Designing Augmented Reality Virtual Displays for Productivity Work

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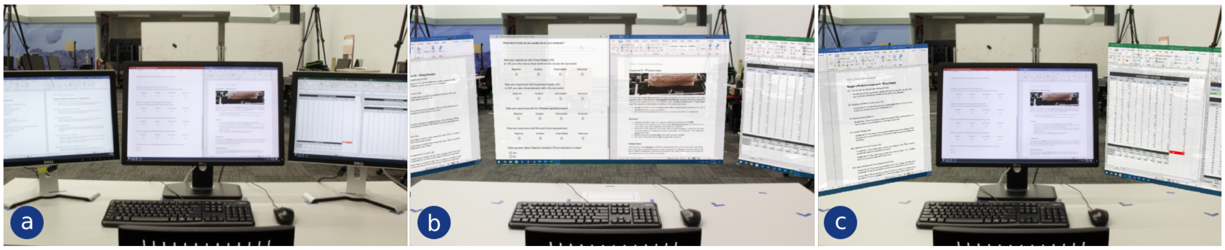

Figure 1: (a) Physical condition had three monitors side-by-side; (b) Virtual condition had three monitors rendered through HoloLens; (c) Hybrid condition combined a central physical monitor with two peripheral virtual monitors.

Abstract

We must consider alternative displays for supporting productivity work in the context of an increasingly work-from-home world. Augmented reality virtual monitors can fulfill these needs by equipping users with large screen real estate, while maintaining portability, cost-effectiveness, and not occupying physical space. However, there are open questions regarding how to design virtual monitors. In my dissertation, I plan to investigate the design of virtual monitors to enhance productivity everywhere. This work comprises a group of design and user study contributions. I conducted a user study to understand the feasibility of virtual monitors and their tradeoffs when compared against physical monitors. I further propose investigating the design of static properties and dynamic behaviors that cannot be achieved through physical monitors.

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

As the world switches into a context of increasingly flexible, remote, and mobile work, we must consider alternative designs that can expand on the capabilities provided by physical monitors. While these monitors have been proved to be valuable, they present problems such as occupying physical space, being less portable, having fixed shape and size, and being individually priced. These are essential problems for productivity workers that require large amounts of screen real estate, such as developers or analysts, for mobile workers, such as airplane passengers, and for people working from home or switching between work and home contexts, which became increasingly important with the COVID-19 pandemic.

A feasible alternative is the use of virtual monitors. These are floating surfaces (plane or curved) rendered through head-worn displays, through either augmented reality (AR) or virtual reality (VR) technologies. While this is a simple idea, there are many considerations that must be investigated. Among other questions, we need to understand how virtual monitors are limited by current technology, what tradeoffs exist when using virtual monitors instead of physical ones, and how to take advantage of the inherent flexibility of virtual monitors to provide benefits for productivity work. An effort should also be made on taking advantage of novel characteristics provided by them to enhance design. The virtual nature of these monitors allows us to make changes such as removing bezels, backgrounds, or size constraints. On the dynamic side, we can also explore how changing depths or sizes during use may be perceived and acted by the user.

Historically, computation has always trended from large-scale computers towards smaller, more portable, and more accessible devices. I believe that virtual displays (either using constrained monitors or more free-form windows) represent the natural next step in that evolution. By virtualizing output, while containing everything inside of a small form factor device, we can provide more flexibility, mobility, and potential for a better user experience. My work will provide knowledge on how virtual monitors differ from existing approaches, and guidance on how we can design interfaces to maximize their unique characteristics.

2 Research Approach

My proposed research approach is structured to explore virtual monitors as they evolve to increasingly deviate from traditional user interfaces. My dissertation revolves around the question "How should we design augmented reality virtual monitors to enhance productivity everywhere?" In a published study, we discussed some of the fundamental differences between physical and virtual monitors when performing productivity tasks [2]. From there, I plan to delve deeply into the design of static characteristics of virtual monitors. Finally, I plan to investigate dynamic behavior changes, which are the most different from physical monitors.

3 Understanding Virtual versus Physical

In our first paper [2], we asked "What are the impacts of replacing or extending physical monitors with virtual ones when conducting productivity tasks while using current technology?" We conducted a user study where 18 participants completed the same productivity task in three different conditions (Figure 1): physical, which had three physical monitors; hybrid, which had one physical monitor and two virtual ones; and virtual, which had three virtual monitors. We used a Microsoft HoloLens 2 device, which displayed a full version

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of Windows 10. Given resolution limitations, one limitation of this study was that the virtual monitors had to be physically larger than the physical ones, to maintain readability.

Results showed that all conditions could be used to perform productivity tasks successfully [2], which encourages further research in this area. We did detect a 14% slower completion time for virtual when compared against physical, but no differences regarding accuracy. Possible explanations for that include the larger size of the screens and the smaller field of view of the HoloLens forcing users to rotate their head more, which was also detected (both in angle amplitudes, and the sum of rotations). Finally, we also learned that, given current technological constraints, the hybrid condition yielded middle ground results between the other two conditions. Therefore, given hardware limitations, it may be more valuable to extend physical monitors with virtual ones, instead of replacing them.

4 Designing Static Properties

Our next investigation will try to answer questions about static characteristics that are not common for physical monitors. We are asking the question "How does the presence or absence of virtual monitor boundaries and snapping behavior affect productivity and user experience regarding organization and window management?" In this study, we plan to compare conditions across two axes: *multi-monitor* versus *canvas*, where *multi-monitor* consists of six monitors with individual boundaries, while *canvas* is a huge monitor that fills the same space but without boundaries or bezels; and *virtual* vs *hybrid*, where *hybrid* would use a single physical monitor surrounded by either virtual monitors or the virtual canvas. This second variable is essential for us to understand how this organization changes in a hybrid setting, giving that most people use laptops for remote work, and it could be advantageous to extend them with virtual elements.

We know that users tend to avoid placing content between physical monitors boundaries [1], and that the discontinuity alone does not lead to a loss in performance [3] or the ability to perform visual search [4]. But how will the lack of boundaries in *canvas* change behavior in terms of window organization? Is it better to have a blank canvas or monitors with sub-divisions? Having a large *canvas* also implies that windows cannot be snapped to fullscreen or half-screen areas on individual monitors. This has become popular in the world of physical monitors, but does the lack of it impact the usability of *canvas* displays?

5 Dynamic Behavior of Virtual Monitors

Finally, I plan to investigate the dynamic behaviors that representing monitors inside mixed reality affords. With virtual monitors, we can resize or reposition monitors dynamically; we can change their depth; and we can even change their orientation (e.g., using a monitor flat on the desk surface for touch screen simulation). Here we focus on two questions: "How can we most effectively make use of the ability to dynamically change virtual monitors to impact user productivity or user experience?", and "How can we take advantage of depth when designing virtual monitor placement, and what effects does it have on usability?". I believe that depth in particular is an important element. While we know that there is a cost in changing focal depth, the extra dimension could indicate meaning, such as the user's current focus during multi-tasking.

I hypothesize that the dynamic behavior will not always be desired, but it could provide important cognitive shortcuts when designed properly, being transparent and peripheral to user action. For instance, in an early prototype, we designed virtual containers where windows can quickly be snapped to the container size (Figure 2). The container size changes based on use, not occupying space while the user focuses on something else, but taking as much space as needed when being used. Another interesting dynamic behavior could be to position windows that are not being actively used further

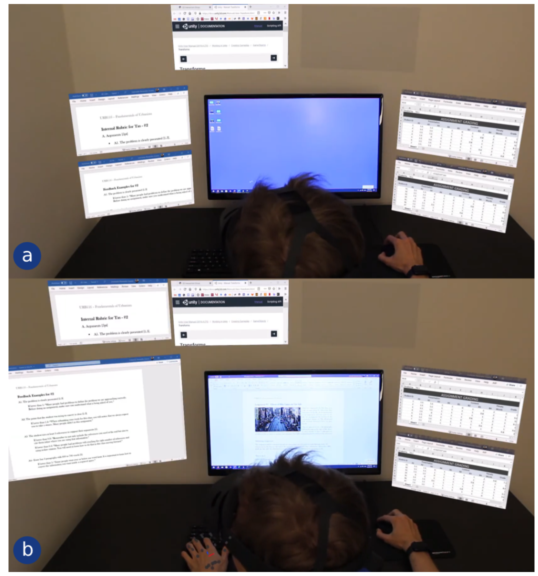

Figure 2: (a) User positions windows on small containers around their physical monitor; (b) user makes one window larger to have more space to work on it, the other containers are still visible.

more distant from the user (such as a wall), potentially making the space less cluttered and more focused.

6 Conclusion

Virtual monitors will have an important impact on the future of work. Understanding how to design these interfaces to maximize usability and productivity is essential to get us there. This dissertation aims to contribute to the field by providing: (1) a quantifiable understanding of the usability of virtual monitors (based on a current state-of-the-art AR HWD) compared to physical monitors when conducting productivity tasks, (2) design implications for how to take advantage of the flexibility of virtual monitors for designing desktop UIs, and (3) guidelines or principles on how to design virtual monitors, considering the context of productivity work.

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