R3-D3: (Photo-)Realistic Real-time Representations of Dynamic 3D-Driven Industrial Trainings

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Figure 1: Examples of (Photo-)Realistic Real-time Representation for Industrial Trainings in Extended Reality

Abstract

Extended Reality (XR) technologies offer transformative potential to enhance remote communication in industrial settings, particularly by facilitating immersive and interactive experiences that bridge physical distances. In this paper, we outline some of the main challenges based on the shortage of experts and deficiencies of the quality of technical skills, of personnel. We also outline how Extended Reality can help with technical training and communication in the industry to mitigate these issues. We outline three different representation formats for (photo-)realistic real-time representations and give concrete examples on how these representation formats can be utilized in dynamic 3D-driven industrial XR applications to offer remote training, remote expertise and quality control, and general remote communication. Finally, the paper proposes a pipeline and generic tool that can significantly simplify testing and experimentation in different use cases of industrial training.

CCS Concepts

• **Computer systems organization → Real-time system architecture**; • **Human-centered computing → Mixed / augmented reality**; *Interactive systems and tools*; • **Information systems →** *Multimedia information systems.*

Keywords

Immersive and interactive multimedia systems, 3D virtual environments, Social XR, RGBD, Point Cloud, Mesh, Stereo 3D, Education

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1 Introduction

The industrial sector faces major challenges due to a shortage of experts. Rapid technological advancements outpace the training of new professionals [14], creating bottlenecks for innovation and affecting operational efficiency and safety. This results in considerable skill deficiencies in numerous industry sectors, and identifying individuals with the appropriate skills has become a more daunting challenge [15], exacerbated by globalization and the increasing complexity of technical tasks.

In this paper, we outline some of the main challenges based on the shortage of experts and deficiencies of the quality of technical skills, of personnel. In addition, we outline how Extended Reality (XR) can help with technical training and communication in the industry to mitigate these issues. We believe that photorealistic representation is needed to enable high-quality trainings and communication for many use cases. In this paper, we outline three different representation formats for (photo-)realistic real-time representations (see Figure 1) and give concrete examples on how these representation formats can be utilized in dynamic 3D-driven industrial XR applications to offer remote training, remote expertise and quality control, and general remote communication. Finally, with this paper, we propose a generic tool and pipeline to support simple integration of the 3 formats in XR applications developed in Unity or WebXR and with this enable a wider accessibility of our technology for prototyping and testing.

2 Current Problems in Industry

The industrial sector is currently facing significant challenges, particularly a pronounced shortage of experts exacerbated by the rapid pace of technological advancement, which exceeds the rate at which new professionals can be trained and integrated into the workforce [14]. The lack of experts is not only a bottleneck for innovation, but also impacts the efficiency and safety of industrial operations. Companies are finding it increasingly difficult to fill specialized roles, leading to project delays and increased operational costs [13].

The problem of expert shortage is further enhanced by the limitation of industrial training facilities and the availability of teachers and instructors. In addition, traditional training methods often do not keep up with the evolving technological landscape, leading to a skill gap that hinders productivity and innovation [3]. Furthermore, the effectiveness of remote training is often compromised by distractions and lack of hands-on experience, which are crucial to mastering complex industrial tasks [3].

2.1 Immersive Industrial Training

Immersive technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), present a promising solution to the challenges faced in industrial training. These technologies offer interactive and engaging training environments that can simulate real-world scenarios, providing trainees with practical experience with the advantage of being in a fully controlled and safe environment [12]. This is particularly beneficial for training in areas that are difficult to access or have restrictions, such as hazardous environments or remote locations [6].

In general, incorporating XR into industrial training solutions can offer various benefits [5] in terms of reducing travel time (for example eliminating the need to travel to rare specialized training facilities), simplifying access to dedicated content (such as refresher courses) and easy access to dedicated expert remotely. Furthermore, past research indicates that work after XR trainings is "comparable to performance after training in a traditional setting" [5].

Finally, evaluating the effectiveness of immersive training environments is crucial to ensure that they meet educational objectives and provide value to learners [2]. This involves evaluating various factors such as user engagement, knowledge retention, and transfer of skills to real-world applications [2]. Rigorous evaluation methods, including both qualitative and quantitative approaches, are necessary to validate the effectiveness of training environments.

2.2 Shortcomings of existing solutions

Although it is clear that XR can offer many advantages to industrial trainings [5], the exact benefits and efficacy are not fully understood [18]. In addition, the different methods and how to apply them in order to create successful XR training applications are not always clear [11]. Furthermore, most of the current work focuses on single-user learning experiences in predefined virtual training scenarios. Thus, XR learning approaches often do not go beyond a simple computer generated VR approach, without considering real-life content used beyond simple simulated situations. However, given the complexity of many technical tasks fine details, photorealism and a personalized training might be needed. Given that user testing and trials are generally cumbersome and expensive, there is a strong need for technical solutions that can cover different use cases and can be easily deployed. utilized.

3 Use Case Examples

We believe that XR can support the lack of experts and improve remote interactions in industrial settings in 3 ways (see Figure 2): 1) remote teaching, 2) remote expertise and quality control and 3) remote communication. In this section, we describe the three use cases and give detailed examples of prototypes that address and support the use cases with XR technology.

3.1 Remote Teaching

One notable use case is the implementation of XR in soldering training, where traditional methods require the physical presence and specialized equipment. The prototype "You AR right in front of me" [7] presents a solution for remote soldering training using augmented reality (AR) glasses to render 3D photorealistic representations of instructors, enabling natural and engaging interactions between students and teachers. Another significant contribution is the "Plug and Learn: eXpeRtise at a Distance" platform [1], which integrates motion tracking and sensor monitoring to provide real-time feedback and ambient condition assessments during soldering tasks. Additionally, the paper "Title Hidden - currently under review" [11] introduces a prototype that utilizes 3D stereoscopic capture to blend the views of students and teachers in AR headsets, facilitating complex technical training tasks. These prototypes demonstrate the potential of XR to overcome geographic barriers, reduce training costs, and improve the quality of industrial training by offering a more immersive and interactive learning experience.

3.2 Remote Expertise and Quality Control

The example of 3D stereoscopic capture and rendering in AR glasses can also be applied to complex technical tasks for support by remote experts and to check manufacturing quality. This approach, as detailed in [10], involves capturing high-resolution 3D stereo images from a microscope and rendering them in AR glasses, allowing for detailed and immersive interaction between students and experts. This method not only reduces travel time and costs associated with traditional training, but also facilitates frequent refresher sessions and real-time quality evaluations. Another significant prototype, presented in [17], demonstrates a multi-user XR collaboration system over 5G infrastructure, where an AR user receives remote assistance from VR experts. This system improves the effectiveness of industrial operations by providing immersive telepresence and social interaction, ensuring that complex tasks are tackled collaboratively and efficiently. Both prototypes underscore the potential of XR technologies to transform industrial tasks by offering scalable, flexible, and highly interactive solutions that bridge the gap between remote locations and expert knowledge.

3.3 Remote Communication

Extended Reality (XR) technologies offer transformative potential to enhance remote communication in industrial settings, particularly by facilitating immersive and interactive experiences that bridge physical distances. For instance, the "Virtual Visits: Life-size Immersive Communication" prototype [4] presents a system that

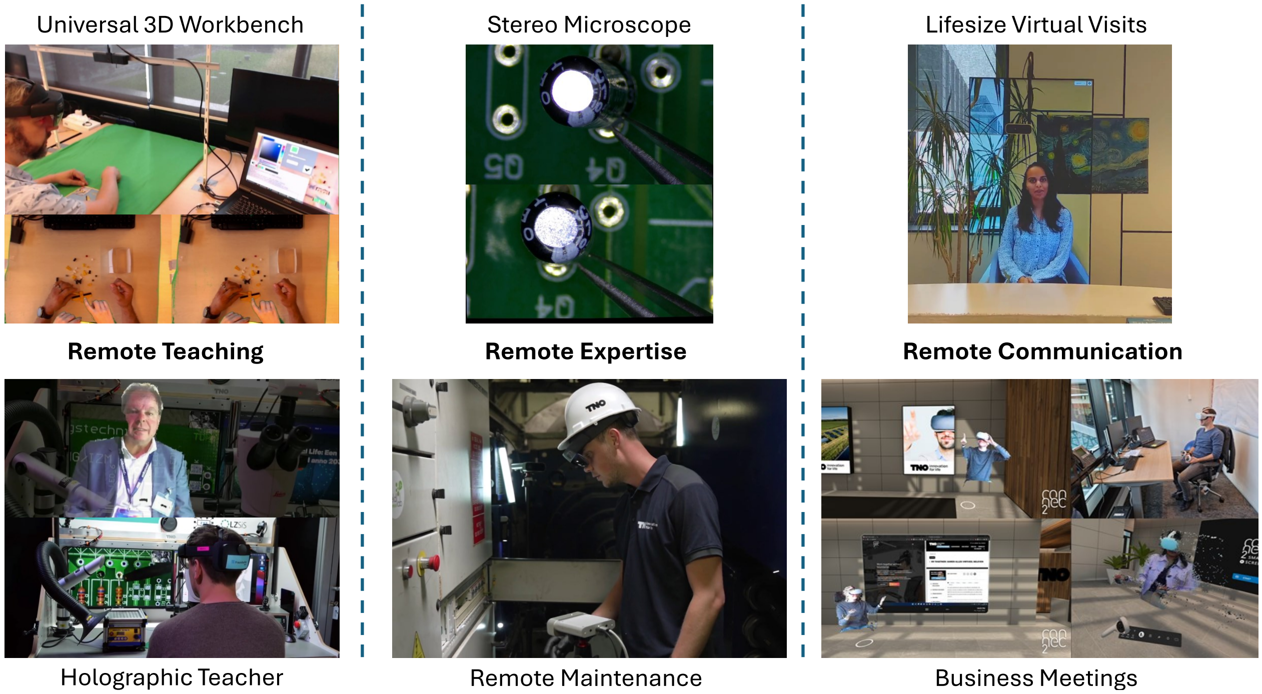

Figure 2: Example of Use Cases in Extended Reality for Industrial Trainings and Communication

enables life-size augmented reality (AR) video calls, enhancing social presence and natural interaction (including limited eye gaze) through 3D user capture and rendering on large displays. This system, originally designed for elderly care homes, demonstrates the feasibility of high-quality natural communication in remote settings, which can be adapted for industrial applications to improve remote team collaboration and training. Similarly, the study "Engagement and Quality of Experience in Remote Business Meetings: A Social VR Study" [16] explores the use of VR for remote business meetings, highlighting the importance of photorealistic avatars and immersive environments in maintaining engagement and communication quality. These prototypes exemplify how XR can be leveraged to create realistic and engaging remote communication platforms, which are crucial for industrial training and operations, especially in environments that are hazardous or difficult to access. By integrating XR technologies, industries can enhance remote collaboration, reduce travel costs, and ensure continuous training and support, thus improving overall efficiency and safety.

4 Universal Modular XR Learning Pipeline

In order to address and test immersive industrial training methods, technological concepts and tools must become more accessible and easier to use and deploy. To allow for this, we propose a modular pipeline (see Figure 3) for dynamic 3D-driven realistic real-time representations of humans and objects. Our modular pipeline design is based on [8] and is shown in Figure 3. The upper left quadrant of Figure 3 refers to the capture devices supported, their characteristics, and the data domain handled. The bottom left quadrant shows the capture module as a genic view of its basic functionality. The middle of Figure 3 (WebRTC block) shows the transmission and data handling to cope with audio, video, and metadata. Finally, the rendering is indicated on the right of Figure 3. We currently provide implementation examples (including rendering shaders) in Unity and WebXR. Ultimately, we support different representation formats, as shown in Figure 1 and our pipeline consists of approximately 3 parts explained below.

4.1 Capture

The upper left quadrant of Figure 3 refers to the capture. In order to support the different capture and representation formats (see Figure 1), we support a variety of example capture and processing modules. Firstly, we support various color and depth sensors (RGBD) that can capture 3D representations of users and objects that ultimately can be rendered as a 3D mesh or a 3D point cloud. The raw RGBD video will be further processed (image quality improvements and user to background segmentation), converted into a 2D video transmission format [8, 9]. Secondly, we support 3D stereo sensors to allow stereoscopic capture and rendering. Finally, we allow capture with arbitrary webcams and machine learning based foreground background removal process to transmit and render humans (for example as flat sprite texture in 3D space). Attached to each sending modalities we support a modular set of image enhancement and processing modules. Important in our approach is that each representation formats results in a 2D image (video) format that is provided to other applications (for example unity) via a virtual

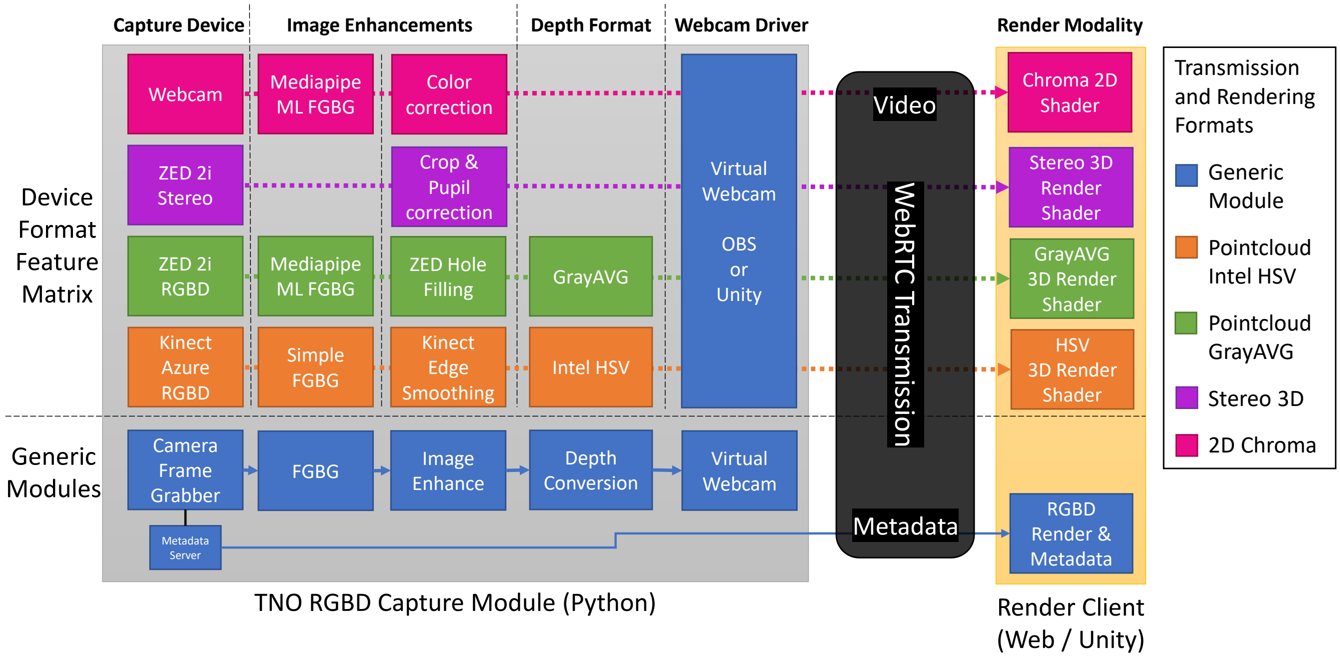

Figure 3: Universal Modular Extended Reality Pipeline to Support the Different Representation Formats

webcam driver. This simplifies using our capture and representations in different applications. Furthermore, our 2D video approach can be encoded and transmitted with existing (highly efficient) 2D video encoding techniques.

4.2 WebRTC Transmission

The middle of Figure 3 (WebRTC block) shows transmission and data handling. Our pipeline uses three types of data: audio, video, and metadata. Audio and video are transmitted over the WebRTC media channel using standard compression technologies such as Opus for audio and H.264 or VP8/9 for video. A 3D stereo image consists of video data with one image per eye (see Figure 1). For chroma-based webcam images, the image replaces the background with a uniform green color. For RGBD data, we follow the approach in [8]. Metadata, transmitted via the WebRTC data channel, includes positions in the 3D space and camera intrinsics for RGBD video. We support WebRTC implementations like Rainbow API[1] and AioRTC[3] to enable communication between clients in Unity and WebXR. These implementations can be easily adapted to other transmission methods.

4.3 Rendering in Unity and WebXR

The rendering modalities are depicted on the right side of Figure 3. The implemented render modules simply work as an opposite projection technique to the capture functionality. Practically, this means different implementations of the graphics shader in Unity and WebGL. In case of stereo or chroma 2D video, the images are rendered as billboards with a chroma transparency effect (Note: Stereo images are mapped to each eye) In case of RGBD video users or objects are rendered in space (by mapping each pixel into space based on the camera properties from the metadata and a geometric transfer function) [8].

5 Discussion and Conclusion

The lack of experts and the skill gap pose significant challenges to many industries. In this paper, we provide further details on this problem and outline how immersive training experiences and XR mitigate this problem, while giving specific examples. However, full benefits and restrictions of different XR approaches and immersive photorealistic representation format are not fully explored, raining the need to new solutions that can easily be adopted and deployed. In this paper, we propose a Universal Modular Extended Reality Pipeline to Support the Different Representation Formats with the following benefits: A) Support of various representation formats and image processing enhancements; B) easy extendibility; c) simplified adaptation and accessibility for different use cases and XR implementations.

Although we propose a generic tool and pipeline, we do not expect all formats to work with all use cases. There needs to be a careful matching. Our proposed pipeline and generic tool can significantly simplify testing and experimentation in different industrial training use cases.

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[1]https://developers.openrainbow.com/, "Because why not?"[2]
[3]https://github.com/aiortc

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