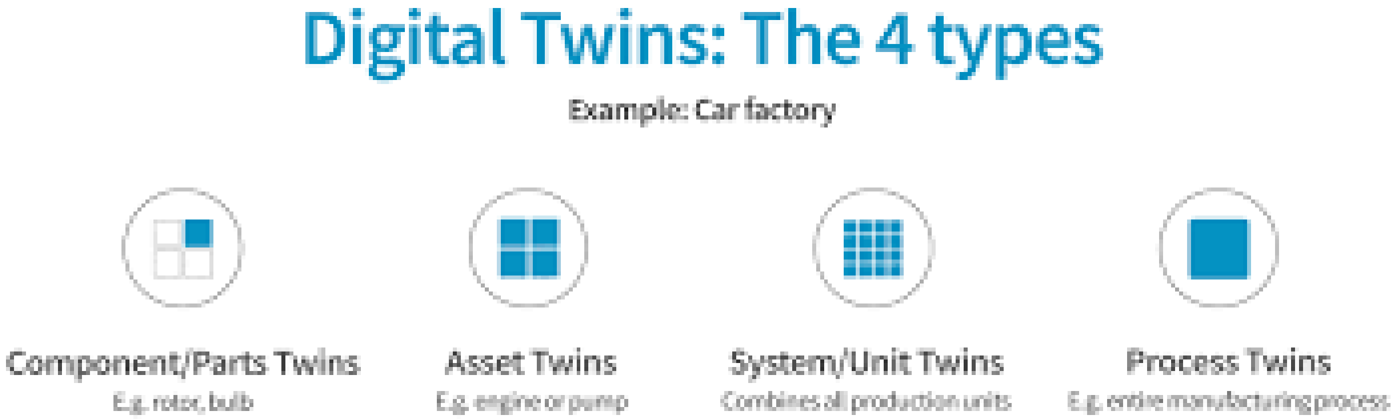
What is a digital twin?

A digital twin is **a virtual model designed to accurately reflect a physical object**. The object being studied—for example, a wind turbine—is outfitted with ...

How does a digital twin work? · Types of digital twins


## Digital twin

A digital twin is a digital model of an intended or actual real-world physical product, system, or process that serves as the effectively indistinguishable digital counterpart of it for practical purposes, such as simulation, integration, testing, monitoring, and maintenance. Wikipedia



# Digital Twins in Robotics - Motivation

**Sim-to-real gap**
Enables development of advanced control strategies by reducing the implementation time

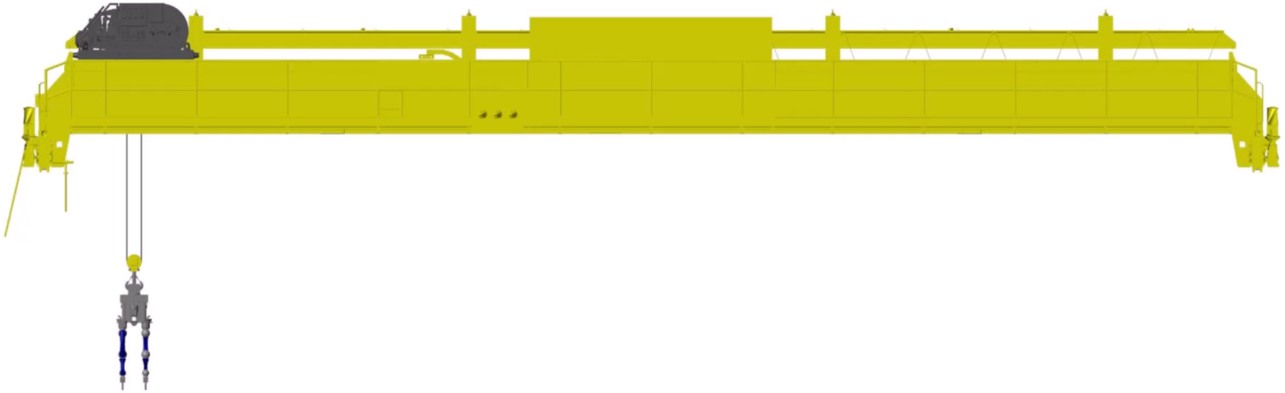
**Teleoperation enhancement**
Augmented reality interaction control

**DIGITAL TWINS**
**in Robotics**

**AI training**
A digital twin allows for the collection of big quantities of data in short time

**Safety**
Produces a safe testing environment for faster control deployment

# CRANEBot

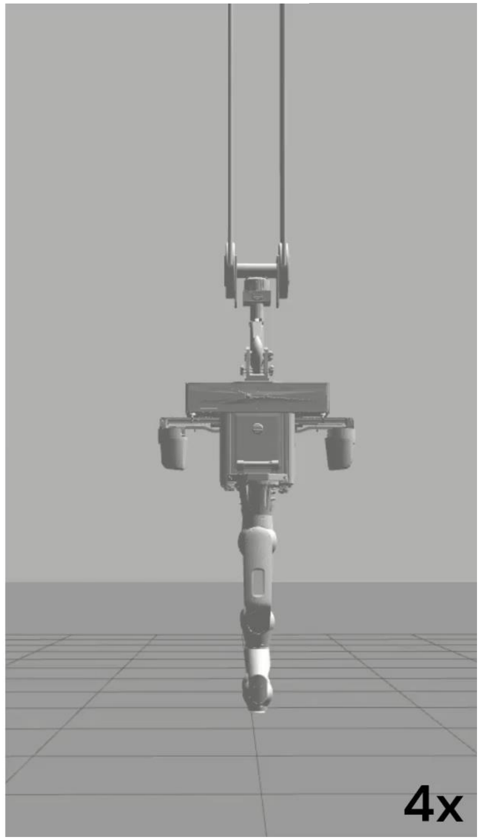


**DIGITAL TWIN**

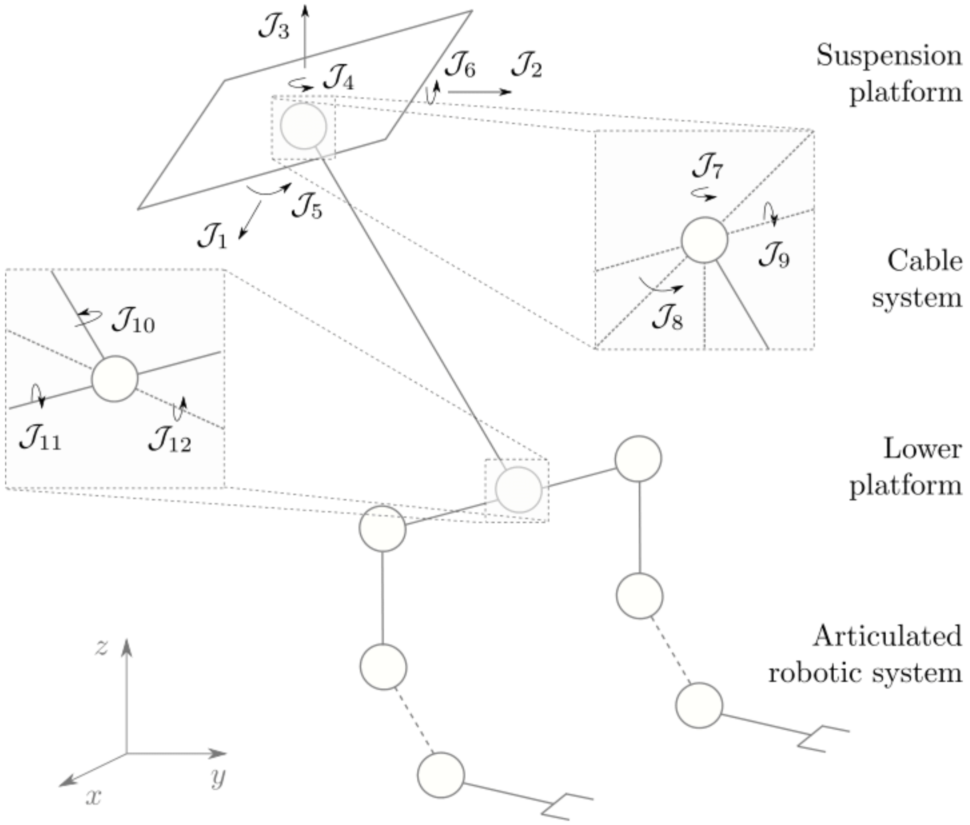
for

**CRANEBot**

**using Gazebo**



# CRANEBot




BRANCHED OPEN-LOOP KINEMATIC CHAIN

**Realistic simulation**

Models are ideal approximations

Dynamic parameters are hard to be found

Identification is essential

**OPTIMIZATION PROBLEM**

Find the **set of parameters** which maximize the **similarity** between measurement and simulation

# SPS Robot: MIRA

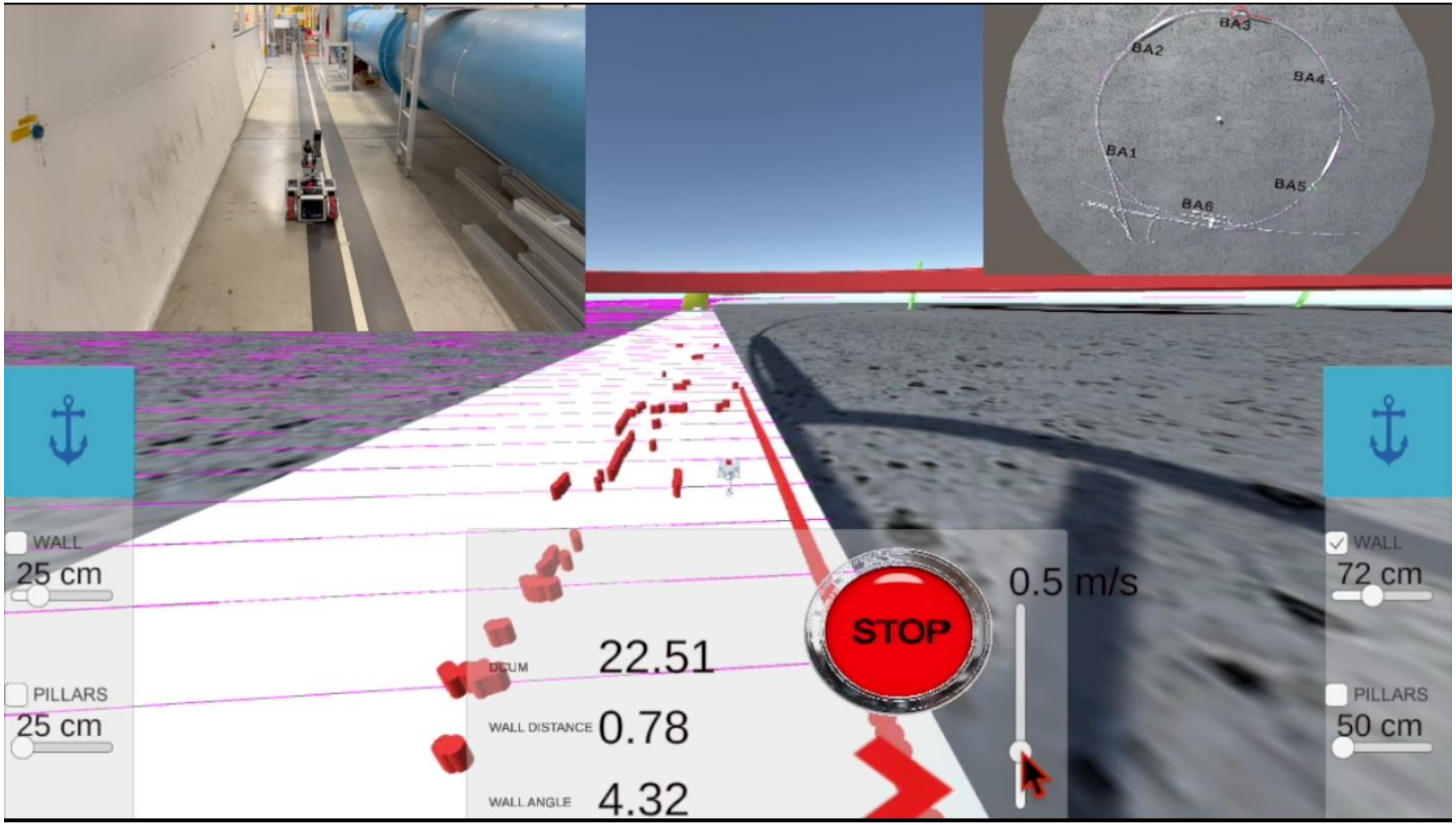
**DIGITAL TWIN**

for

**MIRA using**

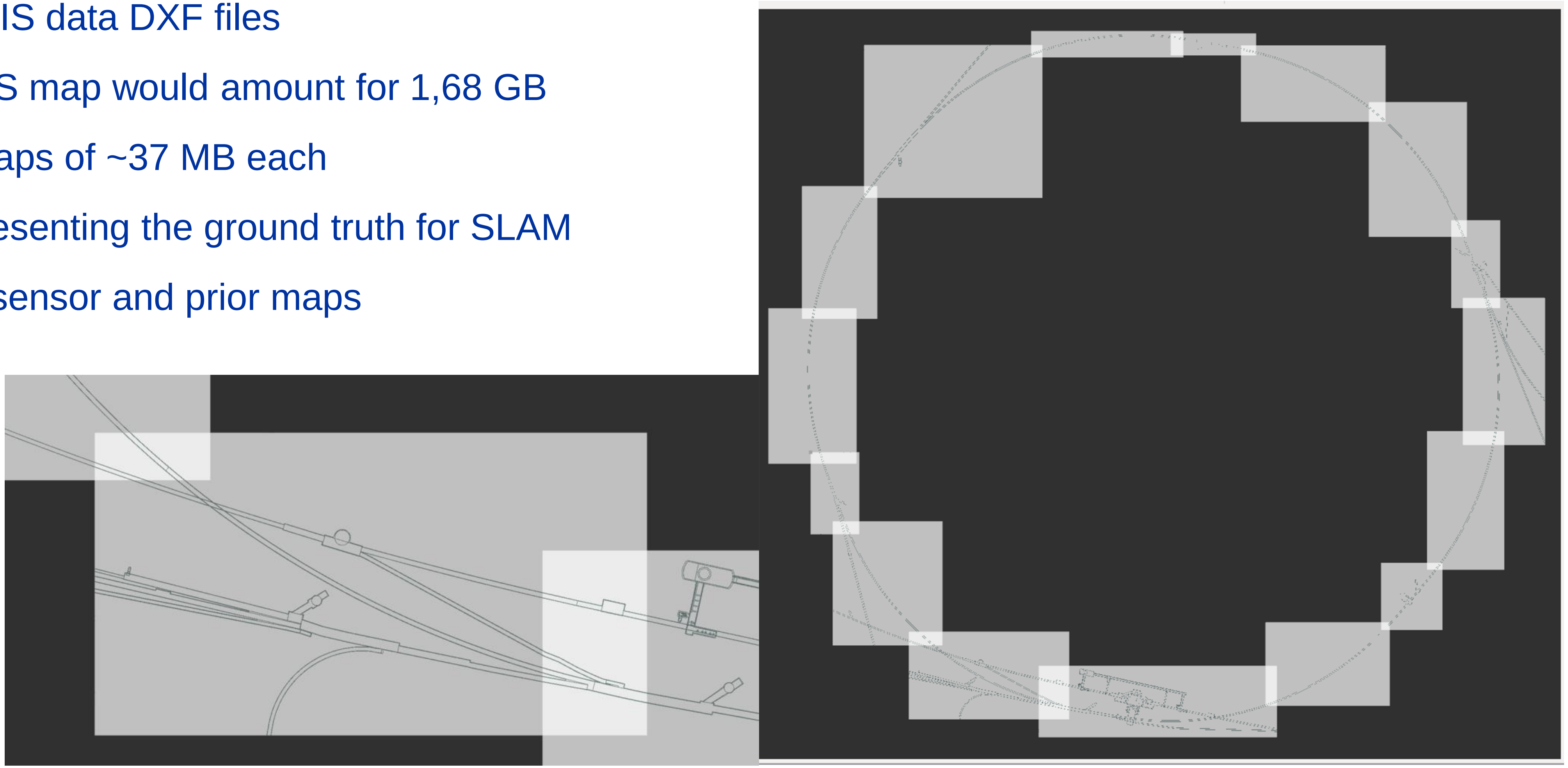
**Gazebo &**

**Unity**

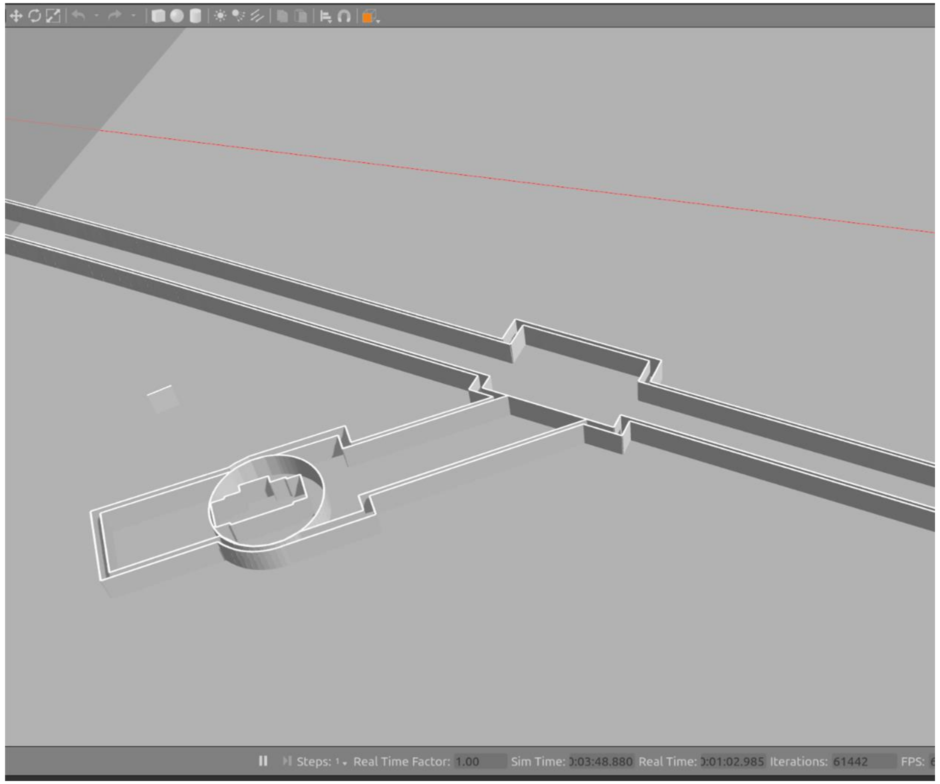


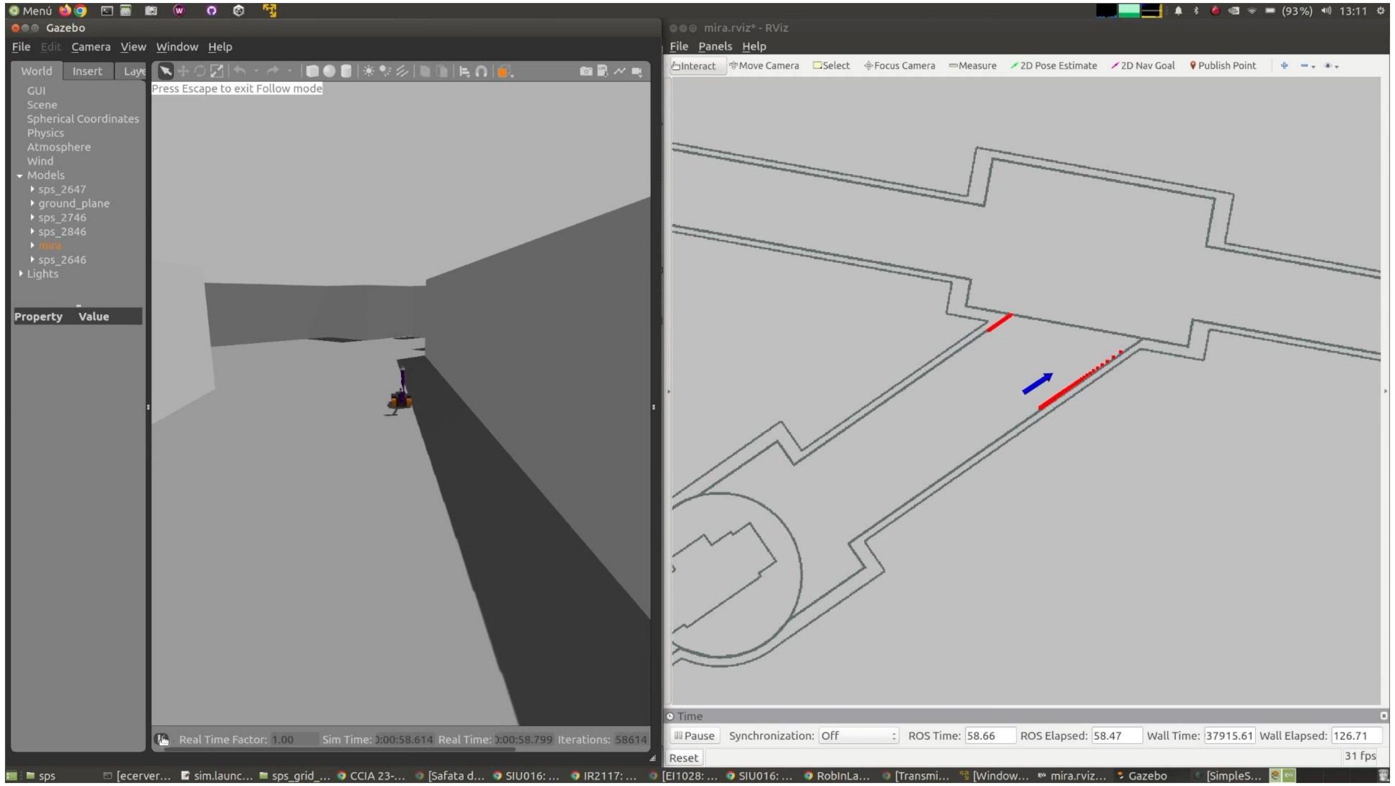
# SPS Robot: MIRA

- Built from GIS data DXF files
- A single SPS map would amount for 1,68 GB
- Set of 16 maps of ~37 MB each
- Map is representing the ground truth for SLAM
- Merging of sensor and prior maps



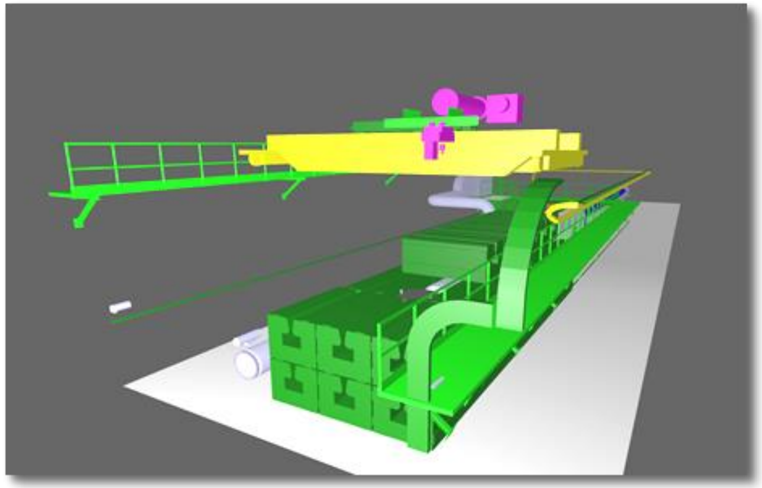
# SPS Robot: MIRA

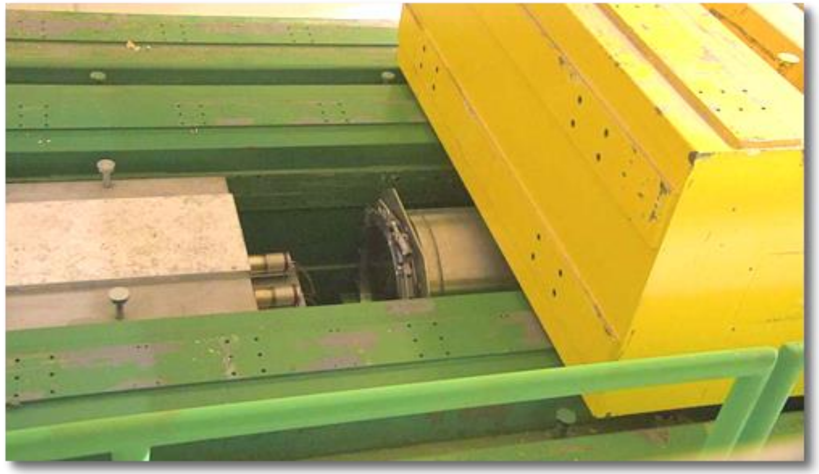


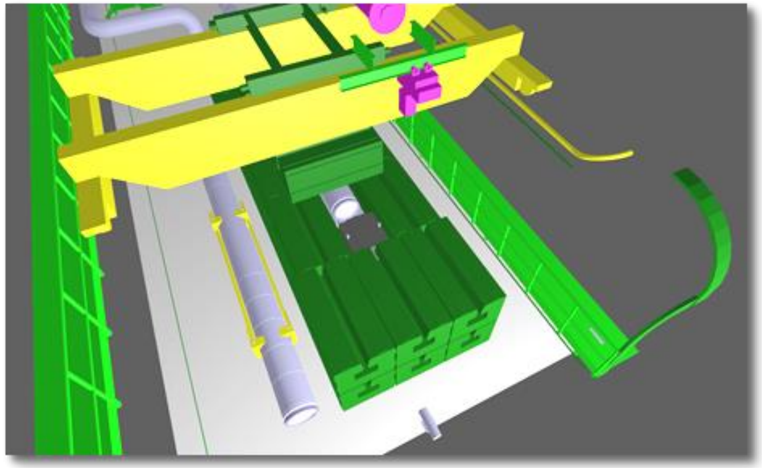


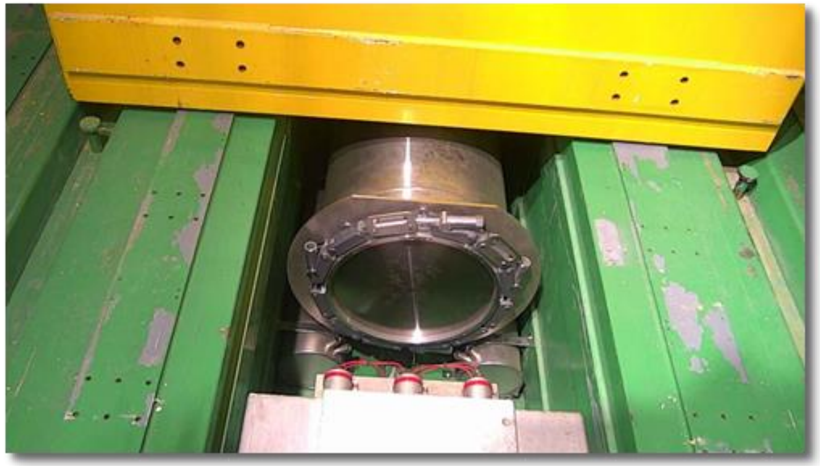
# Challenging Teleoperation

- LHC TDE inspection

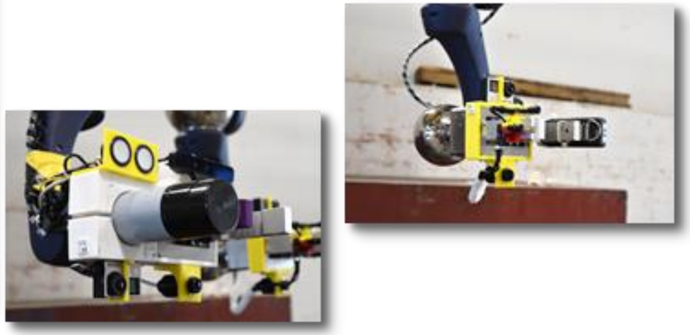






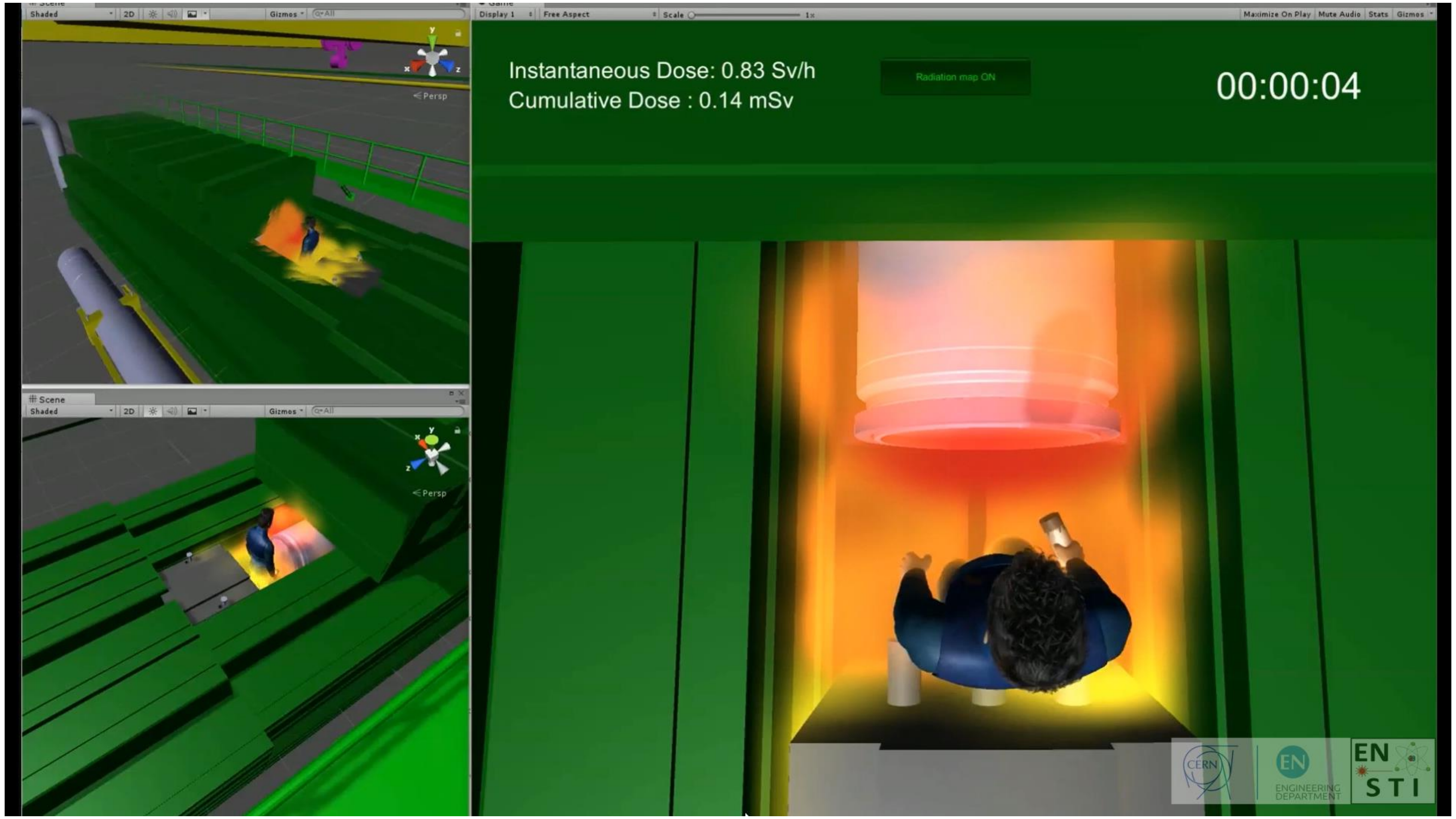


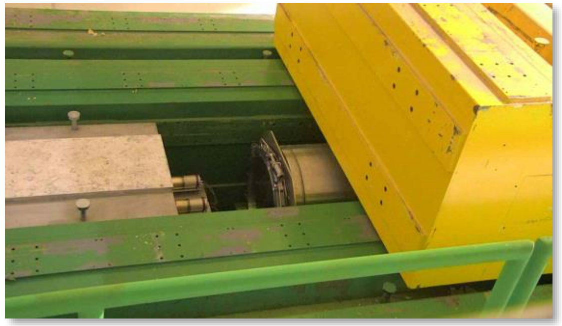
CERNbot v1.0 core

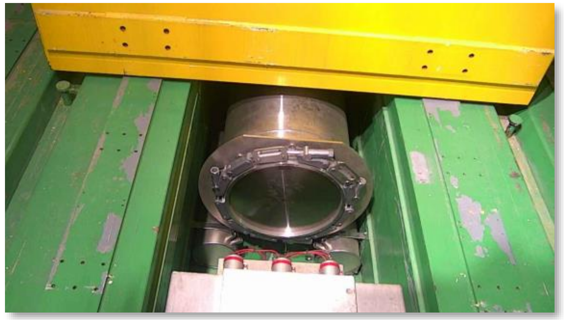


# Challenging Teleoperation

- LHC TDE inspection



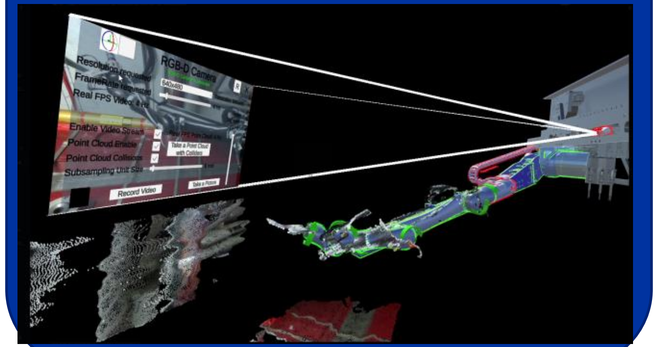


# Current HRI of the Robotic Service

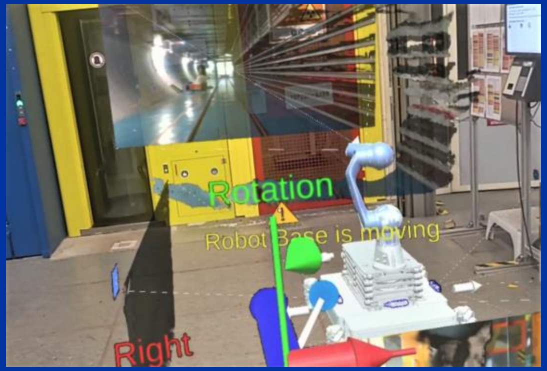
Unity

## 2D HRI


## 3D HRI

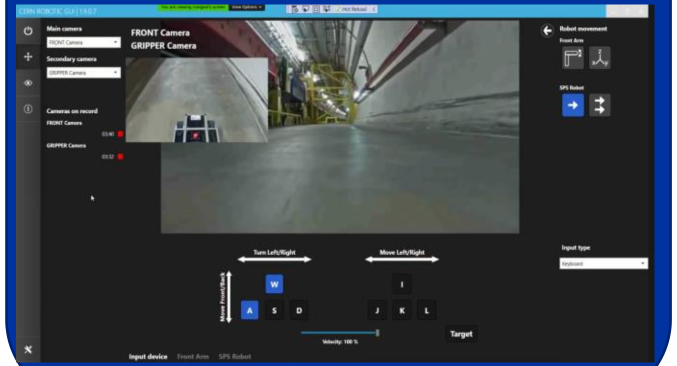



## XR HRI



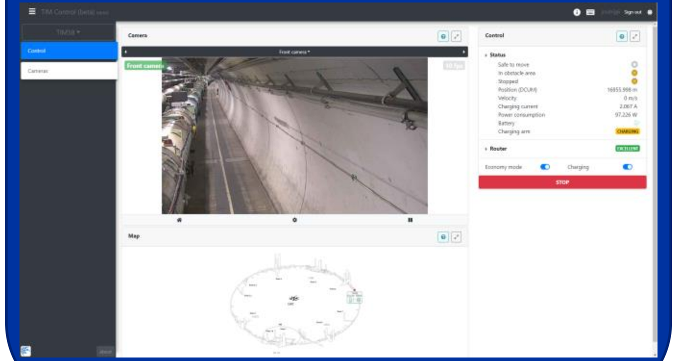

WPF

## 2D HRI

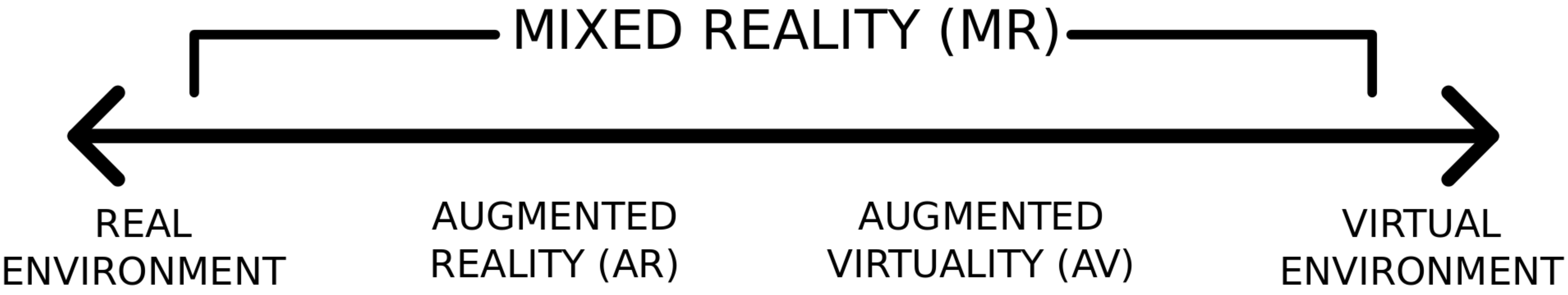



Web Tech

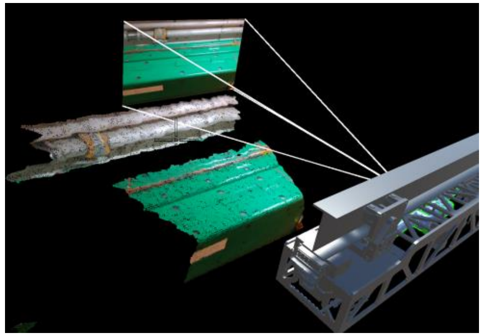
## 2D HRI

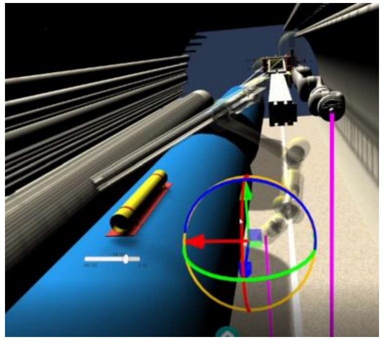


# Next Generation Graphical User Interface

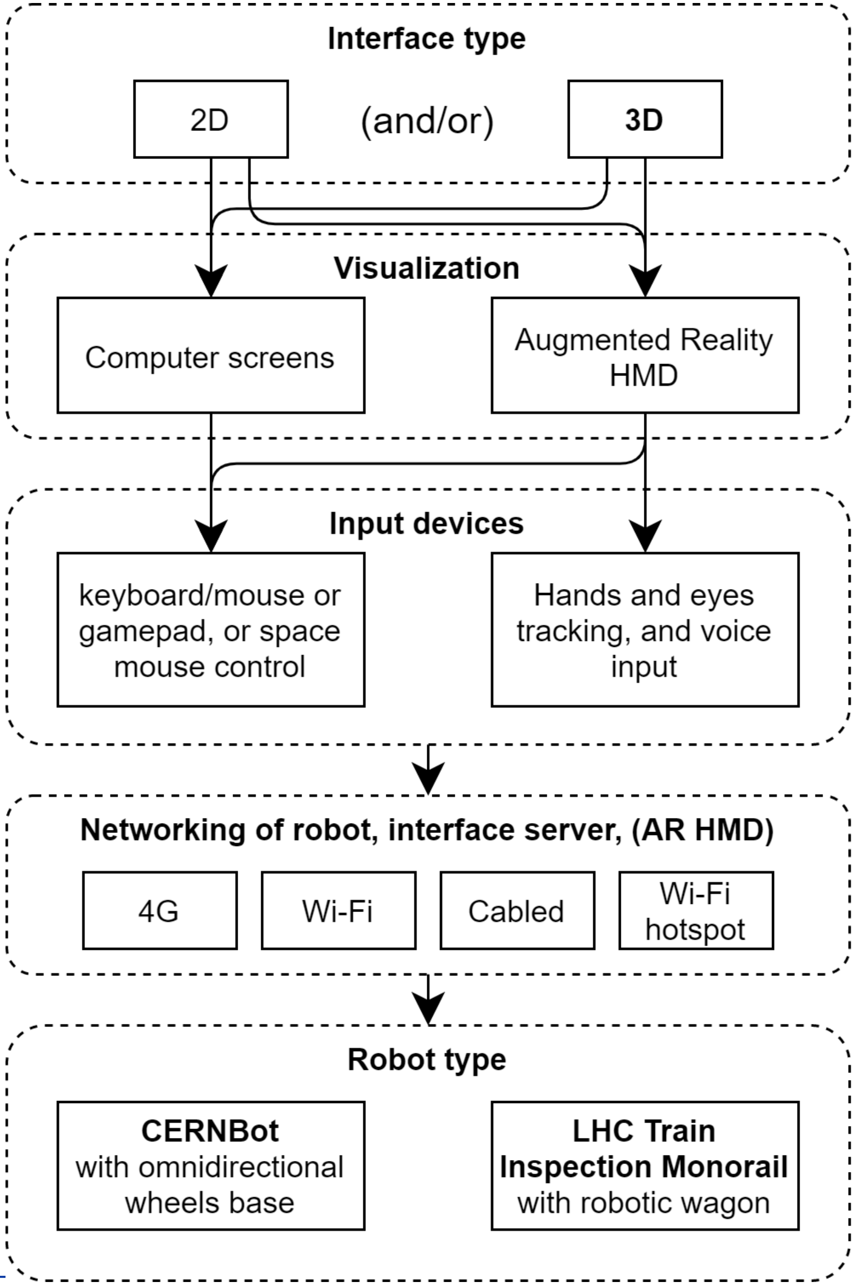



Here
Are
We

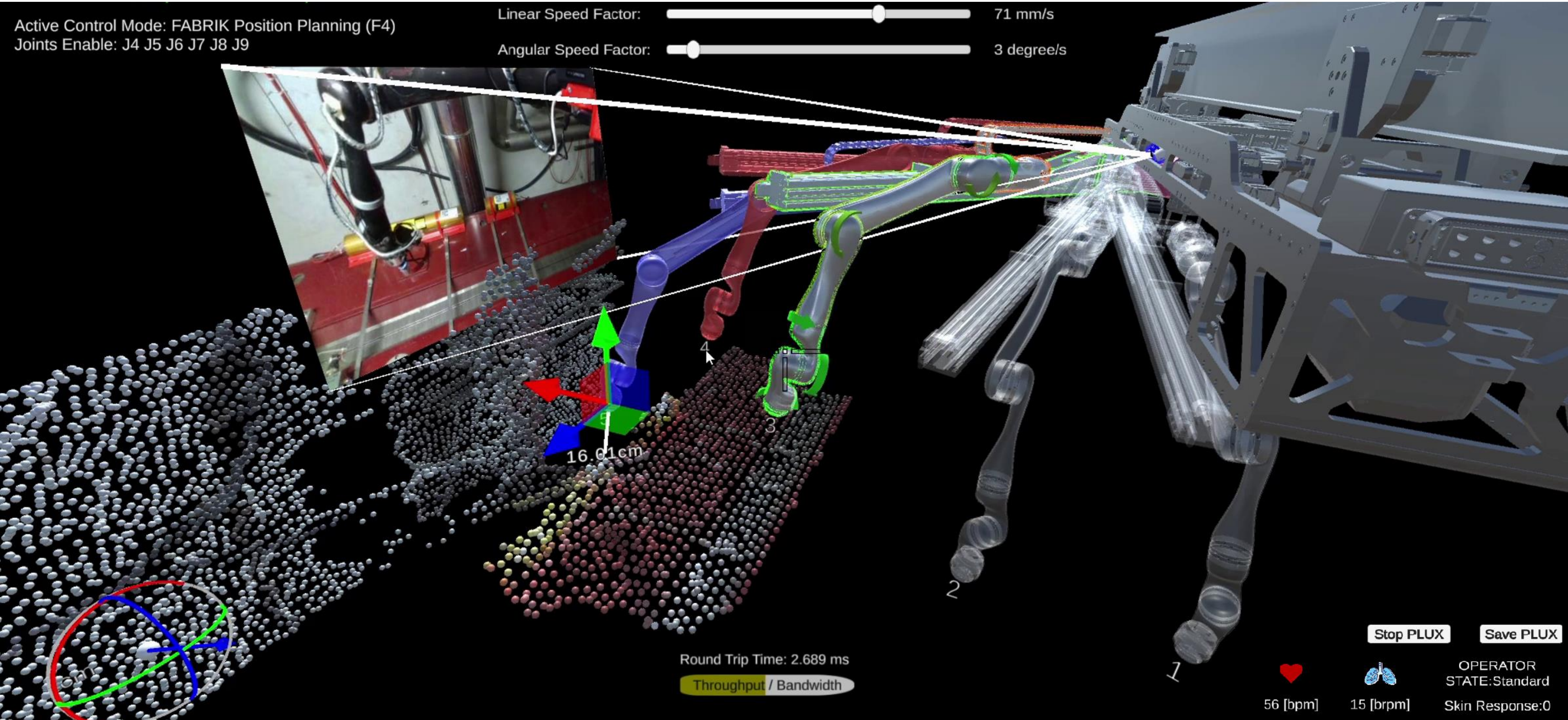


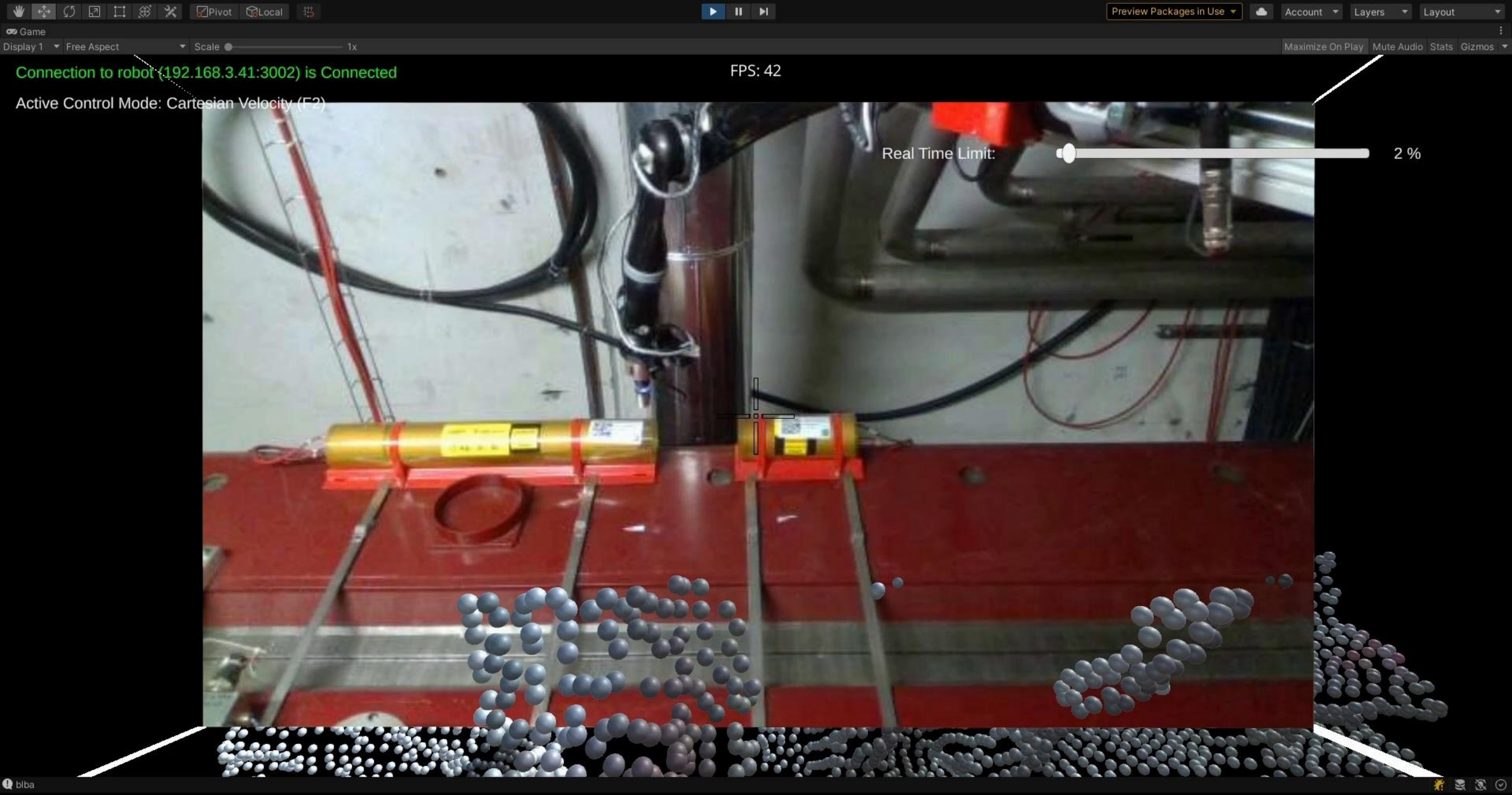


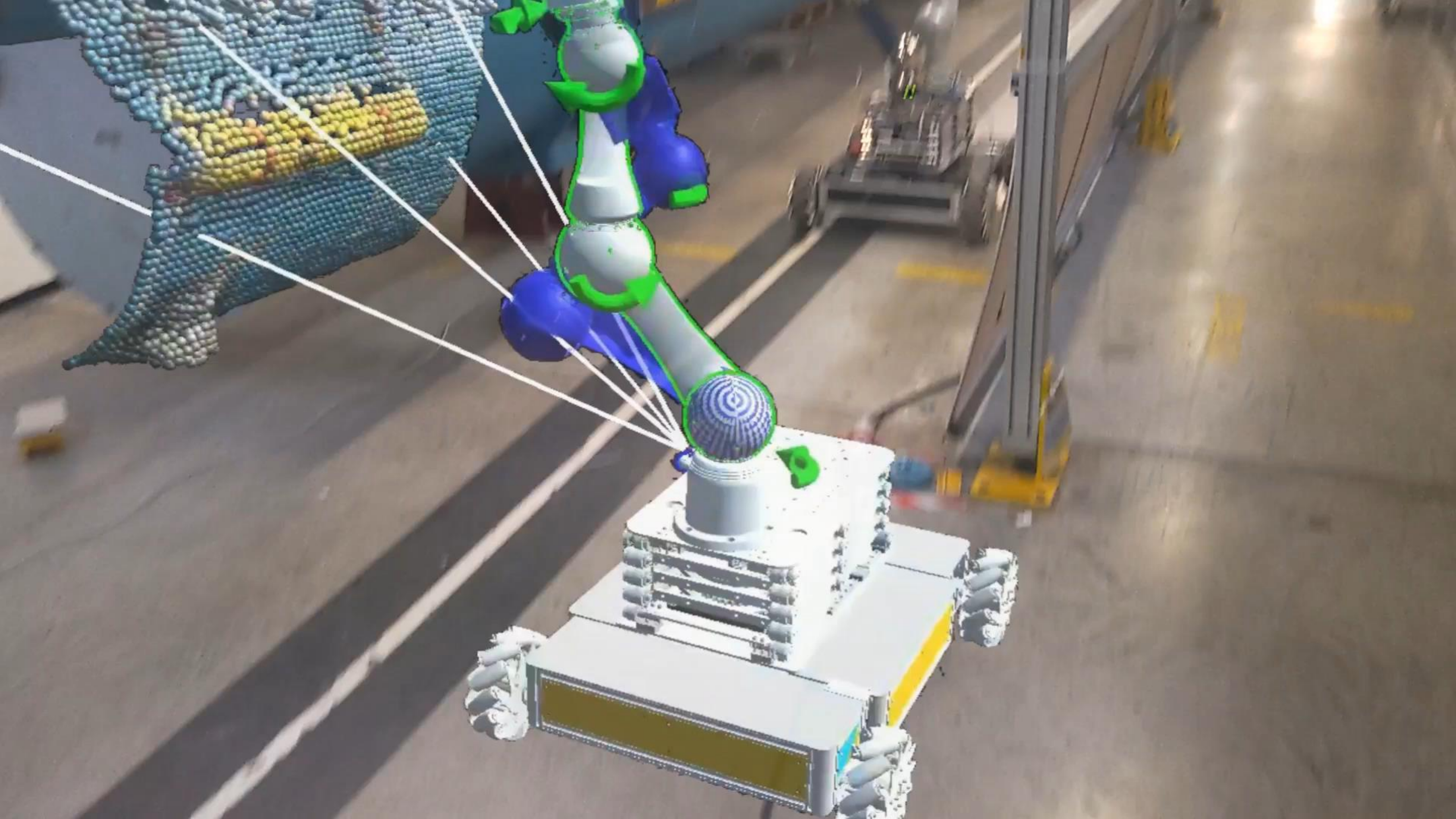
# 2D, 3D, VR, AR, MR synergies



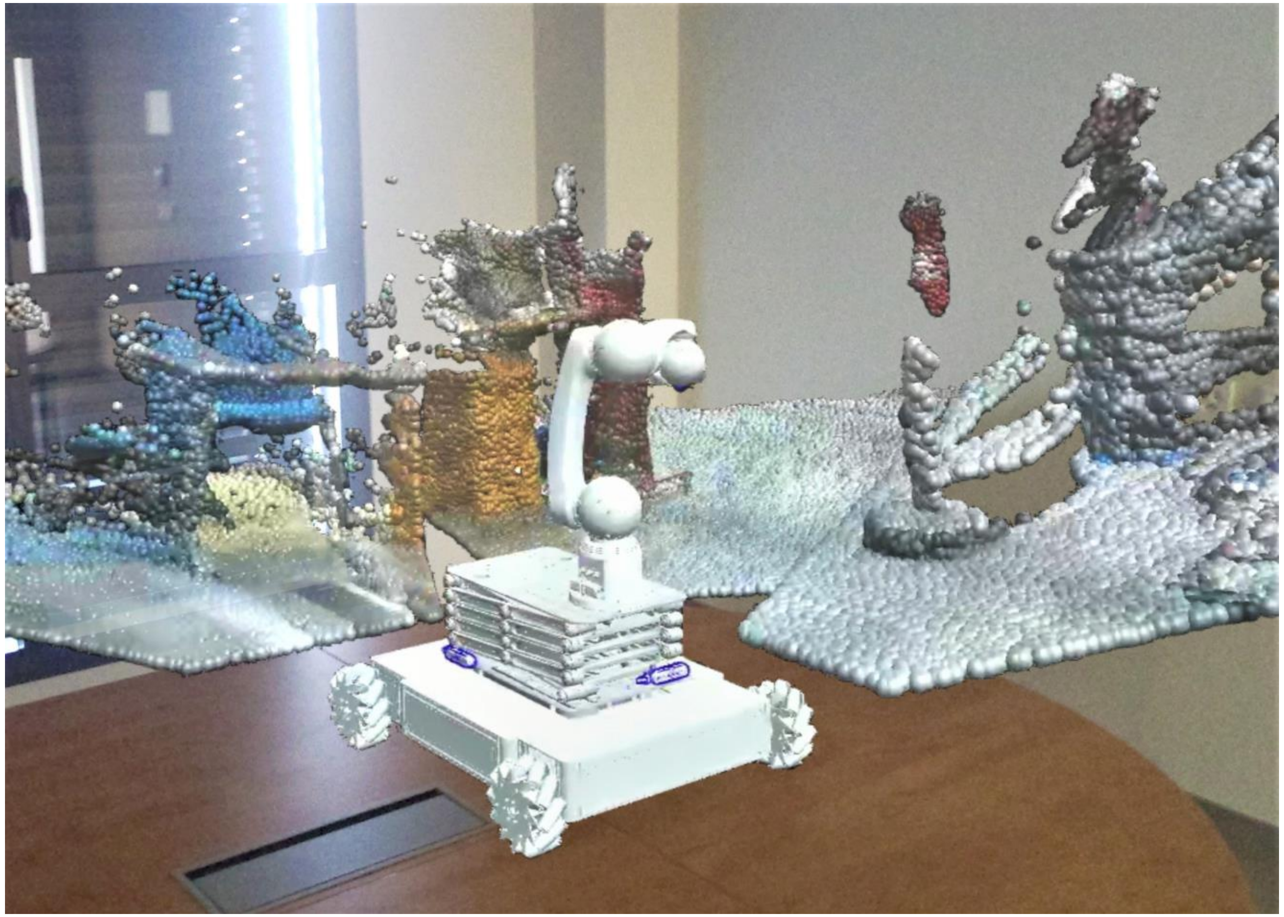
# Augmented Virtuality on screens

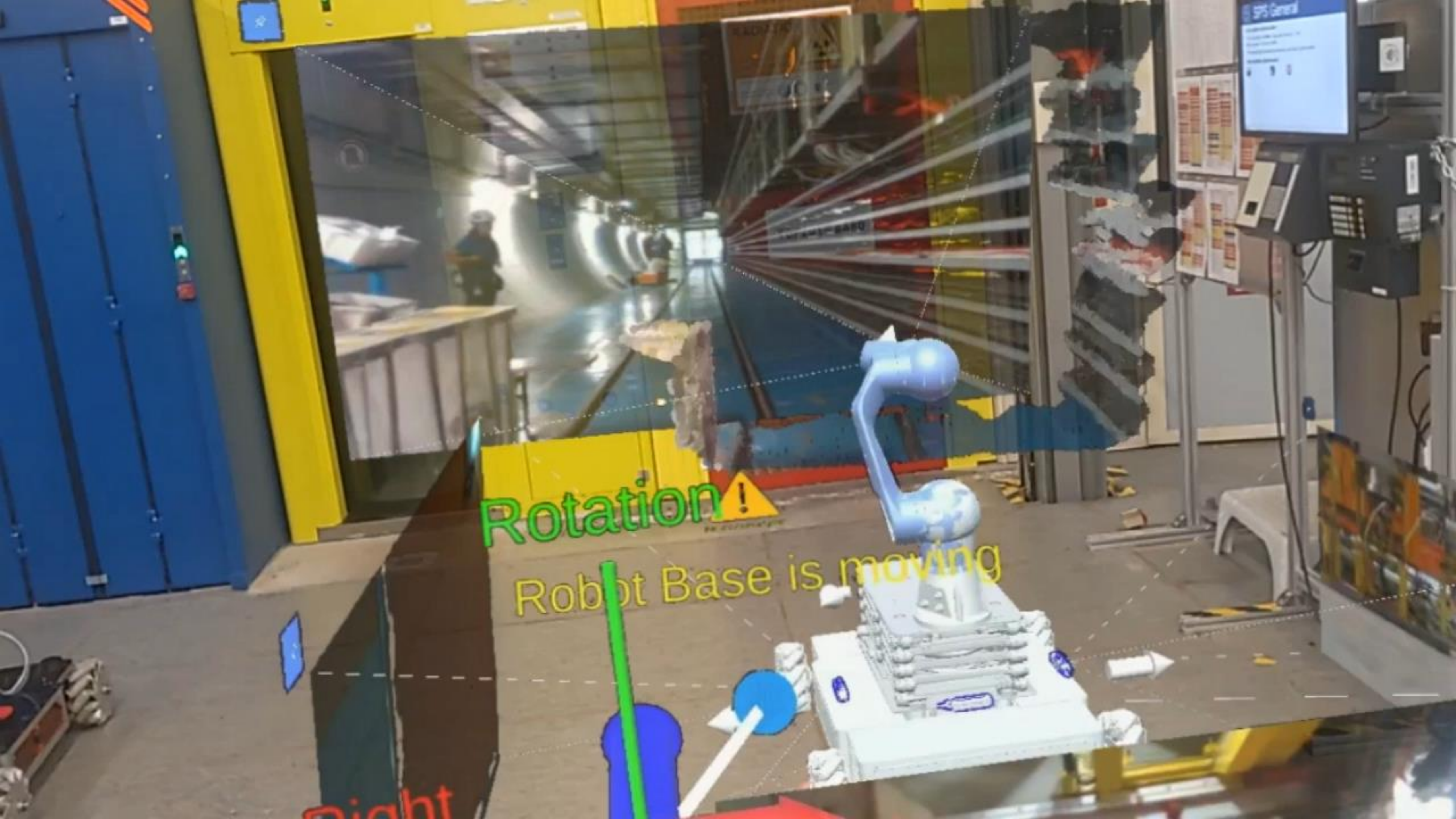



Pivot
Local
Preview Packages in Use
Account
Layers
Layout
Game
Display 1
Free Aspect
Scale
1x
Maximize On Play
Mute Audio
Stats
Gizmos
Connection to robot (192.168.3.41:3002) is Connected
FPS: 42
Active Control Mode: Cartesian Velocity (F2)
Real Time Limit:
2 %
blba



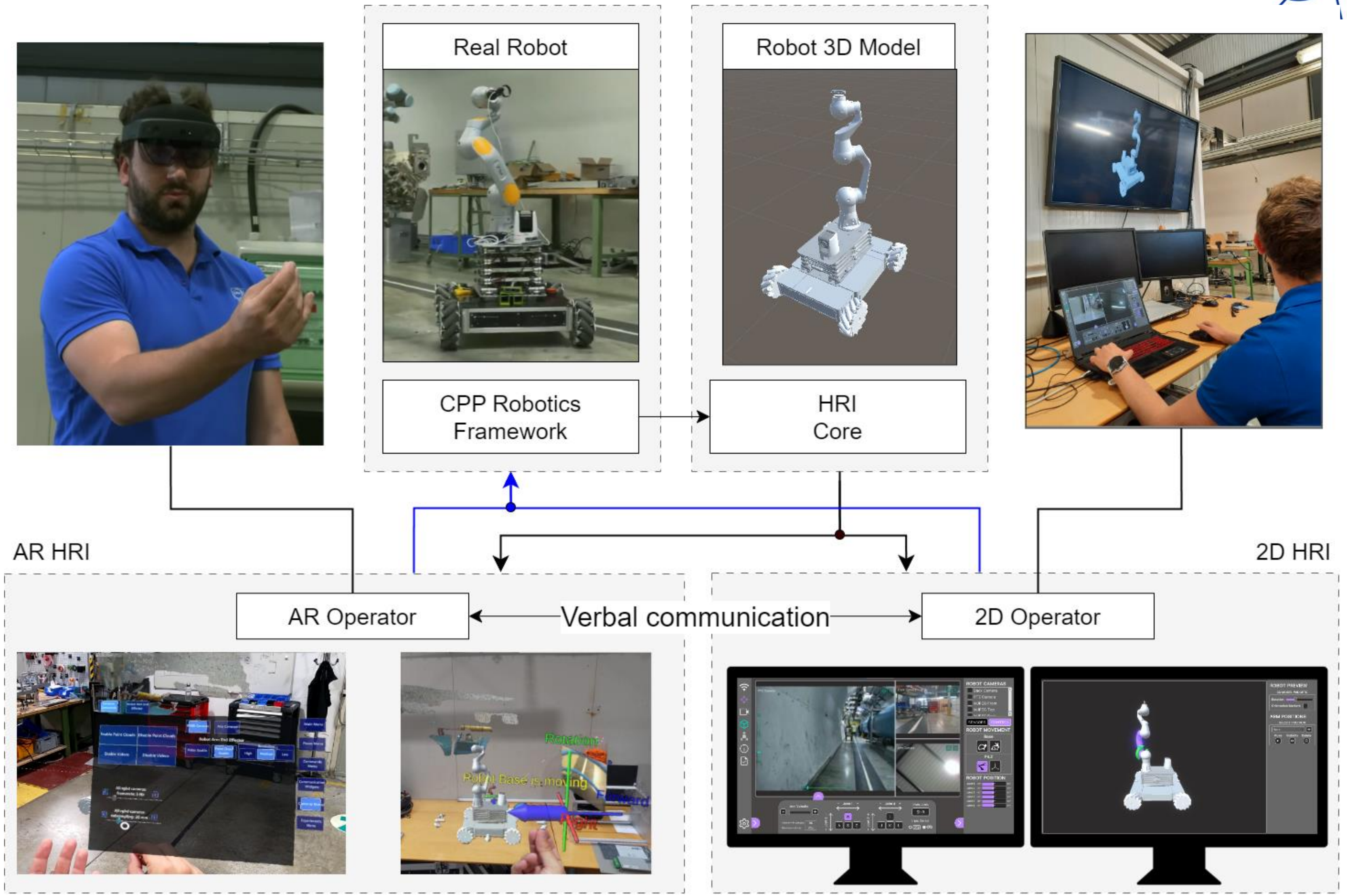
# Full view of environment and robot: videos and point clouds

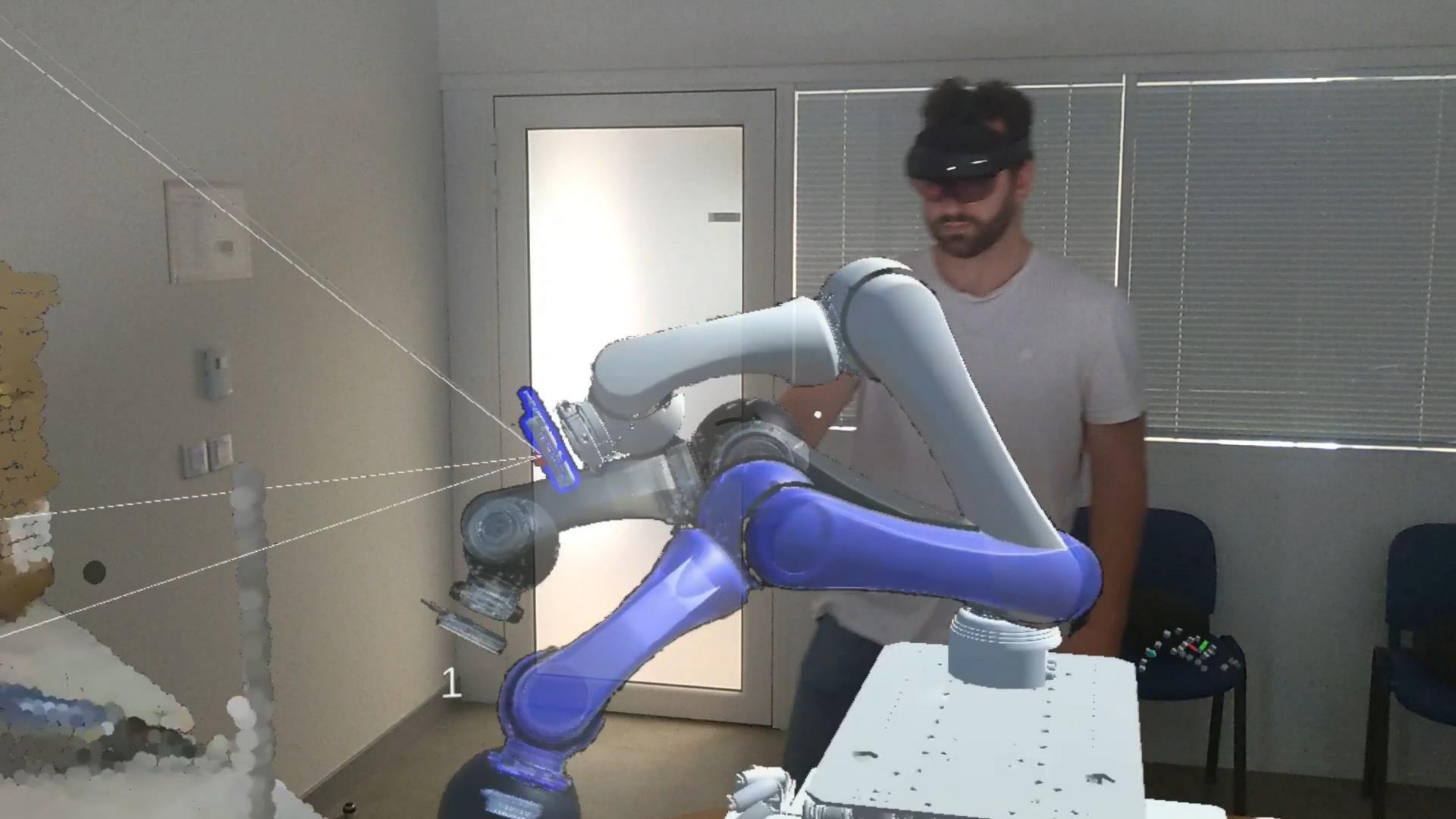



Rotation
Robot Base is moving

# Multiuser 2D and AR GUI

- The operator can select between different types of interfaces (2D/3D, AR and 2D/3D + AR).
- There are common modules (code, 3D objects) for every interface.
- The user can interact with the other users through verbal communication or gestures.
- Flexible and modular HRI interface.

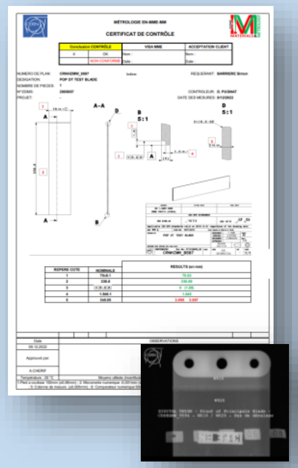



1

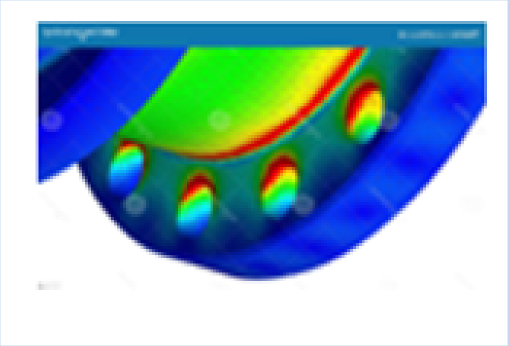
# Examples Of Digital Twins in EN-MME group
# Design and production followup

## Training Dataset

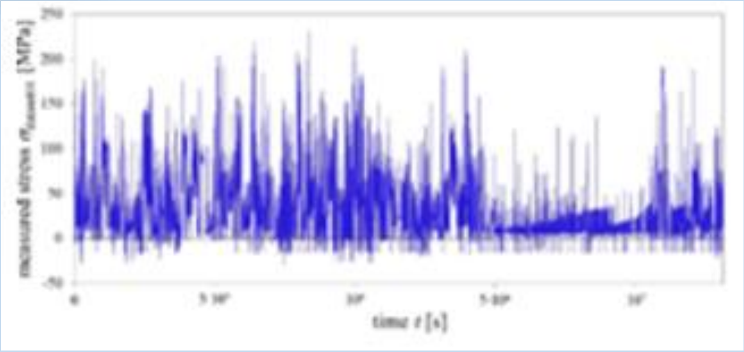
### QA



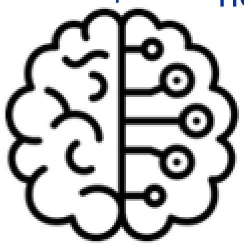
### FEA



### Measurements Historic



**Model Training**



- polynomial
- gaussian processes
- neural networks

**Virtual Sensors**
**Untrained Situations**
**Anomalies**

**Live Data + Model Opuputs Visualization**

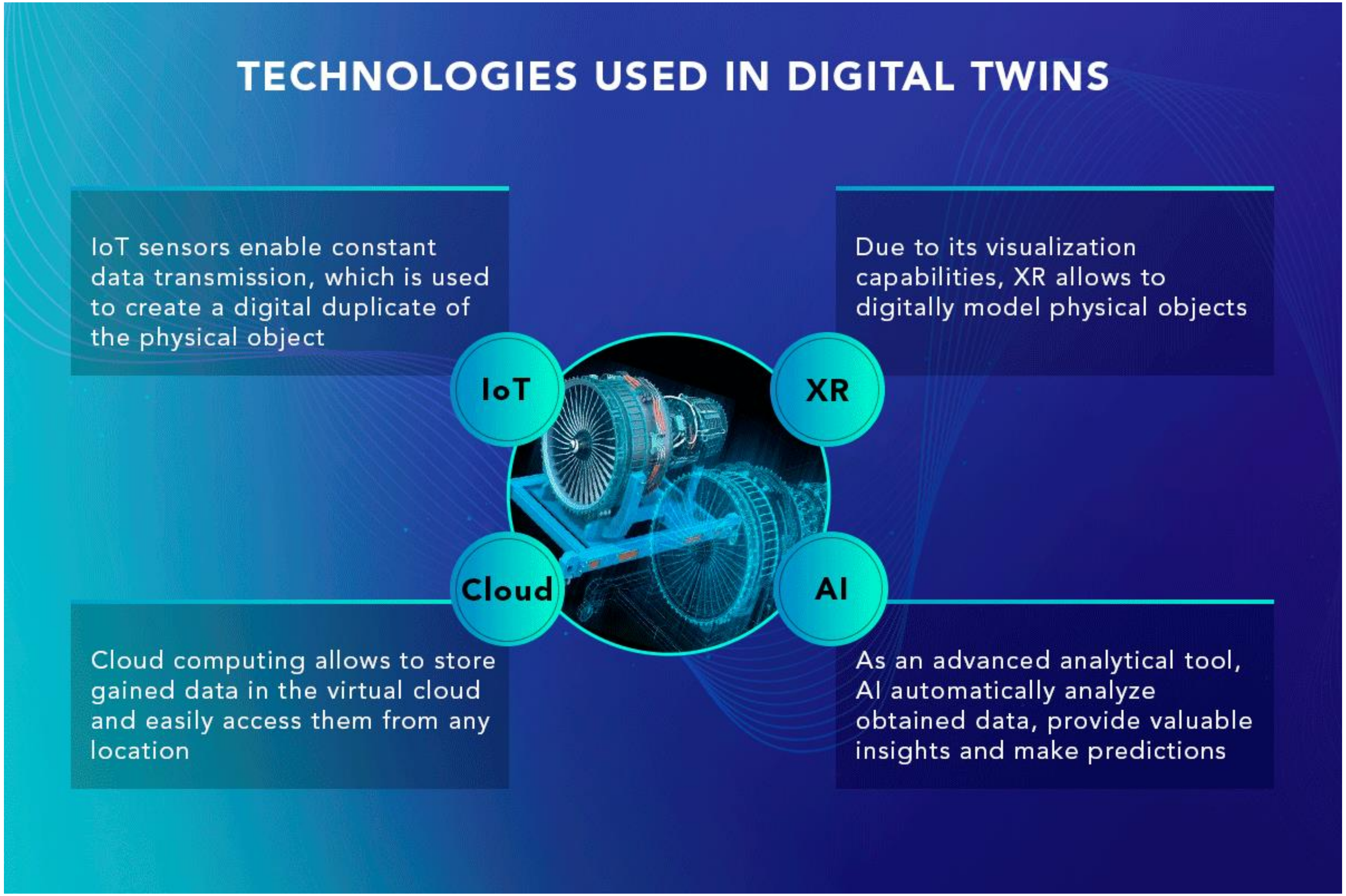
**Model Feed**


**Real Time Data Acquisition**

**Courtesy of Oscar De Frutos**

# Examples Of Digital Twins in EN-IM group Information management

Courtesy of Jugen De Jonghe



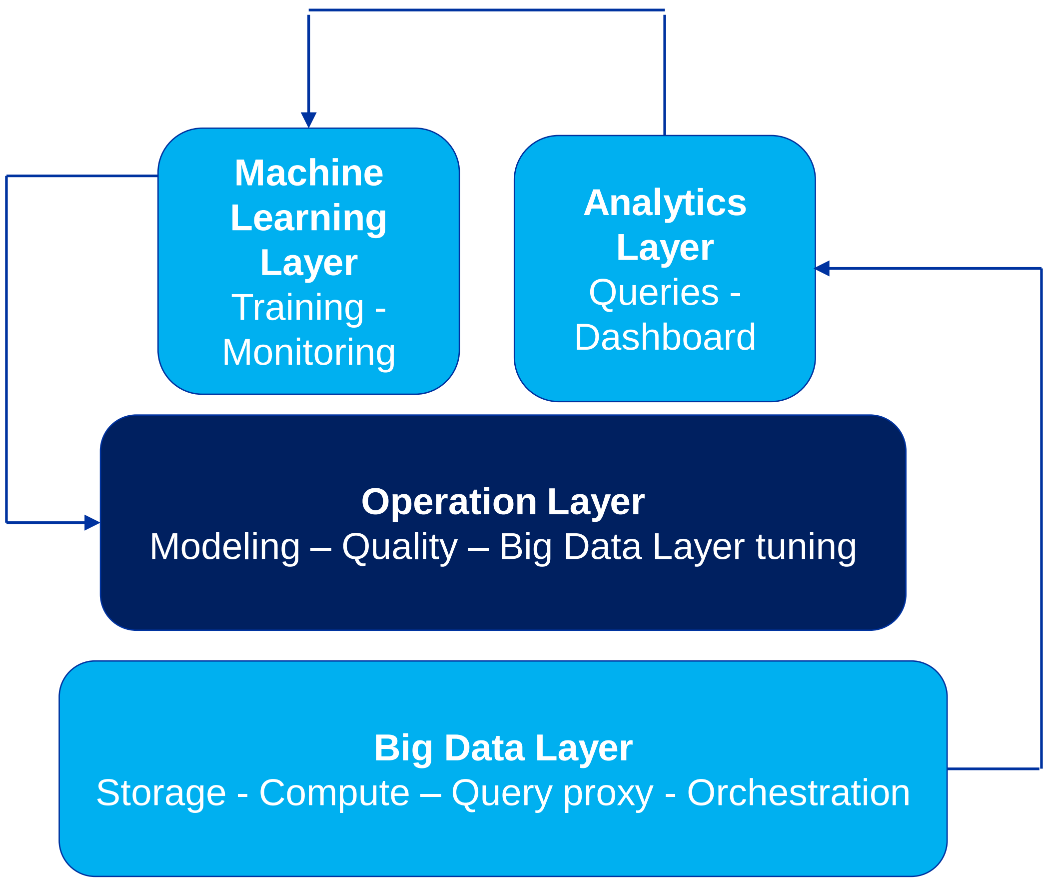

**Digital twins → Intelligent (Data, IoT, Cloud, AI) data model with advanced visualization capabilities**

# Data driven reliability and data quality

- To understand how to execute, maintain and improve machines, **data are needed**
  - ✓ Key aspect is to put together data scientist, developers and equipment experts → cross functional learning

- Predictive analytic model of machine components could be extrapolated from data
  - ✓ Failures could be anticipated, feedbacks for operation and quality

- Every year, poor/bad data quality costs to organizations an average of $13 millions
  - ✓ Right data / data quality is needed → Data reliability engineering (DRE) approach to data quality is needed. **Treating data quality like an engineering problem**




Data stack based on Bigeye solutions

**Question could be**: how much money will it cost?

**Answer could be**: how much money could be saved in prospective?

**It's not only about money, about SAFETY.**

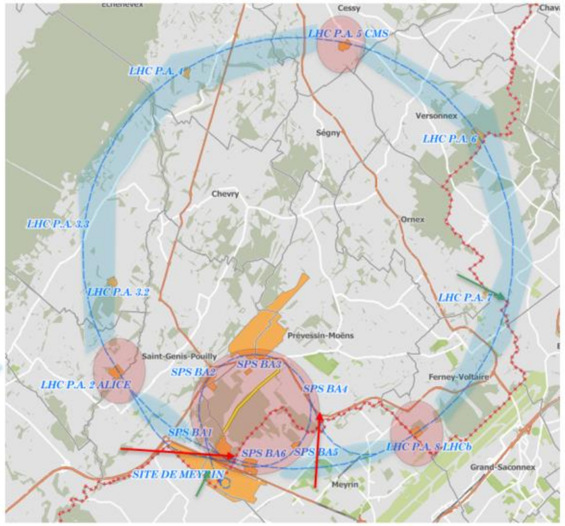
# CERN and wireless IoT

- **CERN embraced the Wireless IoT for:**
  - ✓ Ground application
  - ✓ Underground application -> Radiation areas!

See S. Danzeca talk “Radiation-Tolerant Multi-Application Wireless IoT Platform for Harsh Environments”, WE3AO01 paper, Wednesday during Hardware technology WE3A session

- **LoRaWAN wireless network has been deployed in the LHC Underground Tunnel**
- **A radiation Tolerant IoT hardware platform allow to communicate to the IoT world**
- **CERN is moving towards a “Smart IoT accelerator”**

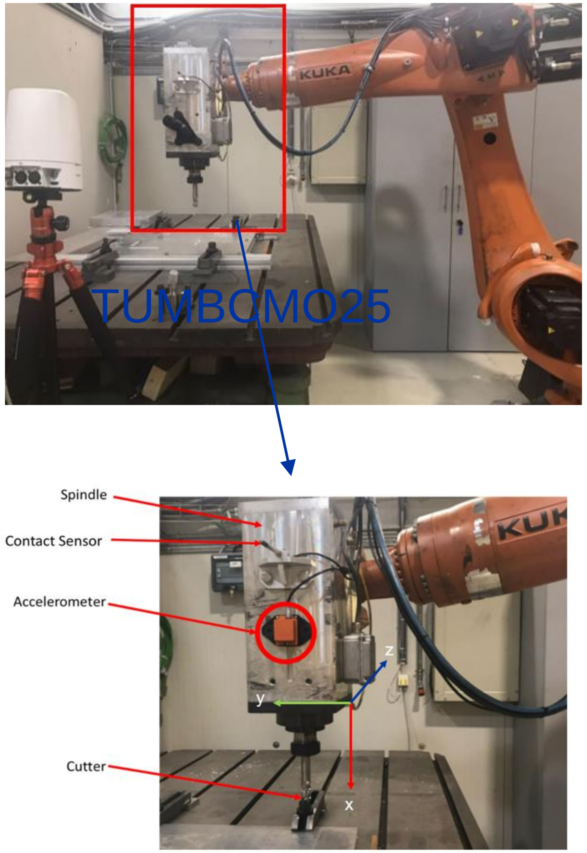
LoRaWan Coverage

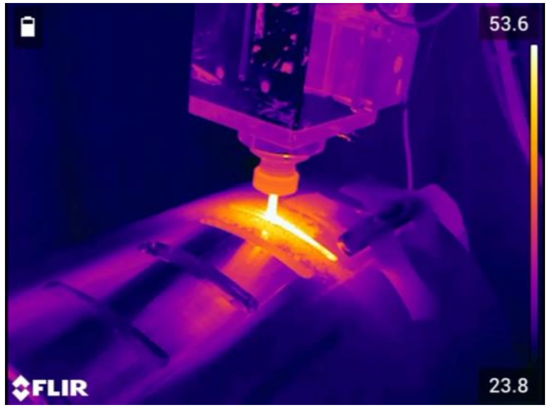



Radiation tolerant IoT hardware platform developed at CERN, courtesy of S. Danzeca

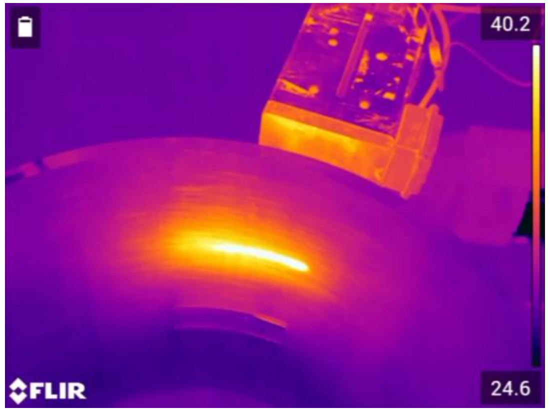
# Use of data to improve process reliability

- **Robotic CNC solution for machining of radioactive objects**
  - ✓ Problem: Robot for fine machining moves in a non ideal way breaking many end effector tools
  - ✓ Solution: real time data collection of several sensors, fusion and analysis with machine learning for anomalies detection
  - ✓ Discovered: problem in online trajectory generation in particular robot poses






# Conclusions

- Digital twins are widely used in industry for engineering and manufacturing
- In robotics, we use digital twins mainly to validate designs and to prepare interventions procedures and tools
- Is this technology still accessible? Are the infrastructure needed to make digital twins efficient available?
- Simulation and reality are still too far?
- How reliable can be this technology to be used to improve the reliability of a process?

# References

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2. "i-TIM: A Robotic System for Safety, Measurements, Inspection and Maintenance in Harsh Environments", Mario di Castro et al, 2018, https://inspirehep.net/literature/1702507
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4. "CERNTAURO: A Modular Architecture for Robotic Inspection and Telemanipulation in Harsh and Semi-Structured Environments", Mario di Castro et al, 2018, https://ieeexplore.ieee.org/document/8391705
5. "Multimodal Multi-User Mixed Reality Human–Robot Interface for Remote Operations in Hazardous Environments", Krzysztof Szczurek et al, https://doi.org/10.1109/ACCESS.2023.3245833


www.cern.ch

More on : Academic training lectures on robotics,
https://indico.cern.ch/event/1055745/

"If you have an apple and I have an apple and we exchange these apples then you and I will still each have one apple. But if you have an idea and I have an idea and we exchange these ideas, then each of us will have two ideas."
*George Bernard Shaw*

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