The Effects of Virtuality on Social Presence in Remote MR Collaboration

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Scaling remote collaboration in MR to multiple users can benefit from different levels of virtuality, enabling adaptation to various situations and mitigating challenges posed by diverse user environments. However, the impact of varying degrees of virtuality on social presence remains unclear. To address this, we propose a study in which two remote participants collaborate across four environments ranging from AR to VR while measuring their social presence. For this experiment, we developed an MR system that synchronizes two rooms with differing layouts and physical objects into a unified virtual environment for seamless collaboration.

CCS Concepts: • **Human-centered computing → Empirical studies in collaborative and social computing**; *Mixed / augmented reality*; *User studies.*

Additional Key Words and Phrases: mixed reality, social presence, environment, collaboration, virtuality

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1 Introduction

Mixed Reality (MR) enables remote collaboration with a strong "sense of being with another" [3], known as social presence, through high-fidelity immersive experiences. Increased social presence has been linked to benefits such as enhanced trust and engagement among collaborators [21, 25]. However, scaling remote collaboration in MR presents significant challenges [7], particularly when integrating both remote and co-located participants situated in diverse physical environments within a shared virtual space: While Virtual Reality (VR) offers fully immersive environments that eliminate external distractions and enhance focus on virtual collaboration [24], it is less suited for integrating co-located collaborators, as it fully replaces the physical surroundings. In contrast, Augmented Reality (AR) blends virtual elements with the real world, enabling interaction between remote and co-located users [18, 35]. Still, AR also introduces challenges, as participants may operate in vastly different environments that are not inherently compatible.

One potential approach to addressing these challenges is dynamically scaling the level of virtuality along the Reality-Virtuality continuum [23] to best suit the needs of a given collaborative scenario. However, the impact of different degrees of virtuality on social presence remains unclear. While prior research has compared the effects of augmenting real environments with avatars and fully virtual spaces [11, 14], the intermediate steps along the MR continuum have been largely unexplored.

Therefore, we want to investigate the question: *How does the level of virtuality in an MR environment influence social presence during remote collaboration?* by conducting a study in which two remote participants collaborate in a game under four distinct conditions, ranging from augmented to fully virtual reality.

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Through this research, we aim to contribute an artifact for facilitating collaboration across diverse physical spaces in MR and an empirical evaluation of how social presence varies along the MR continuum.

2 Social Presence in MR

Social presence, the perception of a mediated counterpart as "real", is essential for effective MR interactions [19, 30, 33]. It enables users to detect emotions and attitudes, enhancing trust, cooperation, and reducing mental effort [25, 26].

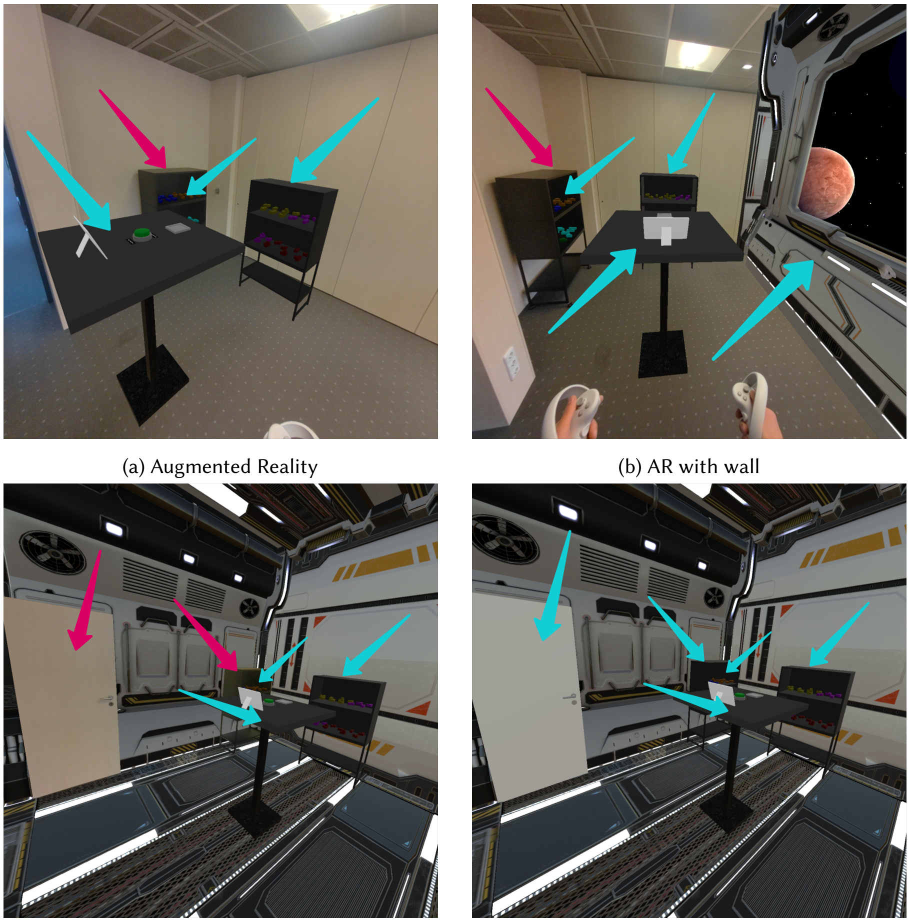
Key factors influencing social presence in MR include immersion, user traits, and task type [25, 33]. Immersion, how well a medium creates a convincing environment, directly impacts social presence [29]. While more immersive modalities generally elicit higher social presence, such as text-based over video-based interactions [2, 16, 25, 28], there is a ceiling to increasing social presence through modality alone [25]. In MR, additional features like stereoscopic displays [1], high-quality audio [5], interactivity [6], and haptic feedback [22] can further enhance social presence. Demographic and personality traits, like gender and social motivation, also play a role, with women and those seeking social interaction reporting higher social presence [8, 10, 12]. Additionally, collaborative tasks tend to elicit higher social presence than independent or competitive ones [25, 32, 33]. Another important factor fostering social presence in MR environment is user representation [25, 26], particularly its behavioral [15, 17, 31] and visual fidelity [20, 27, 34], as increased realism of avatars generally enhances social presence [13].

Regarding the realism and virtuality of the environment, Kang et al. (2023) developed a teleconference system with the two remote users positioned in front of a display, being able to showcase a realistic representation of their collaboration partner and background or a rendered version of each. Their study, which compared the four combinations of visual realism during collaboration, found that realistic backgrounds generated a higher sense of social presence than virtual ones [14]. Utilizing head-mounted displays, Jo et al. (2017) investigated the impact of avatar realism and environment type on social presence and trust in MR teleconferencing, comparing video see-through AR with rendered VR backgrounds. Their findings revealed that AR consistently fostered higher social presence than VR, independent of avatar realism [11]. While this provides initial evidence that AR can enhance social presence, the study involved a static interview task and only examined the two extremes of the MR continuum.

3 Evaluating Social Presence on the MR Continuum

To systematically investigate the effect of varying levels of virtuality on social presence within the mixed reality continuum, we plan a within subjects lab experiment with approximately 30 dyads of participants that know each other. They will collaborate across four conditions shown in Figure 1, which will be presented in counterbalanced order. In each condition, participants work together to build a cube using blocks positioned on two shelves, one real, one virtual, in their respective rooms. One participant is aware of the next required block and describes it to the other participant, who then retrieves the block and places it according to the instructions. Once the block is correctly positioned, the roles will switch until the cube is complete.

The first condition represents a fully AR scenario, where participants see their entire physical room, augmented only by the objects necessary for the task. These are a virtual standing table, a shelf, building blocks and the avatar of the partner. In the second condition, in addition to the virtual objects, one of the room's walls is augmented to appear as a space station, providing participants with a view into outer space. The third condition introduces augmented virtuality, where the entire room is transformed into a space station, enclosing participants in a fully virtual environment. However, some real-world elements, such as the real shelf, a trash can, and the room's door, remain visible in the virtual space. In



(a) Augmented Reality

(b) AR with wall

(c) Augmented Virtuality

(d) Virtual Reality

Fig. 1. Environments to be used in the evaluation with an increasing amount of virtual objects. Arrows highlighting the real (red) and virtual (blue) objects of interest: table, shelf, building blocks, wall, door.

the final condition, participants are entirely immersed in a virtual environment, with those real-world objects replaced by virtual counterparts.

We intentionally selected a space station as the virtual environment rather than a realistic rendering of the real room, as it more fully exploits the immersive capabilities of virtuality, transporting participants into an entirely different environment. This approach also mirrors the types of unrealistic environments commonly seen in online collaboration environments, enhancing the contrast between the real and virtual spaces.

To assess participants' sense of social presence, we will measure two dependent variables. First, we will use the Networked Minds Social Presence Inventory (NMSPI) [4, 9], where participants will rate their agreement with statements reflecting various social presence factors on a 5-point Likert scale. Additionally, we will record interpersonal distances between participants, which will serve as a behavioral indicator of social presence [4]. After the experiment, we will conduct semi-structured interviews to gather qualitative feedback, asking participants to identify which environment fostered the highest sense of presence and to discuss the perceived advantages and disadvantages of virtual versus augmented environments.

4 Apparatus: Scaling MR Environments to Different Physical Spaces

The experimental setup will be identical for both participants and will include a standalone Pico 4 headset, along with a room furnished with a shelf, trash can, and door.

For the software, we developed a multi-user AR application using Unity 2021.3.24f1, integrating Pico's SDK for hand tracking and mixed reality features, enabling video-see-through AR and AR anchor creation. Custom inverse kinematic arms movements enhanced hand tracking. Mouth movements were synchronized with voice output using the Oculus Lip Sync SDK. The Unity Netcode for GameObjects was used to synchronize server/client interactions, including voice chat and player positions. The server ran on a Microsoft Windows Server 2019 Virtual Machine, with clients connecting via OpenVPN. We also developed a custom Android tablet app using Avaturn's API to scan participants' faces and generate photorealistic avatars, which were customized by participants and downloaded in real-time to the Pico headsets.

To accommodate various rooms throughout the study, our application can be adapted to different physical spaces. When initializing in a new room, users define its four corners and ceiling height. Afterward, a semi-transparent virtual shelf, trash can, and door can be placed to match the positions of their real-world counterparts, with precise placement ensured by the preview feature.

Once both users connect, their room centers and orientations are synchronized. The position of each player's physical shelf is saved relative to their room center and displayed as a virtual shelf in the corresponding position for the remote player. This alignment ensures that all game-relevant objects (shelves, players, and the table) are consistently positioned for both users, allowing for natural references and interactions, such as pointing or directional statements. Additionally, while the orientation of virtual walls is synchronized, their exact positioning remains independent. This setup allows users to orient themselves according to features of the virtual space while ensuring that it matches to the actual room size. Although discrepancies may occur if one player's physical space is larger than the other's, potentially causing the remote player to appear to walk through virtual walls, preliminary tests suggest that users tend to stay within the relevant space (between the table and shelves). Instead of resizing the environment to fit the smallest room, our approach emphasizes local coherence, ensuring that the virtual walls align closely with real ones.

Finally, the space station environment is composed of modular components that adapt to the size of the real room. Larger rooms add more modules, while smaller ones scale down. When room dimensions do not exactly match the modular increments, elements are subtly stretched or compressed.

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