Experiences with Off-The-Shelf Solutions for XR-supported Knowledge Work

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ABSTRACT

XR has the potential to be an effective tool for knowledge work. The recent XR head-worn displays, along with productivity-oriented software tools, are being actively researched for innovative applications in this field. In this paper, we reflect on the use of off-the-shelf XR devices in the scope of studies focusing on supporting knowledge work. The studies focus on the long-term effects of using virtual reality (VR) in workplace settings, the impact of using extended reality (XR) devices for knowledge work in public settings as well as on using XR for supporting monitoring and teleoperation of automated vehicles. The insights from these studies underline the necessity for further development in XR technology, focusing on ergonomics and user-friendly design, to fully realize its potential in enhancing knowledge work productivity, and user comfort.

Index Terms: Human Computer Interaction—Knowledge Work—Extende Reality;

1 Introduction

Extended Reality (XR) offers new possibilities for knowledge work and can transform conventional office work into a flexible work environment where information workers can create a flexible workspace that adapts to their needs. It envisions a future where office work is conducted using portable devices and immersive Head-Worn Displays (HWDs), thereby enabling a location-independent work experience and an enriched work environment [20, 21].

XR headsets can be used to render large, ergonomic virtual display spaces, thus meeting the needs of knowledge workers and overcoming the physical and ergonomic limitations of traditional multi-display setups [25]. Additionally, Pavanotto et al. [26] have shown that a hybrid approach, which integrates virtual and physical monitors, presents a favorable trade-off between the reliability of physical monitors and the extra space of virtual monitors. XR environments for knowledge workers also have the potential to enhance productivity while reducing distractions and stress by immersing users in the environment [21]. Another crucial aspect that facilitates knowledge work in XR is the utilization of various interaction techniques including working with 2D content in 3D, eye-tracking, spatially tracked pens, and using immersive HWDs and virtual enhanced keyboards [20]. For example, Biener et al. [17] explored the use of VR for enhancing presentation authoring in mobile settings (PoVRPoint), integrating pen- and touch-based interactions on mobile devices with VR capabilities such as eye-tracking.

Hence, integrating XR into knowledge work has the potential to represent a significant shift from traditional office environments to more dynamic and flexible workspaces. However, challenges to realizing this shift persist. Within this work, we aim to first review recent XR technology for supporting knowledge work. Then, we reflect on the experiences with selected XR devices through existing studies, which include examining the long-term effects of VR, working in XR environments in public places, and supporting monitoring and teleoperation of remote automated vehicles.

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2 Off-the-Shelf XR Hardware and Software

In the field of XR, numerous devices and software solutions are shaping the future of knowledge work. This section categorizes these solutions into hardware and software, providing a clearer overview to understand and compare the various off-the-shelf options.

2.1 XR Hardware Solutions

In the field of XR technologies, there is a diverse range of devices, yet in the scope of this work, we will highlight recent devices and their key features that might be employed for knowledge work.

Lenovo ThinkReality A3 [13] glasses enable the creation of a custom workspace with multiple monitors, potentially boosting knowledge worker productivity. These glasses also keep sensitive data more private, ideal for working with confidential information in public while maintaining ergonomic comfort.

HoloLens 2 [6] can support work across various fields such as education, healthcare, engineering, and manufacturing.

Nimo Planet [11] glasses is an AR headset designed as potential laptop replacements, with a focus on enhancing productivity with features like multiple virtual screens.

Spacetop [12], the "First AR laptop", introduces a novel concept by blending the laptop experience with AR technology, offering a user-friendly workplace solution designed to support and empower users in their daily tasks.

The **Bigscreen** [4] VR headset combines micro OLED displays and pancake optics. Due to its relatively low weight (127 g), it might potentially better address ergonomic issues during long-term work compared to existing VR headsets like the Meta Quest Pro (722 g).

HTC Vive XR Elite [15] features high-resolution screens (1920x1920 px) and color passthrough, and its modular design promises a portable user experience. This device offers a range of software features designed to enhance the productivity of knowledge workers.

Varjo XR-4 Secure Edition [14] is a headset with video pass through. Moreover, it promises an immersive experience with "industry-leading visual fidelity", which could be particularly beneficial for knowledge work.

Meta Quest Pro [9] offers features like hand and keyboard tracking, which can be valuable tools for knowledge work.

Apple Vision Pro [3], "Apple's first spatial computer", is advertised to support productivity by allowing to arrange of existing applications in the physical environment, supporting multitasking, and hand-based interaction. In addition, EyeSight, a pass-through view on the user's eyes, could potentially facilitate collaborative work without the need to repeaditily put on and off the headset. It also integrates with Magic Keyboard and Magic Trackpad, allowing users to create a customized workspace which can be beneficial for knowledge workers.

2.2 XR Software Solutions

This subsection covers software solutions designed with the aforementioned hardware, or independently, to potentially maximize the productivity of knowledge workers.

Mirage [10] is a software compatible with HoloLens 2, that allows to mirror a virtual desktop on the HoloLens 2.

VIVE Desk Beta [5] allows the creation of flexible multi-screen setups in a virtual space, integrating with physical tools through its color passthrough feature, and is compatible with HTC Vive.

Meta Horizon Workrooms supports collaborative tasks in a virtual meeting room with tools for presentations and collaborative brainstorming such as virtual whiteboards, multiple virtual screens, spatial audio, customized avatars, and environments.

Similarly, **Immersed** [8] features virtual windows in a single-user mode as well as virtual meeting rooms, multi-screen sharing or remote whiteboarding in a multi-user mode. It is compatible with multiple headsets such as the Meta Quest Pro or the VIVE XR Elite.

Virtual Desktop [7] also allows access to PCs in VR and is compatible with various VR devices like the HTC VIVE XR Elite and Quest Pro.

In summary, the rapid advancements in off-the-shelf XR hardware and software, as showcased by the latest AR and VR devices, have the potential to support knowledge work, offering professionals innovative tools to enhance productivity and collaboration in a dynamic virtual environment.

3 Insights about XR Productivity Solutions

To understand the practicability and impact of XR technologies in the knowledge work context, our analysis primarily focused on the insights from papers by Biener et al. [16, 18, 19] and Kalamkar et al. [22, 23]. The initial work by Biener et al. focuses on the long-term effects of VR in knowledge work, assessing user experiences [19] and user behavior [16] over extended periods. Another study explored XR users working in public spaces, emphasizing user and bystander perceptions [18]. Finally, the work by Kalamkar et al. [22,23] focuses on investigating if VR-HWDs can be a suitable alternative to physical displays in remote monitoring and teleoperation of automated vehicles.

3.1 Long Term Effects of VR

The potential advantages of knowledge work in VR become apparent when it is feasible to engage in it for an extended duration of time. However, to investigate the impact of prolonged VR work Biener et al. [19] conducted a study (n=16) in which participants worked in both a VR environment and a physical desktop setup for an entire week. The study aimed to quantify the effects of a VR-based work environment and compare it to a desktop-based one. For the study, an Oculus Quest 2 and a Logitech K830 keyboard with an integrated touchpad were used and the integrated browser was utilized to remotely connect to a Windows machine. Their finding revealed that while VR technology offers potential benefits for knowledge work, such as improved focus, it also induces higher task load, frustration, and visual fatigue compared to physical setups. Usability concerns and comfort issues like headset weight affected the user experience.

3.2 Video Analysis of Behavioral Patterns in VR

A follow-up analysis of the video data gathered throughout the study (n=16) [16] revealed that participants seemed to adapt to VR over time, as, for example, they adjusted and supported the VR HWD less at the end of the week. Still, challenges in routine tasks persisted, such as eating, drinking, or using physical objects, highlighting the current limitations of VR technology in potentially impacting user productivity and overall experience in knowledge work environments. Despite these challenges, many were open to future VR use for work, conditional on advancements like lighter, higher-resolution HWDs and ergonomic improvements.

3.3 Working in XR Environment in Public Places

The advantages of XR seem especially valuable in crowded or confined spaces like public transportation or coffee shops. Therefore, Biener et al. [18] examined in another study (n=18) how XR users feel when working in public spaces and how others react to this relatively uncommon sight. In the study, an HP Envy laptop served as the baseline for both AR and VR conditions. The AR setup involved Lenovo ThinkReality A3 smart glasses connected to the laptop, using Lenovo's Virtual Display Manager software to manage multiple virtual displays. For VR, the Meta Quest Pro, coupled with the "Immersed" app was used. They found that it may increase users' feelings of safety when they can see their virtual surroundings, as users felt safest without XR followed by AR and least safe in VR. Therefore, it is surprising that most participants did not use passthrough windows in VR.

3.4 Remote Monitoring and Teleoperation in VR

In a series of three studies, Kalamkar et al. compared a physical multi-monitor setup for monitoring and teleoperation of remote automated vehicles with a replicated environment in VR [22, 23], both using a software was custom-made for the study. Notably, they found in a first study (n=16) that a VR interface using the HTC VIVE Pro 2 [2] replicating the physical interface did not outperform the physical interface. A second study (n=24) further quantified that the perceptual and ergonomic problems induced by VR outweigh its benefits. The third user study (n=24) was a replication of the second study, but additionally employed a newer generation headset (Oculus Quest Pro in addition to a Vive Pro 2). The results indicated that this newer-generation VR headset had the potential to catch up with the current physical displays in terms of reaction time, task load, and user preference.

4 Lessons learned with selected devices and software

The lessons learned from these studies can be examined from two perspectives: hardware and software. From a hardware standpoint, a key area of development has been in the design of VR HWDs, with an emphasis on making them lighter and more comfortable. The weight and comfort of the HWDs have been an issue in all previously mentioned studies. While there have been advancements, as seen in the Meta Quest Pro's improved balance compared to the Oculus Quest 2 [1], issues such as pressure on the forehead and the absence of a top strap for better weight distribution suggest that there is still room for improvement. Also looking at other current devices like the HTC Vive XR Elite or the Varjo XR-4, it is evident that achieving an optimal balance between weight, comfort, and functionality remains a challenge. Another significant consideration is the ease of access to the face, an aspect emphasized in the studies for routine tasks such as eating, drinking, and rubbing eyes [16]. The HoloLens 2, for example, addresses this with its lift-able visor design. Similarly, the Meta Quest Pro, when used without the light blocker, offers somewhat easier access to the face. These comparisons underline the ongoing challenge of achieving an ideal balance between weight, comfort, and functionality in VR HWDs.

From a software perspective, we have seen that off-the-shelf applications such as "Immersed", or the built-in software of the Quest 2 and the Lenovo Think Reality A3 are usable for knowledge work, but beyond simply providing a workspace, XR-software could integrate features that enhance ergonomics and user comfort. There is also a need for features like relaxation modes to enhance the well-being of knowledge workers. In addition, our long-term study [19] reveals that while integrating hand tracking with HWDs is innovative, it sometimes encounters functional issues, similar to the challenges faced when tracking physical keyboards to visualize them in VR. Furthermore, the integration of passthrough in VR requires further research as participants in our public study [18] rarely used it, even though awareness of the physical surroundings seems to increase their feeling of safety.

5 Conclusion and Future Work

Current XR devices offer diverse and innovative solutions for knowledge work, incorporating a range of VR and AR technologies designed to enhance productivity, collaboration, and user engagement in various environments. Despite significant advancements in XR software and hardware engineering, there are still technical challenges that rely on commercial off-the-shelf hardware and software development [24], specifically, working in XR will be demanding on the user as it depends on many factors such as the size, weight, and quality of the HWD, its limited FoV, latency, and the authenticity of the representation of the world around users [18, 19]. Consequently, the development of more ergonomic and user-friendly XR hardware remains a priority to facilitate widespread adoption. Further studies on integrating XR with technologies like Artificial Intelligence (AI) show potential for enhancing productivity in knowledge work. For instance, XAIR, a framework for integrating Explainable AI (XAI) with AR, aims to foster transparent and intuitive AI interactions within AR environments. When this framework is applied to knowledge work in XR, it can significantly enhance user understanding of AI systems in XR, thereby improving decision-making and user interactions with intelligent XR systems [27].

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