Challenges of XR Transitional Interfaces in Industry 4.0

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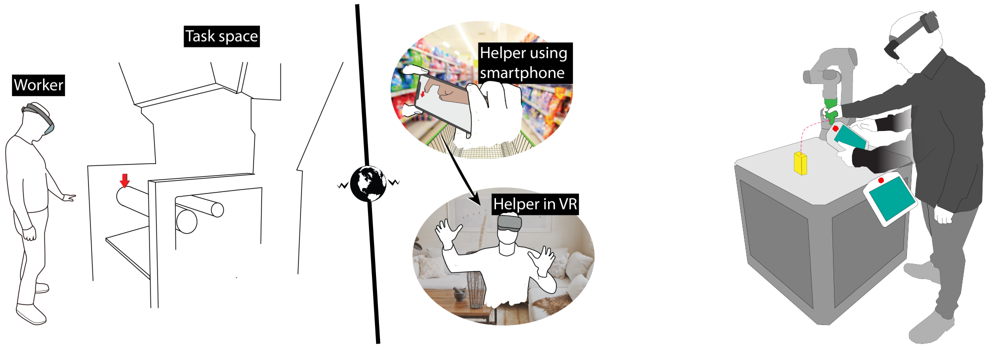

Fig. 1. Transitions, such as going from virtual to augmented reality, are of particular interest in Industry 4.0. For example, scenarios in remote assistance (left) and human-robot collaboration (right) involve transitions between the Reality-Virtuality classes. In the remote assistance scenario a helper transitions from using a smartphone to using VR depending on the physical context (supermarket or living room). In the human-robot collaboration scenario, an operator transitions from perceiving augmented reality waypoints on the end-effector to looking at the teach pendant in reality.

Past work has demonstrated how different Reality-Virtuality classes can address the requirements posed by Industry 4.0 scenarios. For example, a remote expert assists an on-site worker in a troubleshooting task by viewing a video of the workspace on a computer screen, but at times switches to a VR headset to take advantage of spatial deixis and body language. However, only little attention has been paid to the question of how to transition between multiple classes. Ideally the benefit of making a transition should outweigh the transition cost. User support for Reality-Virtuality transitions can advance the integration of XR in current industrial work processes – particularly in scenarios from the manufacturing industry, where worker safety concerns, efficiency, error reduction, and adhering to company polices are critical success factors. Therefore, in this position paper, we discuss three scenarios from the manufacturing industry that involve transitional interfaces. Based on these, we propose design considerations and reflect on challenges for seamless transitional interfaces.

CCS Concepts: • **Human-centered computing** → **Virtual reality**; **Mixed / augmented reality**.

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Additional Key Words and Phrases: XR, Industry 4.0, Transitional Interfaces, Cross Reality

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1 INTRODUCTION

Industry 4.0 has been driving the adoption of XR technologies in the manufacturing industry to support a variety of processes and tasks, such as skill acquisition, digital and remote assistance, and human-robot collaboration. Past research has demonstrated that individual steps of these processes and tasks can be supported by interface technologies with varying degrees of virtuality on the Reality-Virtuality (RV) continuum [20]. Hence, if we were to support full work processes, users would have to interact with *Transitional Interfaces* (TIs) as they move in the RV-continuum. However, in practice, researchers frequently explore a single interface technology to address only a part of a process, and ignore its overall integration into larger workflows. TIs are not explicitly considered in the design, or not considered at all. Arguably, a more holistic perspective of the various technologies involved and transitions in the RV-continuum may lead to more successful adoption of XR technologies in industry.

In this paper, we present three scenarios from the manufacturing industry to illustrate work processes where TIs can be beneficial (Figure 1). We then attempt to define the key characteristics and design considerations of TIs, based on the presented scenarios. To conclude, we identify challenges for designing seamless TIs.

2 RELATED WORK

Milgram et al.'s Reality-Virtuality continuum provides the theoretical basis for TIs, describing how the ratio of real vs. virtual content can be considered on a continuum between fully physical and fully virtual realities [20]. We specify each point on the continuum as having a particular "degree of virtuality" and TIs allow users to move between these points. As Billinghurst pointed out in his 2015 survey, hybrid interfaces that involve multiple realities are increasingly becoming important – to connect AR to GUI, ubiquitous computing, VR and other realities [5]. A seminal example of a TI is the Magic Book [6], where a physical book is extended to access augmented content and to enter a full VR scene. Knibbe et al. explored methods to ease the exit from a full VR to the physical reality [17], noting that participants find the abrupt exit disorienting and that both mental and physical phases of transitions are important. Slater et al. described how both the entry into and exit from VR is easier by using the same virtual environment as the physical environment [32]. Pfeuffer et al. investigate eye-gaze to activate and interact with in-situ AR information in the world, as a way for users to transition from reality to AR at a glance [24, 25].

Research has investigated collaborative virtual environments where multiple distinct realities, such as AR by projection, mobile AR, and VR are fused in one shared experience [13, 16, 23]. This allows, e.g., a non-headset user to quickly enter and leave the virtual experience, e.g., by simply starting an app on their phone for AR. XRDirector mixes several VR and AR realities as a role based immersive authoring tool [21]. Piumsomboon et al. investigated hybrid XR environments for remote collaboration, [26–29], where one user in VR and another user is in AR.

Industrial scenarios have long been identified as a main application domain for XR technologies, ranging from medical, manufacturing, repair, robot to military domains [3]. Several research efforts have demonstrated the differences and advantages of AR and VR for worker assistance [8, 11, 15]. These show the utility of systems with various degrees of virtuality, but leave open the design of intermediate transitions.

3 EXAMPLE SCENARIOS IN THE MANUFACTURING INDUSTRY

Based on our past industry collaborations, we describe three scenarios where TIs can be considered beneficial. Central questions include what technologies are relevant, what purpose they serve, and how the transition from one degree of virtuality to another is realized to ensure effective work processes.

3.1 Scenario 1: Remote Assistance

Research on XR technology for remote assistance on physical tasks is well-established [1, 29, 31]. A worker, who encounters a physical problem with an industrial machine, may switch from reality to AR to get remote assistance while the remote helper may transition from a smartphone interface to immersive VR for a virtual site visit. Both of the aforementioned helper interfaces support navigating a 3D reconstruction of the worker's space, however, the interaction techniques for navigation and the level of immersion differs. A helper may require the ability to switch back and forth between levels of immersion and thus interfaces depending on the social and physical context. For instance, the helper may receive an urgent call from the worker in an everyday context, where fully immersive VR interfaces and interactions are not (yet) socially acceptable (e.g., supermarket), so she uses her smartphone and touch gestures to provide remote assistance temporarily [30]. Later at home, she turns her smartphone into a VR device by changing remote assistance mode in the phone's UI and placing it in a headset. Then, she continues the ongoing remote assistance session in VR.

3.2 Scenario 2: Human-Robot Collaboration

An operator programs a collaborative robot (cobot) via demonstration by manually guiding the robot's end-effector to desired waypoints while seeing its computed path through an AR HMD and saving desired positions through interaction with a mid-air menu [2, 12]. As end-effector positions that are indicated in this way cannot be very precise, the operator may make fine adjustments to each saved position through the teach pendant, which is the interface for state-of-the-art cobots consisting of a touchscreen tablet. This represents a transition from AR to reality, which may be achieved by tracking the user's gaze and hands within the robot's coordinate system to detect visual focus on and interaction with the teach pendant vs. the end-effector. Additionally, the user may transition to VR for programming a virtual robot (i.e. digital twin) whenever the physical robot is unavailable (e.g., the robot is running in production or not located nearby) [19].

3.3 Scenario 3: Training

XR technologies have been widely applied in training and digital assistance recently [4, 9, 14]. Winther et al. demonstrated that training with a VR application facilitates workers' skill acquisition in industrial contexts without having to be present at their workspace [34]. In contrast, according to Webel et al., AR training is advantageous because users can engage in learning at their place of work increasing the probability of successful adaptation after practice [33]. Thus, VR may be more suitable for cost-efficient training when workers are not able to access manufacturing facilities, whereas AR may provide better opportunities to learn sophisticated skills that involve manipulating real-world objects and dexterity. Imagine a TI that combines the strengths of AR and VR in Augmented Virtuality (AV): The user's proximity to real-world tools is used to transition from VR to AV, thereby enabling manipulation of the tools in particular training steps and improving skill acquisition.

4 DEFINITION AND DESIGN CONSIDERATIONS FOR TRANSITIONAL INTERFACES

Based on previous work, we understand TIs to have the following three defining properties:

1. TIs involve transitions along the Milgram and Kishino's Reality-Virtuality continuum [20]. This can include minimal transitions (e.g., activating an AR filter in Snapchat) as well as obvious transitions between degrees of virtuality (e.g., putting on a VR headset to go from the real environment to VR).
2. TIs can be supported on the same device (e.g., AR, AV and VR in the same video see-through HMD), in contrast to cross-device interaction [7], which implies a change of devices or simultaneous use of multiple devices.
3. TIs are strictly tied to a task. An interface is only "transitional", if the user transitions from one point to another on the Reality-Virtuality continuum while pursuing that same task.

In the context of the industry scenarios presented above, we identify the following design considerations for TIs:

- **Transition Control:** Transitions may be triggered explicitly by the user, e.g., by switching modes in the UI (Scenario 1), or implicitly based on context inference, e.g., the user's environment or task (Scenario 2 and 3).
- **Transition Distance:** The distance a transition covers on the Reality-Virtuality continuum may impact the user's experience and ability to effectively continue work on the task at hand. Thus, a transition directly from immersive VR to the real world, may be assumed to be more disruptive, than a transition from VR to AV Maintaining a continuity of information between degrees of virtuality can contribute to a seamless experience.
- **Locality:** Transitioning from the real world to the virtual can allow us to quickly change places, e.g., switching from the local office space to a remote production site represented through its digital twin (e.g., Scenario 1).
- **Physicality:** The varying integration of real-world content into the virtual workspace in form of haptic props, physical products, or entire physical workspaces is important in many industry scenarios. For instance, the integration of haptic props in VR training, which results in a transition from VR to AV, is important for effective skill acquisition in Scenario 3.

5 CHALLENGES

In this section, we discuss three challenges as major factors to achieve seamless TIs.

Interaction Techniques. Applications need intuitive interaction techniques to support seamless transitions across the RV-continuum. First, interaction techniques should be consistent through different degrees of virtuality, meaning that knowledge of how to interact in one degree of virtuality should be applicable in another degree of virtuality. Moreover, it is important to explore input modalities that do not impose high costs on users. For instance, requiring users to grab different input devices for every transition can be inefficient and present an additional obstacle for the adoption of TIs. In that case other input modalities that do not require handheld devices, such as gestural input and eye-tracking, can contribute to seamless transitions.

Adaptive User Interfaces. TIs can adapt to the user's context. Applications should be aware to some extent of aspects such as the user's environment, task, and actions, and leverage this data to improve interaction and propose transitions when appropriate. For instance, a successful TI should only propose a transition from MR to VR if that is adequate, considering the current user's task, and that spatial requirements for a good VR experience are met. Existing research and our scenarios have demonstrated how different context categories such as the user's task [18], environment [35], and actions [10] play an important role in XR user interfaces.

Visualization Techniques. In a collaborative setting, visualization techniques can render users aware of their collaborators' current position, degree of virtuality, and transitional state in the RV-continuum. This is important to ensure a correct mental model of collaborators' communicative capabilities, e.g., an AR user on a smartphone has a smaller range of non-verbal social cues than a user fully immersed in VR. Further, the appearance of user representations and content should be considered across the RV-continuum. An example of this from remote assistance research is how 2D annotations made by the remote helper on a smartphone are interpreted in the worker's 3D space [22, 31].

6 CONCLUSION

The number of devices supporting different positions in the RV-continuum increases rapidly, raising questions on how we can design TIs that reduce transition costs and provide seamless experiences to the user. In this paper, we looked at several industrial scenarios that benefit from TIs and propose a definition, design considerations, and challenges. We hope that this will stir interesting thoughts at the workshop, and that it will lead to a better understanding of TIs and eventually to their better integration in industry.

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