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Resource requirements of an Edge-based Digital Twin Service

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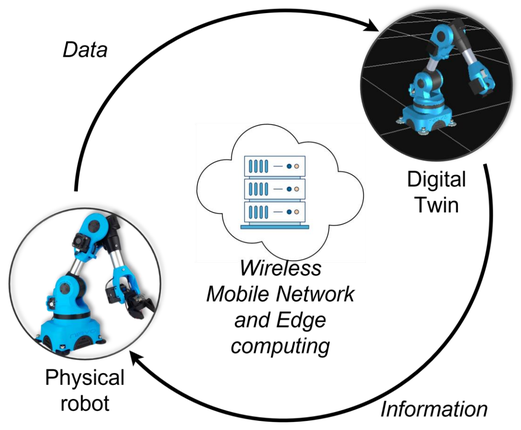
Research context and motivation

- **Industry 4.0** paradigm:
  - Industrial robots, e.g. robotic arms, and automation;
  - digital transformation of modern industries towards **service-oriented industries**;
  - unprecedented levels of flexibility, safety, productivity, cost-efficiency and smart.
- Digital Twin (DT) is the **smart and evolving virtual counterpart of a physical system**, and supports the intended industrial digital transformation.
  - Monitoring DT
  - Simulation DT
  - **Operational DT**
- Thanks to **Edge-computing**, **NFV** and **5G**:
  - DT as a **network service**;
  - lightweight and cost-effective robots.



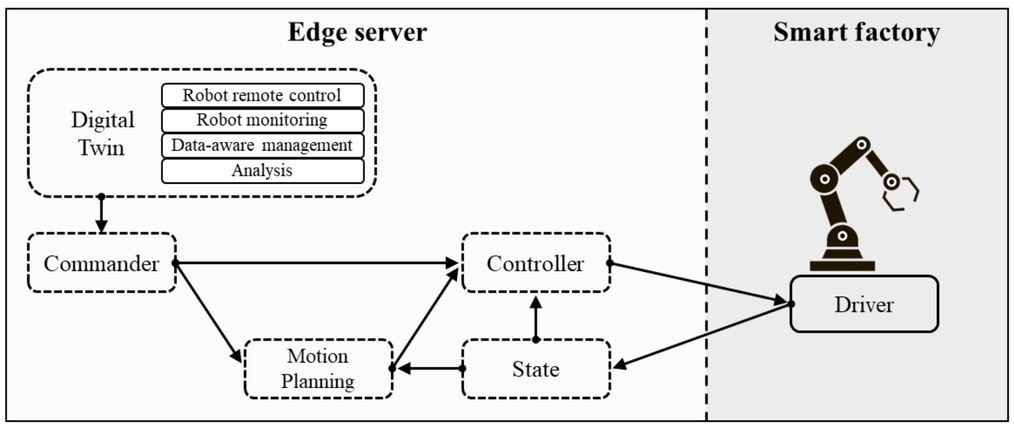
Addressed research questions/problems

- System prototypes to to gradually validate and optimize Digital Twin solutions.
- An effective characterization of the Edge-based DT service is required by automated resource scaling and orchestration frameworks to achieve **resource usage savings** and **performance guarantees**:
  - DT service resource profiling;
  - Exploration of the parameters influencing the service resource requirements.

Novel contributions

- Edge-based, virtualized implementation of a **DTaaS prototype** for **robotic arm remote control** in an **experimental laboratory testbed**;
- An insight into the entanglement between **service resource requirements** and **service demand load**, i.e. the number of robots concurrently requesting the DT service;
- Novel evaluation of the **impact of industrial applications**, i.e. command abstraction-levels, on the DT service resource profile.

The Edge-based Digital Twin service solution



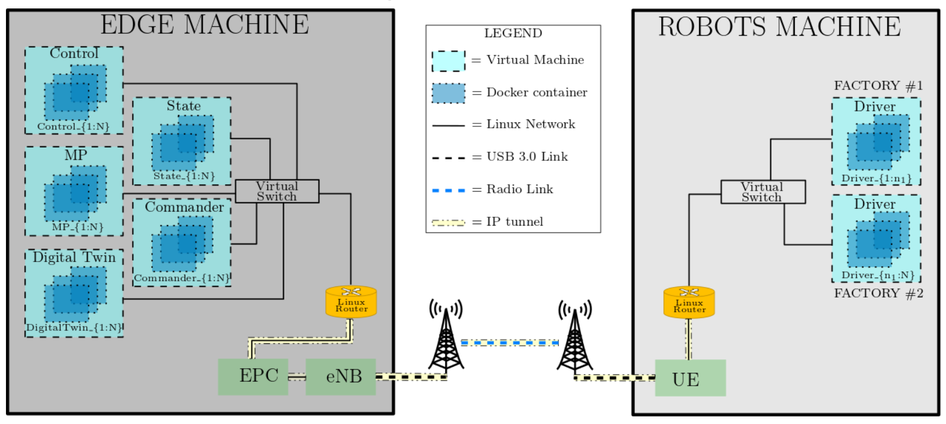
- A DT solution for robotic arms is decomposed into VNFs:
  - **Driver VNF**: low-level interface with the robot hardware and sensors.
  - **Control VNF**: runs a hard-real-time-compatible control loop towards the Driver VNF.
  - **State VNF**: it is in charge of computing the direct kinematic.
  - **Motion Planning (MP) VNF**: it receives as input both the current and the desired robot end-effectors and computes the inverse kinematics and the trajectory.
  - **Commander VNF**: Commands validation and redirection.
  - **Digital Twin (DT) VNF**: it provides high-level abstraction of the robot and of the entire service stack, hosting updated robot's virtual replica, and enabling user applications to interact with the robot through the DT.

Submitted and published works

- S. Tripathi, C. Puligheddu, C. F. Chiasserini and F. Mungari, "A Context-Aware Radio Resource Management in Heterogeneous Virtual RANs," in IEEE Transactions on Cognitive Communications and Networking, vol. 8, no. 1, pp. 321-334, March 2022, doi: 10.1109/TCCN.2021.3115098.
- F. Mungari, "An RL Approach for Radio Resource Management in the O-RAN Architecture," 2021 18th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON), 2021, pp. 1-2, doi: 10.1109/SECON52354.2021.9491579.
- Mungari, F. , Groshev, M., and Chiasserini, C., "*Resource Requirements of an Edge-based Digital Twin Service: An Experimental Study*", Virtual Reality & Intelligent Hardware, 2022, 4.(4): 1–15 (Accepted for publication)

Adopted methodologies

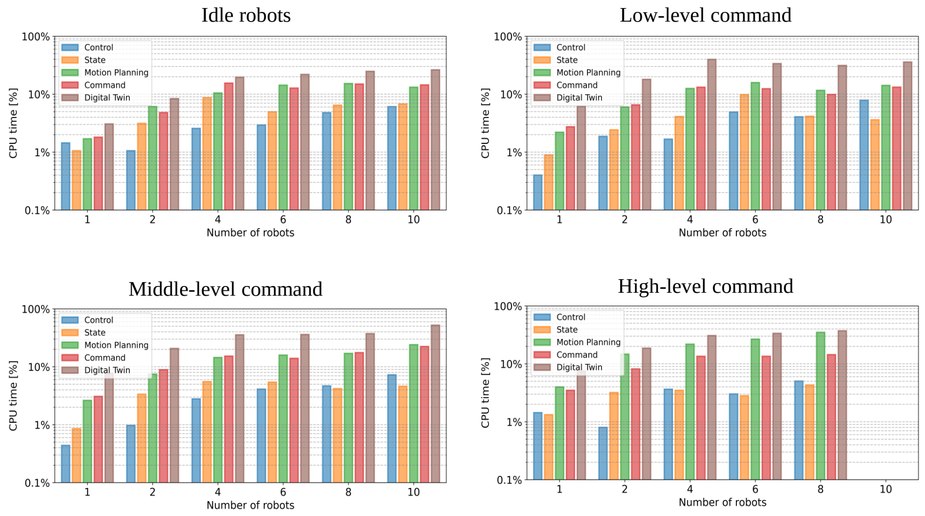
- **Niryo One simulated robotic arms**: 6-axis open source collaborative robots designed for R&D built upon the open-source Robot Operating System (**ROS**).
- Connectivity between the Edge and Robots Machines is based on **srsRAN**, an open-source SDR LTE full-stack implementation.

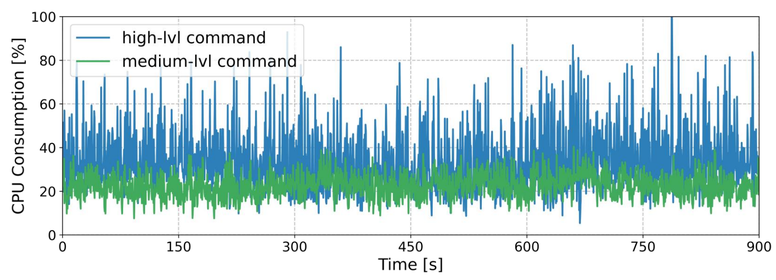


- Robot Command abstraction-levels: Strong correlation with industrial use-case.
  - **High-level commands**: low precision in position control. Use-cases: polishing, grinding, and welding
  - **Middle-level commands**: medium precision in position control.
  - **Low-level commands**: high precision in position control. Use-cases: waterjet cutting, drilling, and milling processes

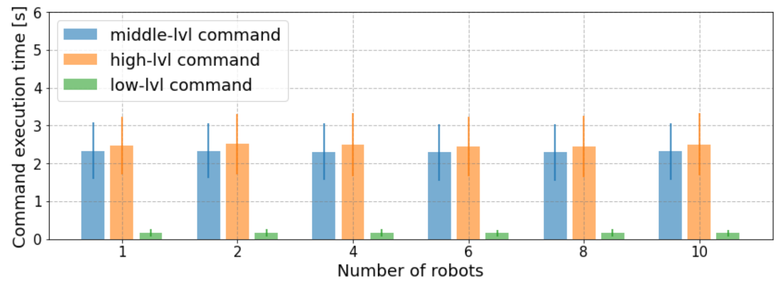
Experimental DT Service Characterization

- Experimental Edge-based DT Service evaluation: **CPU profiling**





- Experimental Edge-based DT Service evaluation: **command execution time**



Future work

- For future research, the testbed is going to integrate enhanced radio communication technologies, i.e., **5G**;
- Design and deploy an **automated smart network service orchestrator** able to ensure resource utilization and energy consumption optimization while avoiding running into service disruptions caused by shortage of allocated resources. Artificial intelligence and machine learning may provide the key tools to achieve the aforementioned goals.

List of attended classes

- 01DTPRV – Connected Vehicles (P.D.2-2 - April, 4 CFU)

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering