SwitchAR: Enabling Perceptual Manipulations in Augmented Reality Leveraging Change Blindness and Inattentional Blindness

Jonas Wombacher
TU Darmstadt
Darmstadt, Germany
jonas.wombacher@tu-darmstadt.de

Zhipeng Li
Department of Computer Science,
ETH Zurich
Zurich, Switzerland
lizhipeng0603@gmail.com

Jan Gugenheimer
TU Darmstadt
Darmstadt, Germany
Institut Polytechnique de Paris,
Télécom Paris - LTCI
Paris, France
jan.gugenheimer@tu-darmstadt.de

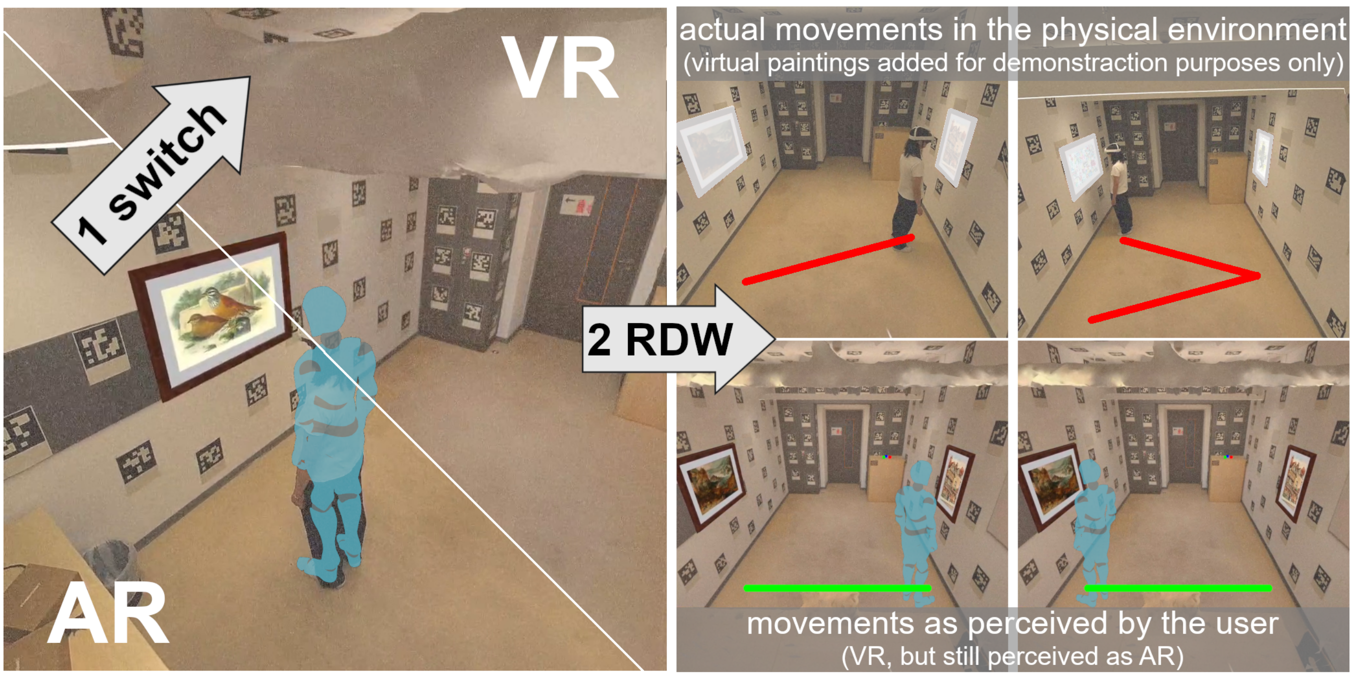

Figure 1: Visualization of the main steps of SwitchAR. 1: Based on an aligned virtual reconstruction of the environment, the user is switched from Augmented Reality (AR) to Virtual Reality (VR) without noticing it. 2: Once the user is in VR, existing perceptual manipulations like redirected walking (RDW) can be applied. In this example, the RDW can redirect the user to create an offset between their perceived virtual position and their actual position in the real room.

Abstract

Perceptual manipulations (PMs) like redirected walking (RDW) are frequently applied in Virtual Reality (VR) to overcome technological limitations. These PMs manipulate the user's visual perceptions (e.g. rotational gains), which is currently challenging in Augmented Reality (AR). We propose SwitchAR, a PM for video pass-through AR leveraging change and inattentional blindness to imperceptibly switch between the camera stream of the real environment and a 3D reconstruction. This enables VR redirection techniques in what users still perceive as AR. We present our pipeline consisting of (1) Reconstruction, (2) Switch (AR -> VR), (3) PM and (4) Switch (VR -> AR), together with a prototype implementing this pipeline. SwitchAR is a fundamental basis enabling AR PMs.

CCS Concepts

• **Human-centered computing → Mixed / augmented reality**.

Keywords

Augmented Reality (AR), Virtual Reality (VR), Perceptual Manipulation (PM), Redirected Walking (RDW)

Author pre-print - CHI EA '25, Yokohama, Japan
2025. ACM ISBN 979-8-4007-1395-8/2025/04
https://doi.org/10.1145/3706599.3721159

ACM Reference Format:
Jonas Wombacher, Zhipeng Li, and Jan Gugenheimer. 2025. SwitchAR: Enabling Perceptual Manipulations in Augmented Reality Leveraging Change Blindness and Inattentional Blindness. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25), April*

26-May 1, 2025, Yokohama, Japan. ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3706599.3721159

1 Introduction

Virtual Reality (VR) applications can make use of a variety of perceptual manipulation (PM) techniques. The subset called Virtual-Physical Perceptual Manipulations (VPPMs)[2, 10] allows developers to influence the users' physical movements. One application for VPPMs is making the users unconsciously change their walking routes through redirected walking (RDW)[6], enabling them to explore virtual environments larger than their real environment. This is possible because VR head-mounted displays (HMDs) fully occlude the real world and, therefore, have full control over the users' visual field of view (FOV). This allows them to leverage perceptual thresholds by manipulating the virtual world displayed to the users.

Current Augmented Reality (AR) HMDs only add virtual content to the real world, rather than fully occluding it. This reduced degree of control over the environment, which is still visible to the user, makes it impossible to apply common PMs. Recently, advances in camera quality and size of the FOV allowed AR HMDs based on pass-through camera feeds to gain popularity (e.g., Meta Quest 3, Apple Vision Pro). Such pass-through AR HMDs are not only able to run AR, but they can also fully occlude the real world in order to run VR instead.

We present SwitchAR, a PM for pass-through AR leveraging change blindness[8, 9] and inattentional blindness[5, 7] to secretly switch between the camera stream of the real environment and a virtual 3D reconstruction. As a result, the user still thinks that they are inside of AR and interacting with the physical environment, while providing full control over the environment reconstruction, allowing developers to use VR redirection techniques. This makes SwitchAR a fundamental enabler for PMs in AR.

SwitchAR's pipeline consists of four steps. (1) Creating a 3D reconstruction of the environment. (2) Secretly switching from the pass-through video feed to the reconstruction. (3) Applying a PM, in our example RDW. (4) Optionally switching back to the pass-through video feed. Across this pipeline, as long as the users are wearing the HMD, it is important that they continuously think they are using AR.

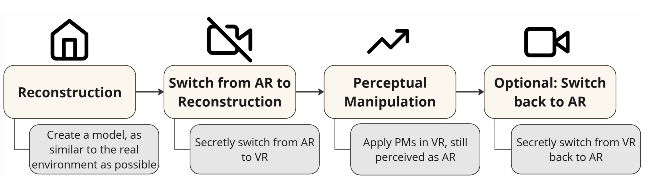

Figure 2: SwitchAR's pipeline, consisting of four steps with their main goals

2 Concept

This section is going to introduce the four steps of SwitchAR's pipeline, as visualized in figure 2. The pipeline combines reconstructing the user's environment, switching from AR to this virtual reconstruction, and then applying the desired PM in order to enable PMs like RDW in AR. The optional fourth step of switching back from the reconstruction to AR can help to provide a seamless experience.

Reconstruction. The goal of this first step is to create a virtual reconstruction of the environment that the application is going to be used in. It should be as similar to the real environment as possible, facilitating inattentional blindness and change blindness to make the following switch less noticeable. This similarity includes the reconstruction's aspects of geometry, scale, alignment with the real environment and its texture.

First Switch. After preparing the reconstruction, the next goal is to switch the HMD from running in AR to running in VR. To achieve this, the reconstruction is displayed on top of the pass-through video feed without the user noticing.

Perceptual Manipulation. Once the application is running in VR, perceptual manipulations already known from VR research can be applied, for example haptic retargeting[1, 3] or redirected walking[6, 9]. During this phase, the users are not supposed to notice the fact that they are not using AR any more. Therefore, perceptual thresholds for the manipulations should not be crossed.

Optional Second Switch. As a last step, the HMD can switch back from VR to AR without the user noticing it, based on the same principles used for the first switch. Depending on the application scenario, this second switch can also be omitted. If the developer intends to manipulate the user only once, or if the manipulation will be obvious to the user anyway, there is no need to switch back to AR.

3 Lab Implementation

This section is going to explain how we implemented a prototype of our pipeline in Unity (version 2022.3.10f1) to enable PMs like RDW in AR.

Reconstruction. As the Quest 3 does not provide real-time access to its pass-through camera feed, it does not allow generating a virtual reconstruction of the environment at runtime. Therefore, we prepared a room that was not changed for the duration of our project. This way, we could use photogrammetry to generate a reconstruction once in advance, and then use that reconstruction in the application later on. To prevent major defects in the virtual reconstruction, caused by large featureless surfaces like the white walls and grey cupboards, we covered them with ArUco markers. Once the room was set up, we took about 3000 pictures of the room with a custom camera rig, containing three Sony Alpha 7R IV cameras paired with Tamron 28-200mm 1:2.8-5.6 Di III RXD lenses.

In comparison to the pass-through camera feed, the images captured with the camera rig contained differences in the color representation, therefore reducing the similarity between the virtual reconstruction and the real AR environment. In order to increase this similarity, we applied a style transfer based on wavelet transforms[11] to the captured images before using them to create the virtual reconstruction. After the style transfer was done, we used the RealityCapture[1] photogrammetry software to calculate a

[1] https://www.capturingreality.com/, last visited: 11.09.2024

virtual reconstruction, including both the mesh and the texture. For performance reasons, we simplified the mesh to 250 000 triangles, allowing the Quest 3 to render it without a drop in frame rate. Figure 3 shows a comparison of screenshots from the pass-through feed, a reconstruction without style transfer, and the final reconstruction with style transfer.

Figure 3: Comparison of pass-through feed with reconstructions before and after the style transfer

Once the virtual reconstruction is available in the HMD, there is another source of dissimilarity between the reconstruction and the real environment. The Quest 3's pass-through AR already contains a small amount of visual grain originating from the camera stream. Because of this, we found that the virtual reconstruction, which did not have any of this visual noise, looked static and artificial in comparison, lacking the visual movement caused by the noise. To solve this problem, we manually added visual pseudo-random noise, based on an asset from the Unity Asset Store[2] to everything in the user's FOV that was supposed to be perceived as part of the real world. This noise was stronger than the pass-through cameras' noise, therefore making the lack of camera noise on the virtual reconstruction not stand out as much any more. Figure 4 visualizes the noise's effect on the pass-through feed (AR), and figure 5 shows the same for the final reconstruction (VR).

Figure 4: Effect of the visual noise on the pass-through video feed

Switching From AR to VR. With the final virtual reconstruction of the room, we can toggle between pass-through AR and VR. For the type of switch, there is a variety of possible options to choose from. After some internal testing, we settled on the following setup. When

[2]https://assetstore.unity.com/packages/vfx/shaders/fullscreen-camera-effects/old-movie-270021, last visited: 11.09.2024

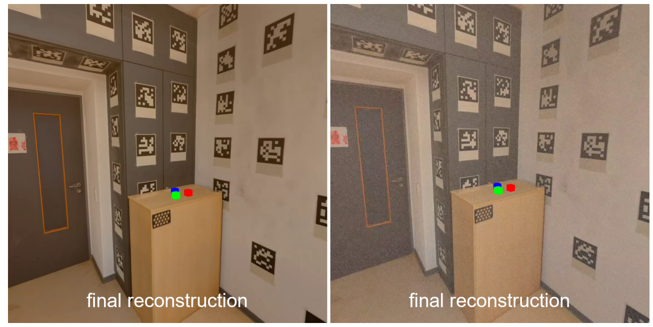

Figure 5: Effect of the visual noise on the reconstruction

instantly turning on or off the virtual reconstruction to switch between AR and VR, we found that the user perceived a lot of visual movement in their periphery. This can be explained with a higher density of rods in the periphery of the human vision[4], which are sensitive to motion. The perceived motion arose from inaccuracies in the reconstruction and its alignment, for example causing an edge of a cupboard to slightly jump in one direction. By gradually fading the reconstruction's opacity over a duration of three seconds, the visual movement perceived at any one moment could be reduced, as any offsets and other changes were spread out instead of happening at once. Preliminary studies with members of our institution showed big promise in being able to secretly switch the user from AR to VR and back without them noticing. We are currently conducting a formal evaluation to demonstrate this effect.

Perceptual Manipulation. Once the users have been brought from AR into VR without them noticing, PMs, that only work in VR, can be applied in what is perceived to still be AR. The manipulation techniques we chose as examples for our implementation are redirected walking (RDW)[6], based on rotation gains, and gradually shrinking the user in body size.

4 Interactivity Implementation

Reconstruction. As the initial implementation of SwitchAR relies on the controlled room in our lab, we created a customized implementation for the Interactivity at CHI. We acquired a foldable, custom printed pavilion, which can act as a portable controlled lab. We then captured a new virtual reconstruction of the pavilion environment and embedded it into the SwitchAR implementation, allowing us to bring the pavilion to the conference in order to run SwitchAR on-site.

Perceptual Manipulation. Attendees will be able to experience SwitchAR with one of two implemented PMs, both of which would not be possible in AR without SwitchAR. RDW will apply rotation gains to gradually create an offset between the attendee's perceived position (which is, unknowingly, relative to the virtual reconstruction) and their physical position in the pavilion. The second PM will be a gradual shrinking of the user. With every step taken, the attendee's body size relative to the pavilion environment will be reduced by an unnoticeably small amount.

5 Demo Applications

After entering the pavilion and putting on a Meta Quest 3 HMD, the attendee will be asked to explore the space and memorize the content of a series of virtual images placed in the environment. This task mainly functions as a distraction, similar to the original work on inattentional blindness asking the user to count basketball passes of one team in a video, which is used to "hide" a person in a gorilla costume crossing the scene[7]. During this task, the HMD will secretly switch from AR to VR at an undisclosed point in time. Following this, one of the two PMs will be applied. Once the attendee finishes the memorization task, the HMD will switch back from VR to AR, this time without hiding the switch. This will reveal the previously unnoticed PM. In the case of RDW, the attendee will be "teleported" to another position in the pavilion. In the case of the body size manipulation, the attendee's perceived body size will abruptly increase.

A display on the table outside the pavilion shows a live transmission of the HMD's POV, allowing bystanders to observe the experience of the attendee currently wearing the HMD. This allows us to both include people that might be uncomfortable with wearing the HMD themselves, and multiple people at the same time in case of a long line-up.

6 Conclusion

In this work, we introduced SwitchAR, a PM for video pass-through AR, that leverages change blindness and inattentional blindness to imperceptibly switch between the camera stream and a 3D reconstruction of the real environment, enabling VR redirection techniques in what is still perceived to be AR. We presented its concept, based on (1) Reconstruction, (2) Switch from AR to the reconstruction, (3) PM and (4) Switch back to AR, as well as a sample implementation for RDW in AR. SwitchAR is a foundational approach unlocking the transfer of VR PMs to AR.

Acknowledgments

This project has been co-funded by the German Federal Ministry of Education and Research and the Hessen State Ministry for Higher Education, Research, Science and the Arts within their joint support of the National Research Center for Applied Cybersecurity ATHENE, and the LOEWE initiative (Hesse, Germany) within the emergenCITY center.

References

[1] Mahdi Azmandian, Mark Hancock, Hrvoje Benko, Eyal Ofek, and Andrew D. Wilson. 2016. Haptic Retargeting: Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1968–1979. doi:10.1145/2858036.2858226

[2] Elise Bonnail, Wen-Jie Tseng, Mark Mcgill, Eric Lecolinet, Samuel Huron, and Jan Gugenheimer. 2023. Memory Manipulations in Extended Reality. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 875, 20 pages. doi:10.1145/3544548.3580988

[3] Aldrich Clarence, Jarrod Knibbe, Maxime Cordeil, and Michael Wybrow. 2024. Stacked Retargeting: Combining Redirected Walking and Hand Redirection to Expand Haptic Retargeting's Coverage. In *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 684, 13 pages. doi:10.1145/3613904.3642228

[4] Christine A. Curcio, Kenneth R. Sloan, Robert E. Kalina, and Anita E. Hendrickson. 1990. Human photoreceptor topography. *Journal of Comparative Neurology* 292, 4 (1990), 497–523. doi:10.1002/cne.902920402 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/cne.902920402

[5] Arien Mack and Irvin Rock. 1998. Inattentional Blindness: Perception Without Attention. *Visual Attention* 8 (01 1998).

[6] Sharif Razzaque. 2005. *Redirected walking*. The University of North Carolina at Chapel Hill.

[7] Daniel J Simons and Christopher F Chabris. 1999. Gorillas in Our Midst: Sustained Inattentional Blindness for Dynamic Events. *Perception* 28, 9 (1999), 1059–1074. doi:10.1068/p281059 arXiv:https://doi.org/10.1068/p281059 PMID: 10694957.

[8] Daniel J. Simons and Daniel T. Levin. 1997. Change blindness. *Trends in Cognitive Sciences* 1, 7 (1997), 261–267. doi:10.1016/S1364-6613(97)01080-2

[9] Evan Suma Rosenberg, Seth Clark, David Krum, Samantha Finkelstein, Mark Bolas, and Zachary Warte. 2011. Leveraging change blindness for redirection in virtual environments. *Proceedings - IEEE Virtual Reality*, 159 – 166. doi:10.1109/VR.2011.5759455

[10] Wen-Jie Tseng, Elise Bonnail, Mark McGill, Mohamed Khamis, Eric Lecolinet, Samuel Huron, and Jan Gugenheimer. 2022. The Dark Side of Perceptual Manipulations in Virtual Reality. In *CHI Conference on Human Factors in Computing Systems (CHI '22)*. ACM. doi:10.1145/3491102.3517728

[11] Jaejun Yoo, Youngjung Uh, Sanghyuk Chun, Byeongkyu Kang, and Jung-Woo Ha. 2019. Photorealistic Style Transfer via Wavelet Transforms. arXiv:1903.09760 [cs.CV] https://arxiv.org/abs/1903.09760