Virtual Displays for Knowledge Work: Extending or Replacing Physical Monitors for More Flexibility and Screen Space

Leonardo Pavanatto*, Doug A. Bowman

Center for Human-Computer Interaction, Department of Computer Science, Virginia Tech, USA

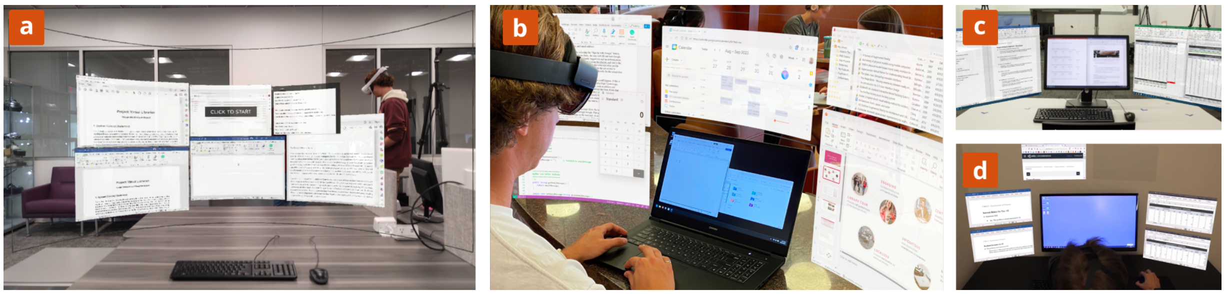

Figure 1: Examples of virtual display usage include (a) creating monitors with large spaces; (b) extending laptop screens when working at locations without display infrastructure; (c) adding extra monitors for quick glancing at content; and (d) visualizing a large amount of information by using dynamic interfaces.

Abstract

In this paper, we explore the potential of virtual displays in supporting knowledge work, focusing on scenarios where conventional physical monitors fall short. Our research investigates the feasibility and productivity costs of extending or replacing physical monitors with augmented and virtual reality displays. We present three compelling use cases, illustrating how virtual displays enhance flexibility, adaptability, and customization in remote and diverse work settings. Lessons learned from user studies highlight hardware and interface design challenges, emphasizing the need for larger resolution and field of view in head-worn displays (HWD). We conclude the paper with research opportunities and a call to address the evolving demands of knowledge work interfaces.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Empirical studies in interaction design

1 Introduction

Knowledge work is undergoing a transformative shift, marked by changes in how, where, and when people work. Technological advances and the COVID-19 pandemic pushed a rise of mixed approaches where workers access their workspace in the office, in the field, during transportation, or simply from home. While this work of "thinking for a living" provides workers more flexibility, they also demand interfaces that seamlessly adapt to diverse tasks and contexts. Such adaptations are not always possible when working with conventional monitors, as they are constrained by physical characteristics that cannot be modified.

Physical monitors are known for displaying content with high-quality, and have been the primary means to conduct knowledge work for decades. However, they also have limitations, such as occupying physical space (which may not be available in certain work locations), reduced mobility (they are either bulky items that take effort to transport and time to set up, or have a reduced screen size), reduced flexibility (the screen will always be the same size and aspect ratio, and the display is always visible even when not used), reduced security (easy for people in the room to look at it), and reduced scalability (need to have multiple monitors if in need of a large setup). These issues make them less ideal for use cases such as completing work from out-of-office, where monitor infrastructure can be reduced or unavailable, or for people with disabilities, who may require more customization. An alternative we have been exploring is to use virtual and augmented reality technologies to extend or replace physical monitors with virtual ones.

Virtual displays offer the unique ability to present content without rigid physical space constraints. As seen in Fig. 1, they can replace or extend physical monitors and be used for various tasks. We define them as interfaces that:

1. are displayed through an augmented or virtual reality (AR/VR) head-worn display (HWD);
2. extend or replace a physical monitor of a personal computer;
3. allow access to the computational capabilities of a personal computer; and
4. can display two-dimensional windows or monitors, on either a plane or any 2D manifold (e.g., a cylinder).

This paper briefly discusses our vision and findings on virtual display research. Our objective is to bring forth an overview of the approach that can help future researchers, designers, and developers further enhance our understanding of this approach. We describe three use cases that we believe are ideal to illustrate the advantages of using virtual displays and the limitations of physical monitors. We then proceed to discuss the lessons we learned through user studies, and finally, acknowledging that there is still much research to be done, discuss some open questions and opportunities for future research.

2 Use Cases

We present three use cases/design scenarios focusing on three distinct benefits of virtual displays: they can be used in places with a lack of structure and an easy setup; they can simplify workflows and

*e-mail: lpavanat@vt.edu

reduce duplicated hardware; and they can support more customization for handling disabilities.

Knowledge Work in a Remote Location A knowledge worker called John finds himself working in an airport terminal due to a layover. He uses this time to get ahead on his work, which includes managing information across multiple documents and analyzing data. External monitors are unavailable in this transient setting, and even if he had one, it would be impractical to set it up in a small space and a short time. Equipped with an AR HWD, John extends his laptop screen effortlessly, creating a workstation with three virtual monitors around his laptop. The flexibility of virtual displays eliminates the need for physical space and setup time, and allows him extra screen real estate, which can increase his productivity.

Power Users in Hybrid Work Situations Meet Alex, a data scientist who alternates his workweek between home office and in person. While Alex possesses multiple monitors in his company office, he only has a single external monitor in his home office, which the company did not provide. The dynamic situation of moving back and forth between the two locations makes it impractical for him to move monitors back and forth, and he requires all the space he can get to manage many datasets and tools. The company equips Alex with a cutting-edge VR HWD; the decision enables him to achieve a large canvas (equivalent to six conventional monitors), which he can use while working from home or in-person at the office without needing double the amount of monitors, and while preserving his work in a single workspace.

Accessibility for Low-Vision Population Michael is a knowledge worker who experiences strong discomfort when using a computer. Due to a low-vision condition, Michael must position his eyes in close proximity to the monitor and move his entire head rather than his gaze while reading. Such movements lead to strong neck strain from the uncomfortable position and excessive, repetitive movement. By employing virtual displays through an AR or VR headset, Micheal can make content larger and place it orthogonally from his gaze while adopting techniques for moving the virtual screen more easily, such as using rotational gains or panning content virtually.

3 Lessons Learned

Feasibility with Current Technology Existing work has shown that it is feasible to complete knowledge work with AR and VR HWDs for short amounts of time (less than 1 hour) [5,7]. Issues such as eye and neck fatigue can become barriers to longer usage periods, as can simulator sickness specifically for VR monitors [1]. Eye fatigue can be reduced by placing the virtual screen near the optical focal point of the lenses, reducing the accommodation-vergence conflict. Neck fatigue can be reduced with virtual gains, that can virtually amplify head rotations [2, 5].

Productivity Cost with Current Technology The usability of existing virtual displays has been repeatedly shown to be inferior to physical monitors [5, 7], with most issues related to the resolution and FOV of HWDs. On physical monitors, content is displayed pixel-perfect over a surface, and the human eye handles any pose distortions (with the equivalent of about 60 pixels per degree of resolution). In a virtual display, the HWD will have to handle any pose distortion before it reaches the eyes, reducing how many pixels are available for rendering the actual screen - even if an HWD has a 4k screen, the actual pixel per degree count is much lower than that of the human vision, and readability gets affected. Especially on AR devices, the reduced FOV due to technical constraints leads to the user moving their head rather than their eyes, affecting both performance and neck fatigue.

High Display Flexibility and Customization Virtual displays have been shown to achieve high flexibility in their use cases through high customization. By not being tied to physical constraints (other than the HWD specs), monitors can take different shapes and sizes, can be optimized for different tasks or environments, and can present dynamic behaviors, changing or adapting to the user's needs [3].

Boundaries Guide Content Placement Research has shown that boundaries in virtual displays can affect how people place content across large screen real estate [6]. In a single canvas display, users tend to have smaller windows placed closer together, and with more overlapping. That could happen due to users trying to reduce head rotations, which in turn comes at the cost of more window management operations, and more placement strategy freedom. On the other hand, the boundaries between screens in a multi-monitor type of setup suggest to users how to divide the content, leading to larger windows, more spread apart, and less overlapping. While users still try to place content closer together, it is harder to fit multiple windows with various properties inside the bounded spaces. This finding shows one of the limitations of partitioning display space, as the partitions may not be optimal for the content one wants to display.

Social and Environmental Factors When working in public locations, social and environmental factors can affect user experience and behavior [4]. Users may feel self-conscious, paying attention to other people looking at them, and bystanders may look at users with curiosity about what they are doing. On the other hand, users may place virtual content on top of people or activities they are trying to ignore while avoiding placement on top of friends and collaborators. The background can impact content placement, such as avoiding putting windows on top of bright areas.

4 Research Opportunities

Many open research opportunities exist to address these topics, both from a hardware perspective and software and UX design. Here, we list some questions that could be investigated from an interface design standpoint.

RQ1. How do users understand and react to dynamic behaviors of virtual displays?

RQ2. How can we design novel yet effective ways to interact with virtual displays?

RQ3. How can we take advantage of stereoscopy to design novel visualization of knowledge work?

RQ4. How can we design interfaces to combine 2D and 3D content in the same workspace effectively?

RQ5. How should we handle window management when a lot more space is available?

5 Conclusion

In conclusion, the evolving nature of knowledge work requires interfaces with more flexibility than physical monitors can provide. Virtual displays can be used for more flexible, remote, and dynamic work settings, given their reduced physical constraints. We presented three use cases that could benefit from them, although the list is by no means exhaustive and there are many other similar scenarios that workers face daily. Through multiple user studies, we have been able to learn some initial lessons, although there is a lot more that can be done. There are research opportunities from both hardware and software perspectives, with a special focus on how to enable novel interfaces.

References

[1] V. Biener, S. Kalamkar, N. Nouri, E. Ofek, M. Pahud, J. J. Dudley, J. Hu, P. O. Kristensson, M. Weerasinghe, K. C. Pucihar, M. Kljun, S. Streuber, and J. Grubert. Quantifying the Effects of Working in VR for One Week. *IEEE Transactions on Visualization and Computer Graphics*, 28(11):3810–3820, 2022. doi: 10.1109/TVCG.2022.3203103

[2] M. Mcgill, A. Kehoe, E. Freeman, and S. Brewster. Expanding the Bounds of Seated Virtual Workspaces. *ACM Trans. Comput.-Hum. Interact.*, 27(3), May 2020. Place: New York, NY, USA Publisher: Association for Computing Machinery. doi: 10.1145/3380959

[3] L. Pavanatto. Designing Augmented Reality Virtual Displays for Productivity Work. In *2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, pp. 459–460, 2021. doi: 10.1109/ISMAR-Adjunct54149.2021.00107

[4] L. Pavanatto, V. Biener, J. Chandran, S. Kalamkar, F. Lu, J. J. Dudley, G. N. Ramirez, J. Hu, A. Giovannelli, P. Ola Kristensson, L. Schlueter, , J. Müller, J. Grubert, and D. A. Bowman. Performing Knowledge Work from Anywhere: Effects of Working with XR Virtual Displays in Real-World Settings. *In preparation*, 2024.

[5] L. Pavanatto, S. Davari, C. Badea, R. Stoakley, and D. A. Bowman. Virtual monitors vs. physical monitors: an empirical comparison for productivity work. *Frontiers in Virtual Reality*, 4, 2023. doi: 10.3389/frvir.2023.1215820

[6] L. Pavanatto, F. Lu, C. North, and D. A. Bowman. Multiple Monitors or Single Canvas? Evaluating Window Management and Layout Strategies on Virtual Displays. *Under review*, 2024.

[7] L. Pavanatto, C. North, D. A. Bowman, C. Badea, and R. Stoakley. Do we still need physical monitors? An evaluation of the usability of AR virtual monitors for productivity work. In *2021 IEEE Virtual Reality and 3D User Interfaces (VR)*, pp. 759–767, 2021. doi: 10.1109/VR50410.2021.00103