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Mirrorlabs - creating accessible Digital Twins of robotic production environment with Mixed Reality

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***Abstract*—How to visualize recorded production data in Virtual Reality? How to use state of the art Augmented Reality displays that can show robot data? This paper introduces an open-source ICT framework approach for combining Unity-based Mixed Reality applications with robotic production equipment using ROS Industrial. This publication gives details on the implementation and demonstrates the use as a data analysis tool in the context of scientific exchange within the area of Mixed Reality enabled human-robot co-production.**

1. Introduction

There are many studies [1] [2], that show that the future productivity within the manufacturing industry (as envisioned by the Industry 4.0 paradigm) will depend on humans working alongside intelligent machines and robots in the factories. There is a lot of new technology, which is introduced to the production floor: collaborative robots (cobots) for close human-robot interaction, new interface technologies like Augmented and Virtual Reality, and new applications based on data and artificial intelligence. If we want to achieve sustainable future production workplaces, the need for designing an "augmentation layer" for the worker arises, which helps the human worker to deal with the increasing complexity and self-organization of the cyber-physical production system (CPPS). This could be done by visually facilitating the vast amount of sensor data and information.

Emerging human-robot interaction techniques like Augmented and Virtual Reality will play an increasing role, among others in plant planning, plant supervision, close collaboration with robots, and plant optimization. Nevertheless, combining AR/VR with existing robotics infrastructure is quite challenging, because it requires knowledge from both domains. The development of a bridging ICT framework is the precondition for being able to conduct studies on how the displayed information could support human situation awareness, sense- and decision making, and the sharing of mental models between humans and machine.

To solve this problem, research needs to be carried out on the entire work socio-technical system, both sides: the AR/VR research and the manufacturing robotics researchers need to team up to provide sustainable solutions.

Existing work covers mainly one part of this, which is certainly due to the general problem of real cross-disciplinary research, but also because the tools are not easily available. There is a lot of work on applying AR/VR to manufacturing, for example, AR-based repair instructions

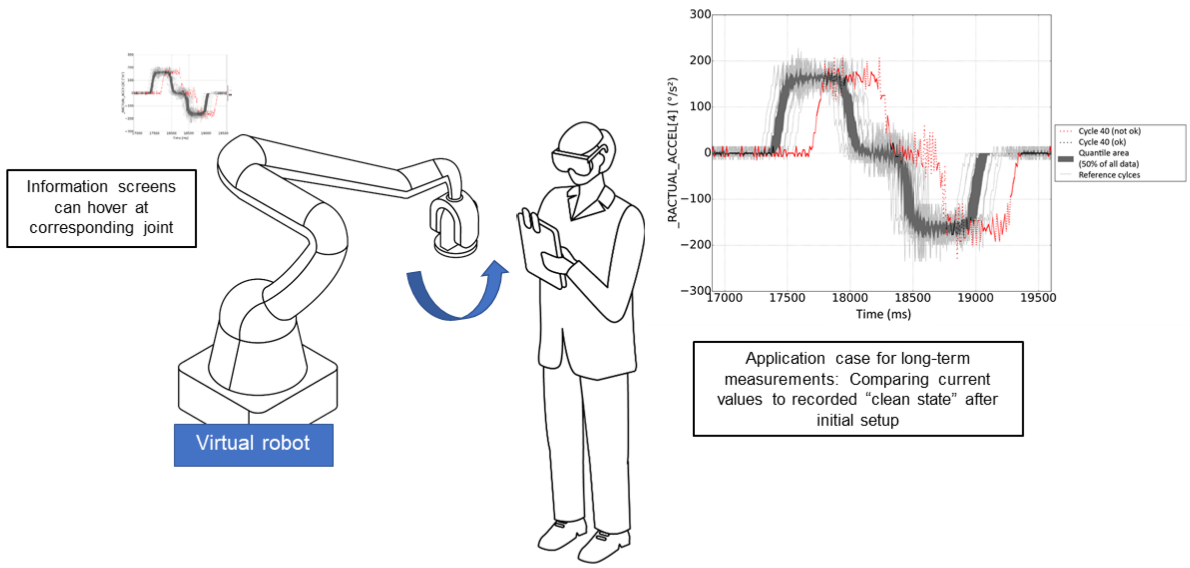

Figure 1. VR application case for data analysis

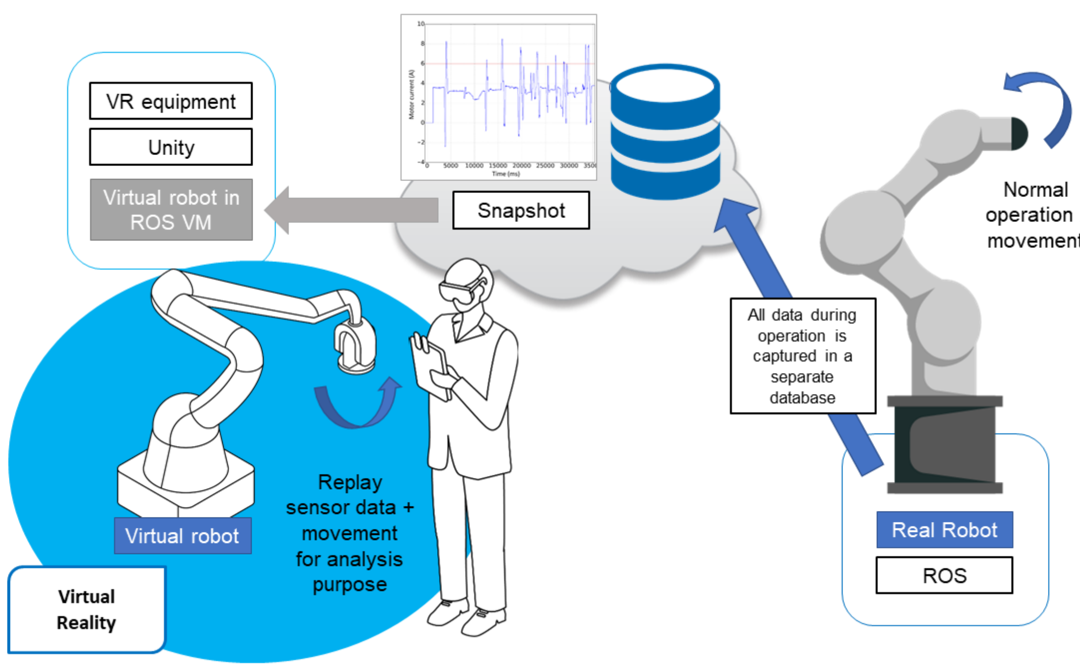

Figure 2. ICT architecture for data display

[3], AR-based picking instructions [4], displaying additional information within a factory [5], or virtual product inspection stations based on VR-goggles [6]. Additionally, there is work on VR-based collaboration [7], the use of exoskeletons within manufacturing tasks [8], and factory planning [9]. On the side of the robotic research, there are tools for developing immersion-based situational awareness (including virtual reality user experience) for robots supported by the robot operation system (ROS) using the native RViz visualization [10], this technology does not enable communication with the main frameworks used for AR and VR development: Unity and Unreal. Although such bridging solutions exist already – for example, a middleware approach for teleoperation [11] or over-the-Internet interface for teleportation [12] – their usage within the state of the art Mixed Reality devices is not entirely comprehensible and easy to set up. This concerns mainly head-mounted displays, especially the Microsoft Hololens which is based on the Universal Windows Platform.

The aim of the EIT Manufacturing project "Mirrorlabs" is the development of an integrated, easy-to-use ICT infrastructure for the off-the-shelf Mixed Reality hardware in combination with ROS-driven (Robot Operation System) production systems and to make it available for education and research.

2. Use cases

The possible use cases of this framework range from a VR-enabled remote analysis of robot-operated production line datasets (as displayed in Figure 1) to the use of Augmented Reality for close collaboration between humans and robots on the production floor. In this section the different use cases of the Framework are discussed and the existing use cases are displayed.

2.1. User task description

2.1.1. Inspection use case. In Figure 1 the use case for data visualisation is displayed. The application context is a visual abrasion check for industrial robot axes. As industrial robots can run for 24 hours a day and 7 days a week, the inspection targets at identifying the amount of abrasion compared to the initial setup of the robot.

In order to realize this scenario, the robot needs to record process data directly after the initial setup (without abrasion effects). This dataset is stored. After a longer time of active robot work, another dataset is recorded. With the help of the framework, it can be displayed on top of the initially gathered dataset. The visual inspection can be either realized within Virtual Reality or as an overlay of the real robot with the help of an Augmented Reality head mounted display.

2.1.2. Teaching use case. The usage of a Virtual Machine robot for a VR application (Figure 5) is necessary for each recorded or simulated VR environment, in which a robot is used. The robot simulator runs in a ROS VM and the movement is displayed in Unity. A very interesting application case is also to use Virtual reality for a dual arm robot position teaching (Figure 6 and 7): The user can move the 6DOF visualization marker and record the positions for a simulated program.

2.1.3. Direct interaction use case. Possible application cases encompass the usage of a head mounted display for showing the movement of the robot (in Figure 4 and 9). Here either measured data could be displayed at the corresponding space (for example temperature at a work piece near the end effector). Or the virtual representation can be used to show past and future movement of the robot or display the work envelope as a safety feature.

2.1.4. Factory planning use case. Additional use cases can be explored with the creation of a "mini factory" visualization (Figure 8), for example for remote supervision and support or factory planning.

2.2. Interaction design requirements

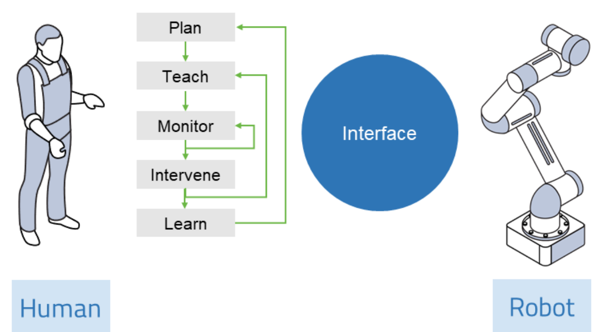

Figure 3. Abstract tasks within human-robot co-production following [13]

In general, the tasks conducted by a human operator within the the "human supervisory control concept" [13] are displayed in Figure 3: Plan, Teach, Monitor, Intervene, Learn. The interface between the robot and the human (in this context realized with the help of Augmented and Virtual Reality) serves the following purposes:

- Ensuring that the user knows "what is going on". This is described in the Situation Awareness concept [14] in three different Levels Perception, Comprehension, and Projection.
- Helping the user with sense-making [15] and decision-making [16].
- Helping to share the mental model between the human and the robot [17].

3. Implementation overview

In Figure 2 the concept of the Mirrorlabs architecture is displayed: A real robot is running in normal operation within a smart factory (testbed). The movement and sensor data are made accessible through the ROS platform and stored into a database. The so-called “snapshot” can be loaded into a ROS virtual machine. MirrorLabs has extended existing ROS with Unity bridge software and tested it with different robots and Mixed Reality hardware. After a VR or AR application has been built using Unity, a user can watch the recorded snapshot visualised using a virtual robot within Virtual Reality.

The software and tutorials are available under /url-http://mirrorlabs.eu/ and will be further maintained and extended. Currently, the framework has been tested for the following supported hardware: Robots: Universal Robots, Franka Emika Panda, Doosan, MiR100. Mixed Reality Devices: Hololens 1 and 2, HTC Vive, Oculus Quest 1 and Rift.

3.1. Unity3D

Unity is a game engine freely available for non-commercial usage (paid for commercial). It uses a combination of scripts (written in C#) and since the first release of Microsoft HoloLens 1, it is the officially recommended and until the release of HoloLens 2 the only supported development platform. Furthermore, it is the primary development platform used for most available VR applications. Leading to a broad variety of open-source projects, tutorials and a vibrant online community of developers. The platform used for AR/VR is Unity version 2019.4.

3.2. Robot Operating System ROS

With the variety of industrial robots commercially available, the transition between robotic installations executing a similar task may require unnecessary time for engineers to rewrite and adapt existing programs. To simplify this transition process, robots can operated using ROS. ROS itself enables engineers to write protocols in Python or C++ once and execute them on a broad variety of robots with significantly reduced transition times. To enable these reduced transition times, ROS uses standardized communication between its core algorithm and secondary algorithms operating the physical robots which only need to be developed once. For many robots these secondary algorithms are available online. Currently Ubuntu with Melodic v18.04 is supported.

3.3. AR and VR Devices

To utilize the vision of MirrorLabs, a variety of Augmented and Virtual Reality devices will be deployed, which are either standalone, wireless or cable bound. Both types of devices alter the vision of a user by either replacing the perceived image with an artificial one or altering the a users perception with additional augmented content. Some commonly used devices are HTC Vive, Oculus Rift and Oculus Quest for VR and Microsoft HoloLens 1 and 2 for AR.

3.4. ROS2Unity bridge

The framework consists of a Unity-Ros-Bridge (using ROS# and Rviz2AR) and aims to establish a generic data-communication bridge between ROS robot hardware and virtual robots in Unity3D (e.g. UR5 robot-arm or COMAU dual-arm manipulator), enabling visualization in Unity of ROS controlled robots, as well as controlling robots from Unity3d by virtual interactions.

3.5. Unity-ROS communication workflow example

In general, the MirrorLabs framework follows the systematic presented in above figure. Commands are initiated within a Unity-made application (HoloLens 2, Oculus Quest or Desktop) and forwarded using ROS#. The ROS environment then processes the command accordingly and publishes the resultant information (joint_states, odom, etc.) which is received by the unity application. Hence, within the unity application no robot specific calculations are made. Furthermore, from ROS the commands can be forwarded to a physical robot. As a result, limited computational resources available on most Head-Mounted-Devices [HMD] is sufficient since no “heavy” calculations are executed within Unity. To simplify the setup and usage of the ROS interaction within the unity-application a Graphical-User-Interface [GUI] is implemented. Currently, these have 2 distinct functions: First, the setup of the ROS# bridge (remote IP address and port of the ROS environment) and how to use it (ROS Mode). Second, the “RobotControl” panel, allowing a user publish control signals including predefined postures for the robot.

4. Summary

This is a preliminar introduction into the possibilities of the discussed ICT framework. There had been work specific usability requirements, remote collaboration and teleoperation among the different labs, which will be published separately. We hope to encourage the reader to try our framework and might even join the MirrorLabs team with deploying the software in their own labs.

Especially the use of Virtual and Augmented Reality within a production environment is an opportunity for student projects – it is at the same time intuitive, motivating, and creates learning benefit. The generation of multiple Mixed Reality visualizations of CPPS with student projects can be both an educational but also a research benefit if we regard the possibility to conduct user studies with the developed applications to deduct more general principles for human-machine interaction within industry 4.0. As numerous research institutions currently have a similar set of hardware (for example UR5, Hololens, HTC Vive, . . .) there is an opportunity to create comparable results and to share algorithms – both for education and research.

Furthermore, there is a benefit of being able to share snapshots of existing smart factory constellations and to “visit each other” remotely (especially useful for pandemic times). The achievement of this goal is only possible with the creation of a "digital twin mirror lab". In the long run, the platform should enable to share algorithms and data recordings, so that also remote maintenance scenarios can be explored between different research institutions.

As an additional benefit, the framework could help to initiate a smart factory research environment. Small and medium-sized enterprises or research institutes that start with this field of research could use the tutorials to set up supported hardware and deploy the software. This enables them to build an "analog twin mirror lab" of an already existing research lab constellation.

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Figure 4. INESC-TEC application with UR10

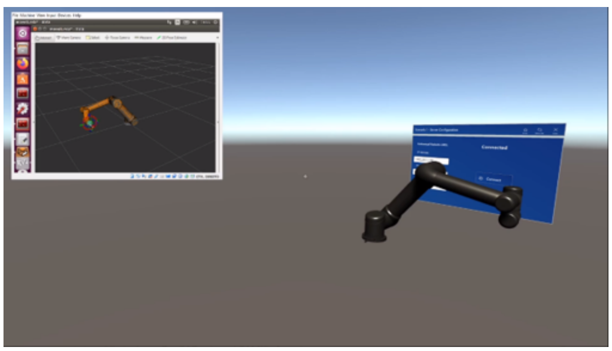

Figure 5. Virtual Machine Robot

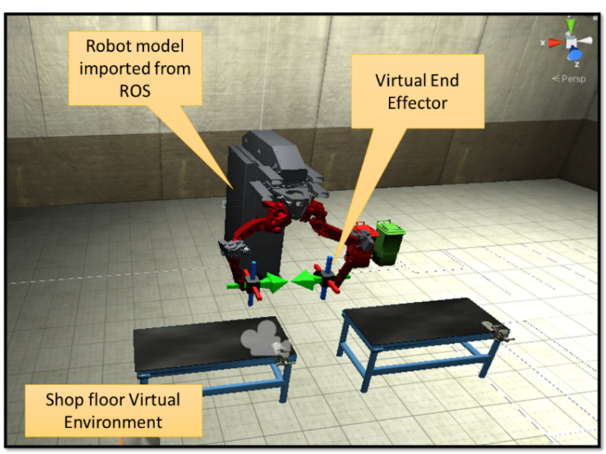

Figure 6. LMS dual arm robot

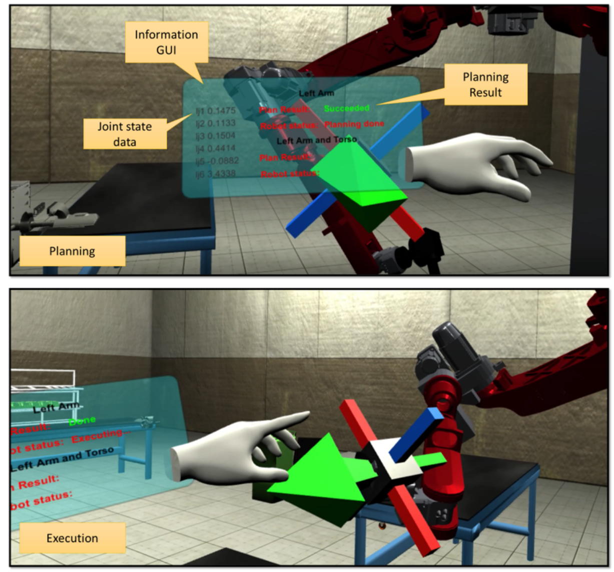

Figure 7. LMS virtual teach-in

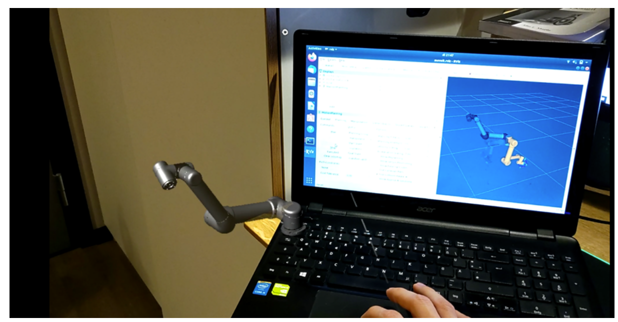

Figure 8. TU Delft application for Mini-robot desktop overview

Figure 9. TU Delft SAM XL application with Doosan Robot