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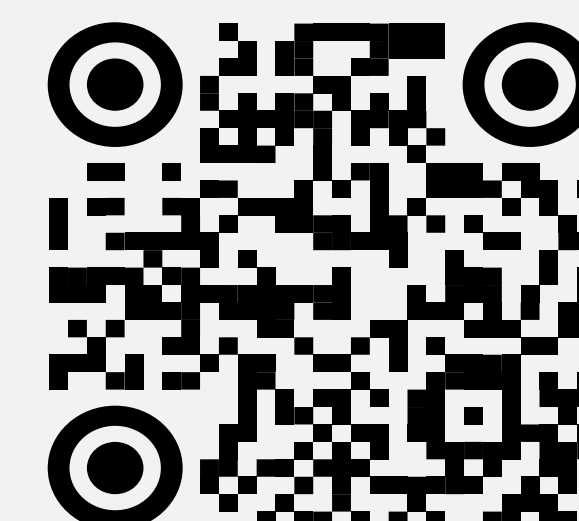
eXtended Reality Applied to Industrial and Collaborative Robotics

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Motivation and background

Today, robotics is undergoing an important paradigm shift in the context of **Industry 4.0**, passing from the main use of traditional industrial manipulators, intended for multiple automation tasks, to **collaborative** robots (*cobots*), capable of working in proximity to human operators, as well as to interact with them in novel ways. In this context, technologies like **Virtual Reality** (VR), **Augmented Reality** (AR) and **Mixed Reality** (MR) or, more in general, **eXtended Reality** (XR) proved to be very effective in supporting the mentioned shift and associated challenges in various domains, encompassing remote assistance, maintenance, training and, more broadly, the wide field of Human-Robot Interaction (HRI).

eXtended Reality Robotic Applications
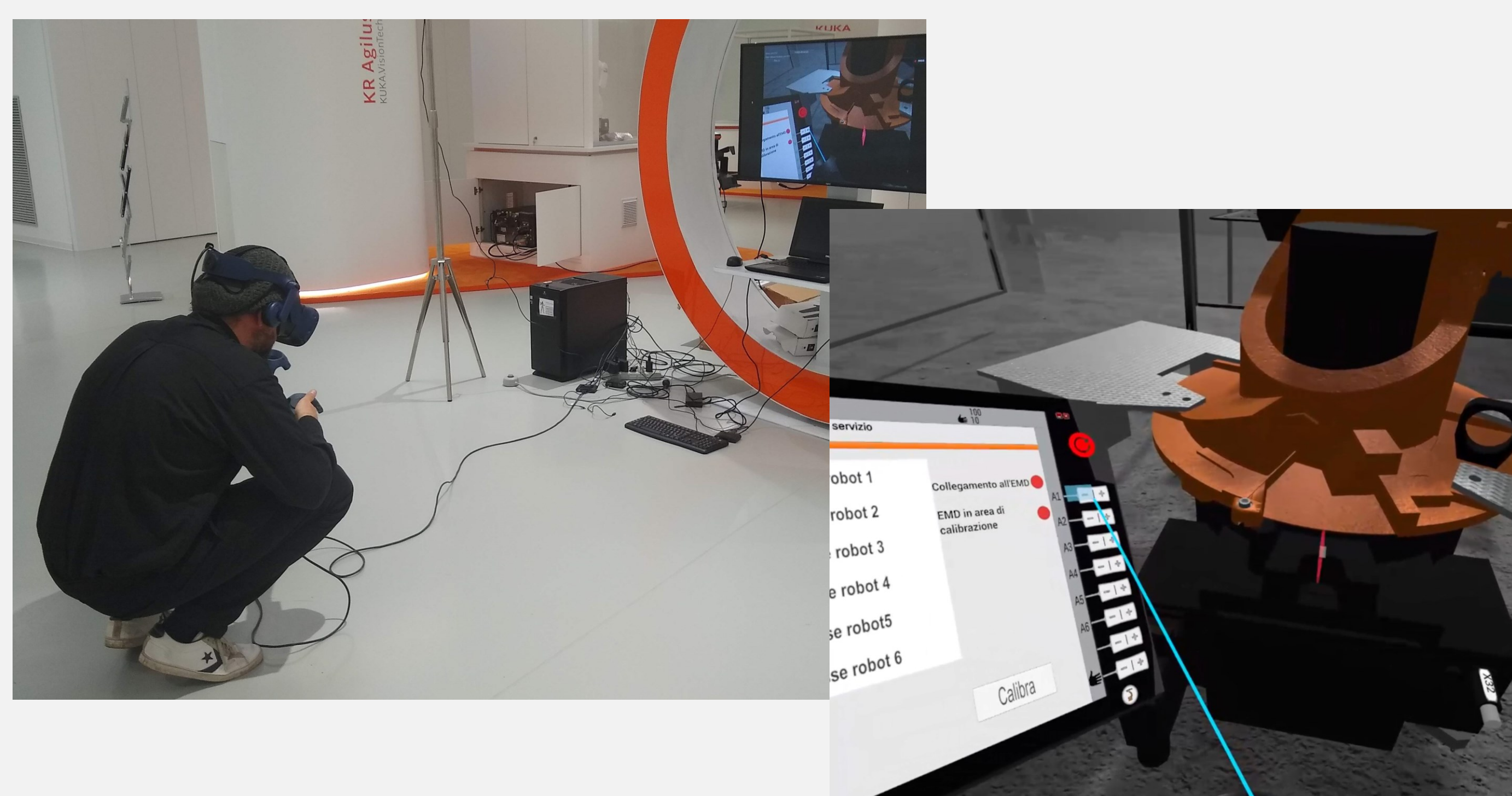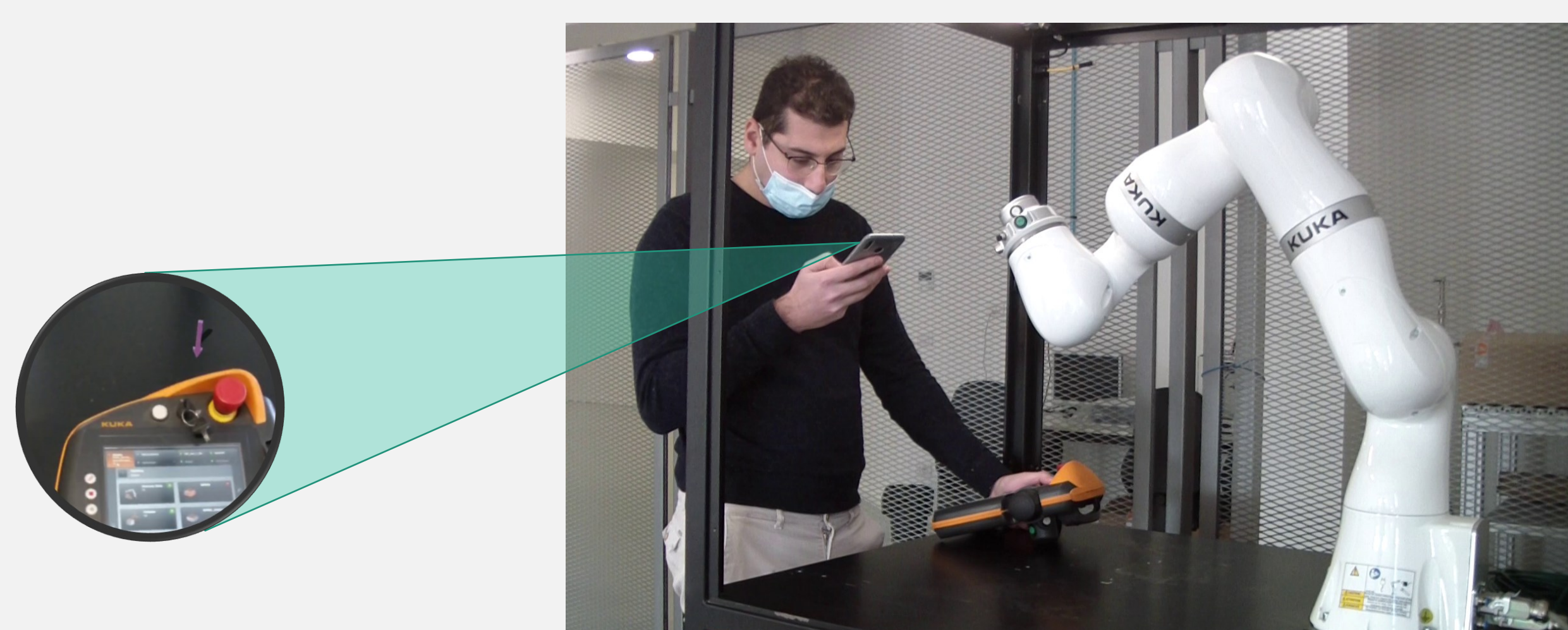
AR-powered Remote Assistance for Robotics

AR has multiple applications in industry, but **remote assistance** represents one of the most widely studied use cases. Although the set of functionalities supporting the communication between remote experts and on-site operators grew over time, the expert typically guides the operator step-by-step, so the **time invested** in the the assistance corresponds to the time needed to execute the requested operations. In this context, AR technology can be used to re-organize the **guidance workflow**, with the aim to increase the operator's autonomy and, thus, **optimize** the use of expert's time.

VR Training Systems for Robot Operators

Although the efficacy of Virtual Reality Training Systems (VRTSs) as a fancy alternative to traditional learning material used by trainers in their lectures has already been proved, their effectiveness as **self-learning tools** not requiring human instructors is still controversial. Moreover, training robot operators poses key **learning challenges** that need to be addressed such as: being educated on how to operate near a potentially harmful moving robot in degraded conditions, prevent equipment damage, perform non-trivial error recovery procedures, learn dedicated user-robot interfaces with *phygital* controllers, and so forth.

Multi-user Cobot Programming in XR

The human direct involvement in **cobots programming** can go far beyond the traditional robot programming. A **multi-user** programming scenario, for example, may greatly benefit from the use of different XR technologies. Distant users could need to share a common setting including virtual reconstructions (i.e., **Digital Twins**) of the elements that are physically present only in one of the two environments and their status/actions. Similarly, local users could benefit from augmented visualizations of both the cobot and the distant, tele-present user.

The activities depicted above have been developed in the context of the VR@POLITO initiative, in collaboration with KUKA Roboter Italia Spa