The Social Impact of Extended Reality Spatial Productivity in Constrained, Public and Passenger Spaces

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ABSTRACT

In this workshop submission, we reflect on the need to balance a breadth of design considerations when supporting mobile, spatial productivity. Whilst performance, ergonomics and usability remain key, there is an increasing realisation that the *social impact* of our designs must also be considered - from the *social comfort and acceptability* of a given workspace or interaction technique, to the *social collisions* they provoke with other passengers, to the *environmental and social awareness* the design facilitates in allowing the user to focus on their task whilst maintaining awareness of their environment and those around them.

Index Terms: Human-centered computing—Interaction paradigms—Mixed / augmented reality; Human-centered computing—Interaction paradigms—Virtual reality;

1 INTRODUCTION

Extended Reality (XR), and in-particular the advent of everyday, ubiquitous Augmented Reality (AR) [5, 11, 17] promises the capability to be productive anywhere, anytime - freeing users from the restrictions of physical displays and even input peripherals by transitioning from physical material computing towards spatial computing - where displays and apps are virtual and inputs might be derived from body-based interactions, what we term *spatial productivity*. Our early research into wide virtual workspaces [7] exemplified the potential here by examining the ergonomic impact that virtual workspaces would have on users head/neck movements, and how to minimize that impact through e.g. the use of rotational gain to expand the bounds of seated virtual workspaces.

However, when we transposing this spatial productivity research to passenger contexts, it became readily apparent that, whilst ergonomics were still a key consideration, a host of new issues arose around workspace and interaction design - particularly given the near-infinite breadth of contexts within which people might wish to engage in spatial productivity-oriented tasks. Of particular consideration is the experience of passengers, and the idea that they might want to make better, more productive use of traditionally ”dead” time in-transit, to achieve a better work-life balance. Consider the worker responding to emails or re-drafting a report on a train or plane, so that they have more free time at their destination.

Passengers occupy a ”worst-case” productivity scenario [8, 10] - seating is often fixed and restrictive [7], exemplifying ergonomics considerations; they occupy a constrained interaction volume [23] aboard a moving vehicle, which poses challenges to interaction design (including motion sickness [9, 20]); and they are often surrounded by other passengers in close proximity [12] and in their eyeline [13], which stresses social comfort and acceptability [22]. And, crucially, solutions that address one challenge (e.g. ergonomics) almost inevitably and inadvertently impact other challenges (e.g. social acceptability). Indeed, we are increasingly finding that some of the most interesting challenges posed by spatial productivity revolve around the interactions between the usability of a system and the social impact of it's use in public i.e. how the worker and their actions/interactions are perceived by others; how the worker anticipates they will be perceived by others; and the cross reality interactions that might occur between the worker passenger and other passengers in close proximity.

In this short workshop submission, we highlight and reflect on four papers from our recent works (2022-2023) from ERC ViAjeRo across ACM IMWUT, ACM CHI, IEEE VR and TVCG that differently examine the social impact of mobile, passenger productivity - and emphasize that the social comfort and acceptability of XR can have a meaningful and significant impact on the design of workspaces and interactions.

2 FROM SHIELDING TO AVOIDANCE: PASSENGER AUGMENTED REALITY AND THE LAYOUT OF VIRTUAL DISPLAYS FOR PRODUCTIVITY IN SHARED TRANSIT

This paper [13] used an AR-in-VR simulation to explore the usability and appropriation of virtual workspaces in four shared passenger contexts: airplanes, trains, cars and subways (see Fig. 1). This paper was the first to demonstrate the social impact of the presence of other passengers on how users chose to design their preferred workspaces, evidencing two predominant camps: those AR users that would use their virtual workspace as a barrier, *shielding* themselves from other passengers; versus those that would *avoid* occluding other passengers, wanting to maintain awareness of their environment and it's inhabitants. This choice would have a dramatic impact on the ergonomics and comfort of the workspace layouts, with avoiders for example having to place displays lower or higher than was normally comfortable to view them.

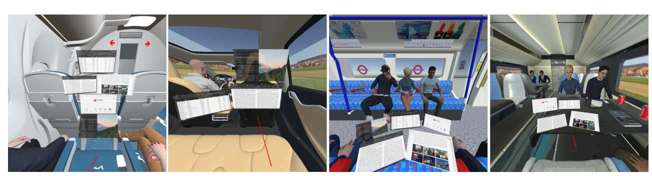

Figure 1: Participant generated examples of AR workspace layouts across four transport environments: airplane, car, subway and train from [13].

Indeed, awareness of others and the surrounding environment continues to be a pressing concern when using XR in shared, public spaces [4, 16], particularly when there are prospective bystanders [18] or there is a need to self-manage your journey by paying at-

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tention to environmental cues such as signs or auditory notices [1], as well as impacting perceptions of passenger safety [1, 19], and the more that productivity tasks occlude our underlying reality, the greater these concerns may be.

3 Surveying the Social Comfort of Body, Device, and Environment-Based Augmented Reality Interactions in Confined Passenger Spaces Using Mixed Reality Composite Videos

This social impact was again seen when considering how to interact with AR content. In this paper [12] (see Fig. 2) we examined a range of body-, device-, and environment-based interactions in a mixed reality composite video survey, to explore the extent to which social comfort might vary when interacting with (invisible to other passengers) virtual spatial content. We found that the seating arrangements, and consequent exposure of actions to other passengers, significantly impacted the perceived social comfort of evaluated interaction techniques. In particular, respondents were uncomfortable with highly visible techniques and those with a high potential for encroachment into others personal space (e.g. mid-air interactions) - again demonstrating that the social pressure of the context can lead prospective XR users to optimize for social comfort over their capability to interact with immersive or spatial content.

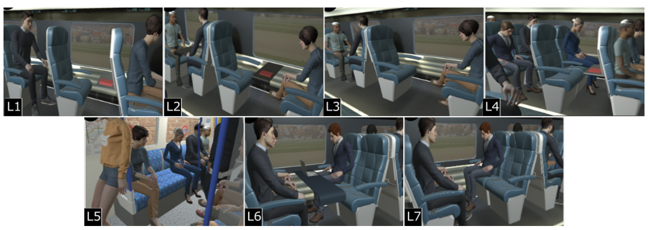

Figure 2: Images illustrating each of the virtual transport seating locations evaluated in [12], absent the AR user/performer (who is present in the empty seat in each location) for clarity. **L1**- Single Row; **L2**-Single Face-to-face with table; **L3**- Single Face-to-face; **L4**-Multiple Rows; **L5**- Multiple Face-to-face Far; **L6**- Multiple face-to-face with table; **L7**- Multiple face-to-face.

4 The Benefits of Passive Haptics and Perceptual Manipulation for Extended Reality Interactions in Constrained Passenger Spaces

In this paper [14], we addressed the dual challenge of supporting high fidelity interaction with virtual planar displays in a way that was both socially comfortable to use and ergonomic. What we arrived at was a solution that appropriated the seatback and surfaces available to the passenger (passive haptics), and then used perceptual manipulation (translational and rotational remapping) to decouple the interaction plane from the viewing plane - meaning that for example the passenger could interact using the tray table in front of them (high social acceptability, but poor ergonomics for viewing) but perceive those interactions in a virtual planar display positioned more comfortable at head height (see Fig. 3). This work exemplified the need to tackle the trade-offs between ergonomics, social acceptability, and input performance, if we are to arrive at effective spatial productivity for constrained spaces.

5 A Lack of Restraint: Comparing Virtual Reality Interaction Techniques for Constrained Transport Seating

However, not all productivity tasks rely on planar 2D displays or content, with e.g. 3D manipulations a common component of a breadth of productivity, from sensemaking tasks [6] to collaborative tasks involving selection and manipulation [2, 3, 15, 21]. Consequently,

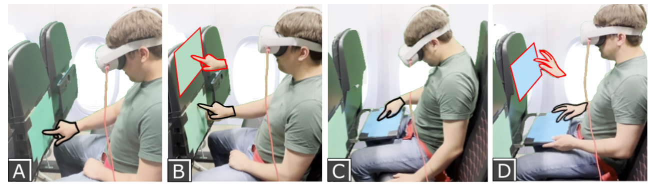

Figure 3: Using passive haptics surfaces in planes for interaction in [14]. (A) shows how the seat-back in front can be used as a passive haptic surface; (B) using translation remapping to create a more comfortable experience; (C) shows the use of a horizontal tray table for passive haptic input; and (D) using translational and rotational remapping for a more comfortable interaction.

in this last paper [23] (see Fig. 4), we have begun to examine how we can facilitate spatial interactions in constrained transport seating, and the problems constrained spaces pose. Of particular note are what we term *boundary violations* and *social collisions*, meaning events that may adversely impact physical safety and social comfort or acceptability. Existing XR spatial interactions such as direct manipulation risk users leaving the boundaries that delineate *their* space as a passenger, opening the possibility of colliding with the environment (e.g. car or plane windows) and with other nearby passengers. But our work also demonstrated that we can redesign interactions to diminish the risk of these social collisions, and our on-going work is currently examining social collisions in collaborative tasks to further understand how to minimize their occurrence in VR.

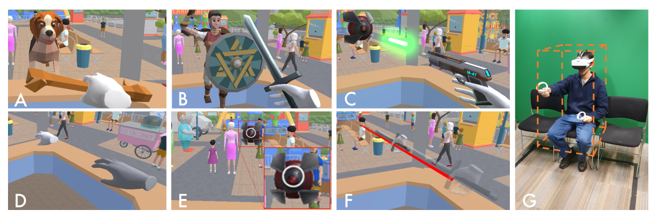

Figure 4: Screenshots from the three gamified tasks (A-C) and three Constrained interaction techniques (D-F) from [23]. A: *Selection & Manipulation* (feeding a dog a biscuit); B: *Sword-Swinging* against invaders; C: *Shooting* robot drones with a laser. D: Linear Gain (real hand shown in grey here, but invisible in VR). E: Gaze-Supported Remote Hand. F: AlphaCursor. G: experimental space, with outline illustrating the constrained interaction volume.

6 Conclusion

In this submission we reflected on four of our papers that exemplified the impact that the shared social space can have on our ability to engage in spatial productivity - including exacerbating perceptions of social (dis)comfort, trying to balance the trade-off between social awareness versus focus in the design of virtual workspaces, and risking social collisions with other passengers that could lead to rejection of spatial computing in such mobile contexts. We argue that it is increasingly paramount to consider not just ergonomics and performance, but also the social fit of a given design - how it (directly or indirectly) impacts others, how it is perceived (in terms of comfort and acceptability from both user and bystander perspectives), and how it impacts necessary awareness of others and the surrounding environment. We argue that the work presented reverberates into mainstream XR adoption in passenger contexts as it transposes traditional interfaces (such as display-based interfaces) into the passenger space and adds novel modalities such as mid-air gestures. And finally, re-appropriate available affordances (e.g. haptic surfaces) and mid-air gestures for these contexts, considering social aspects of the passenger space.

Acknowledgments

This research was funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement #835197: ViAjeRo).

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