XRmas: Extended Reality Multi-Agency Spaces for a Magical Remote Christmas

YAYING ZHANG[1], BRENNAN JONES[2], SEAN RINTEL[3], CARMAN NEUSTAEDTER[4]

[1]Microsoft Corporation, [2]University of Calgary, [3]Microsoft Research Cambridge, [4]Simon Fraser University

[1]yayzhang@microsoft.com, [2]bdgjones@ucalgary.ca, [3]serintel@microsoft.com, [4]carman@sfu.ca

Figure 1: XRmas overview.

The COVID-19 pandemic has raised attention toward remote and hybrid communications. Currently, one highly-studied solution lets a remote user use virtual reality (VR) to enter an immersive view of a local space, and local users use augmented reality (AR) to see the remote user's representation and digital contents. Such systems give the remote user a sense of 'being there', but we identify two more challenges to address. First, current systems provide remote users with limited agency to control objects and influence the local space. It is necessary to further explore the relationship between users, virtual objects, and physical objects, and how they can play a role in providing richer agency. Second, current systems often try to replicate in-person experiences, but hardly surpass them. We propose XRmas: an AR/VR telepresence system that (1) provides a *multi-agency space* that allows a remote user to manipulate both virtual and physical objects in a local space, and (2) introduces three family activities in a Christmas context that adopt holographic animation effects to create a 'magical' experience that takes users beyond merely the feeling of 'being there'. We report on preliminary insights from the use of such a system in a remote family communication context.

1 INTRODUCTION

The COVID-19 pandemic has raised attention toward remote communication, and there has been increasing interest in adopting augmented reality (AR) and virtual reality (VR) in telecommunications. One model of such systems is the Augmented Virtual Teleportation (AVT) model [28]. In AVT systems, the local user sees the remote user and digital content in their own space through an AR device (e.g., Microsoft HoloLens). The remote user uses VR to view the local space and the local user, displayed either through 360° video or as a reconstructed 3D model or point cloud. The remote user can also be represented to the local as a 3D-modeled avatar or 3D point cloud. Current AVT systems try to reduce asymmetries for the remote user (e.g., [16,17,24–26,28]). However, we identify two gaps that are worth addressing.

First, since AVT systems provide a remote-collaboration solution for activities that are conducted in a local space (e.g., remote surgery [8]), one of the main challenges is to increase the remote user's agency to manipulate and influence the local space. To fully explore such systems' advantage of letting the remote and local users feel they are in the same space, both local and remote users should be able to manipulate virtual and physical objects, and virtual objects should understand the physical environment instead of being isolated. However, current studies merely focused on providing the remote user with richer agency in relation to just shared virtual objects. Some systems allow users to see and place virtual objects in a shared space (e.g., [27,28]), but these virtual objects are segregated from the real-world objects.

Moreover, previous explorations of AVT have made great strides in imitating the experience of face-to-face presence, but have yet to surpass it. In fact, recent research has hypothesized that AVT systems have taken telepresence into an "uncanny valley" [17]—that is, the AVT experience is closer to face-to-face, but might be less preferred than "less realistic" telepresence experiences such as those provided by video/audio conferencing. However, the significant feature of AR/VR as a medium is to create '***magic'*** in *space*—that is, letting us enter a digital space (VR) or letting digital objects enter our space (AR). In this paper, we use the term 'magical experience' to refer to XR experiences that do not exist in real life. E.g., spawning objects in the air, or walking on the clouds. Creating 'magical' experiences for local and remote users could help push AVT systems "beyond being there" [13] and achieve what face-to-face communications cannot achieve.

To enhance user agency and enable a magical experience in AVT, we propose a system called ***XRmas***, or *'E**[x]**tended **R**eality (XR) **M**ulti-**A**gency **S**paces for a Magical Remote Christmas'* (Fig. 1). We focused on remote family communication because we felt it could nicely demonstrate the ideas of multi-agency and 'magical' experiences, and we were motivated to support remote family communication during the COVID-19 pandemic. We focused our design on the Christmas holiday because it is considered in some cultural groups to be one of the most important holidays for family gatherings. In this paper, we describe the system design and report preliminary findings of its use in a family communication context.

2 BACKGROUND

2.1 Augmented Virtual Teleportation (AVT)

XR remote collaboration systems can support end users in conducting activities in either their own locations (no shared space) [23,37,38], together in a virtual environment [1,39,40], or together in a local environment, which is the interest of XRmas. Connecting users to a local space can be achieved by 'augmented video conferencing' that allows the remote user to view the local space and draw annotations in 3D (e.g., [6,7,9]), or by systems like AVT. AVT systems (e.g., [28]) allow the local user and the representation of the remote user to *co-exist* in the local space. The local user uses an AR device to view augmented content (the remote user and virtual objects) overlaid on the physical space. The remote user uses a VR device to see an immersive view of a recreated version of the local space where the digital objects also live.

This immersive view of the local space can be captured using a 360° camera (e.g., [41]). Such systems (e.g., [16,17,25,26]) present a realtime panoramic view of the local space, but often do not provide depth for virtual objects to interact with. Another approach is to recreate the local space as a pre-created 3D model (e.g., [24]) or realtime captured point cloud or 3D model (e.g., [8,27,30,31]). This method can add benefit by providing depth for the VR user to view the space from different angles. A downside though is that they either require effort in creating the 3D model as well as in adding interactive features to it (e.g., to turn on the lights) or they provide lower visual resolution and missing data from the back or occluded sides of physical objects. Finally, there are some explorations that combine the advantages of 360° videos with 3D reconstruction (e.g., [28]). Our XRmas system also combines 360° video streaming with a pre-captured 3D scan of the local space to create the illusion that virtual objects can interact with physical objects in the local space.

2.2 Remote User's Agency Level in the Local Space

Agency is one of the most important affordances of AVT systems: allowing the remote user to access the local space. From the least to the most, there are three agency levels that the remote user can have: (1) only seeing the space; (2) also manipulating the **virtual** objects in the space; and (3) also manipulating the **physical** objects in the space.

Seeing the space is the most basic requirement. An even greater challenge is enabling viewpoint mobility, especially in 360°-video-based AVT. VROOM [16,17] enables this by attaching a 360° camera to a robot steered by the remote user.

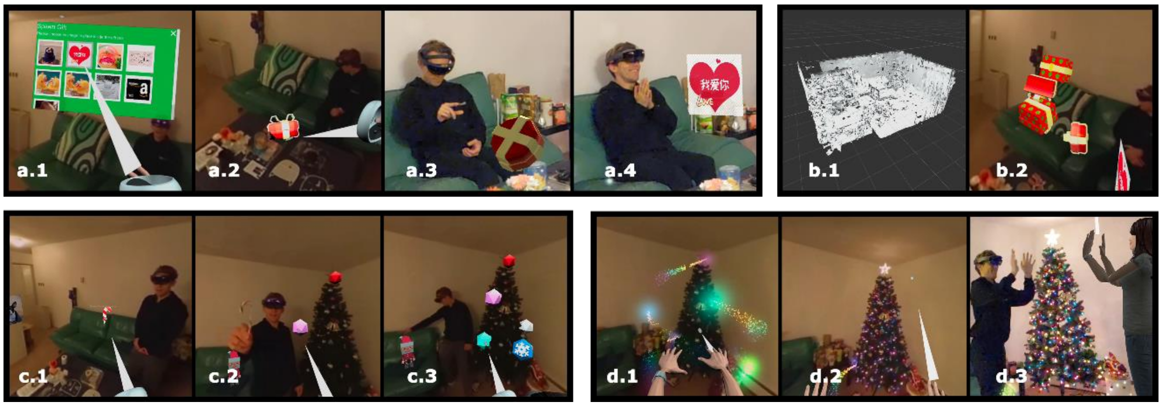

Figure 2. (a) Giving gifts. (b) The implementation of the physical layer. (c) Decorating the room. (d) Lighting up the Christmas tree.

Manipulating virtual objects is also achieved by many AVT systems, including via spawning, moving, and deleting virtual objects (e.g., [27,28]) and annotating in the air (e.g., [8,27,30]). However, only a few systems enable smart virtual objects that understand the physical environment (e.g., [28]).

Manipulating physical objects is more challenging. To the best of our knowledge, no AVT systems have enabled physical object manipulation for remote users. Instead, it is usually the local user who manipulates physical objects, and the remote user gives instructions (e.g., [24,27]). However, there are other systems that allow users to remotely manipulate physical objects. One means is to allow remote control of robotic arms [32,42]. Another way to is enable remote control through Internet of Things (IoT; e.g., [15,43]). XRmas tries to create a *multi-agency space* that provides all three levels of agency to the RU by 360° video streaming, virtual object, and IoT-powered object manipulation.

2.3 Remote Family Communication

Previous research has explored the use of technology for remote family communication. Distant family members typically prefer synchronous mediums to keep in touch due to their in-the-moment nature demanding full attention from all involved [4,20,29]. However, standard synchronous mediums such as video conferencing merely provide 'talking heads' experiences; but providing a *shared experience* (e.g., a shared interactive activity) can add value to remote communication [3]. In particular, children can benefit from more interactive or playful engagements with their remote loved ones [14]. Researchers have proposed video conferencing tools that add interactivity for children and other family members to make the experience more engaging. For example, OneSpace [5,21] focuses on merging the contents of the two video frames to make end users feel as though they are playing together in a shared space. ShareTable [33] and IllumiShare [18] focus on drawing attention toward shared physical artifacts in each of the users' spaces. In XRmas, we provide a shared MR experience with holographic animations that allow users to partake in playful activities together.

3 SYSTEM DESIGN

XRmas (Fig. 1) is an AVT system that connects a remote family member to a local space. What makes XRmas unique from other AVT systems is that (1) it enables a **multi-agency space** in which the RU can see and interact with both digital and physical objects, and (2) it tries to create a **'magical'** experience via user scenarios that adopt animations and special effects to enable the playful interactions of sharing gifts, decorating the room, and lighting up the Christmas tree.

3.1 AVT and Multi-Agency Space

First, we designed a basic AVT setup for the RU to have the basic level of agency to see the local space and for the LU to see the representation of the RU. In the local space, a 360° camera on a tripod streams video to the RU. The LUs use AR devices (HoloLens and a smartphone) to see the RU's avatar overlaid over the 360° camera. In the remote space, the RU uses a VR headset to see the 360° streaming and their first-person avatar body, creating the illusion that they are present in the local space. We used an avatar body of the RU's choice, containing a photorealistic head created from a photo of the RU's face. The system synchronizes the RU's head and body orientation, hand movements, and speech activity to the avatar. The RU controls a pointer to manipulate objects in the space using *VR controller mode* (e.g., Fig. 2-c) or *hand tracking mode* (e.g., Fig. 2-d). LUs can also see the RU's pointer in the AR view.

On top of these, to give the RU more control and influence over the local space and make the interaction more engaging, we created a **multi-agency space**. We augmented the local space with a digital interactable layer in which the RU can, to some degree, change the digital and physical objects in the local environment, including by:

1) ***Manipulating Virtual Objects.*** The RU can spawn, move, and delete virtual objects in the local space. The objects that the RU edited will appear synchronously in the VR and AR views.
2) ***Accessing Physical Objects.*** The RU can control smart devices in the local space via IoT technology. For example, the RU can control the IoT smart plug in the local space to switch devices on and off.
3) ***Mixing Virtual and Physical Objects.*** The digital contents in the magical space also, to some degree, understand the real environment and co-exist with the real objects instead of being independent of the local environment. In XRmas, we implemented this mixing via physics interaction. E.g., a virtual box can land on the physical sofa (e.g., Fig. 2-b.2, c.1) instead of falling through it, and if part of a virtual object is behind a wall, that part will be invisible.

3.2 User Scenario and Magical Experience

To leverage XR's feature of creating a magical illusion in the space, we designed a user scenario adopting animations and special effects in a Christmas context. We chose Christmas as the theme because, in some cultures, it is one of the most important holidays for family gatherings. We designed three activities to prompt playful interactions:

1) ***Giving Gifts.*** The RU can choose a picture of her choice to place inside a virtual gift box (Fig 2-a.1), and spawn that gift box into the room. After being spawned, the LUs can see the gift box synchronously. The RU can move the gift box to any location using her pointer (Fig. 2-a.2). The LU can open the gift using a tap gesture on the HoloLens (Fig. 2-a.3). Upon doing so, the gift flies in the air toward the LU and transforms into the gift picture (Fig. 2-a.4).
2) ***Decorating the Room.*** The RU can choose from a set of virtual Christmas decorations to spawn and decorate the room with (Fig. 2-c), including both decorations that exist in real life (e.g., ornaments) and those that do not (e.g., a dancing Santa). Decorations float in place where the RU places them, and LUs can view them synchronously in AR.
3) ***Lighting up the Tree.*** In *hand tracking mode*, the RU can point her arms toward the real Christmas tree. Upon doing so, virtual light particles spiral around the tree as if the RU is casting a spell (Fig. 2-d.1). The particles intensify as the RU holds her gesture. After a few seconds, the tree lights turn on and the particles fade away (Fig. 2-d.2).

3.3 Implementation

XRmas extends the open-source implementation of Microsoft's "VROOM" prototype [34]. In the **local space**, we used a Microsoft HoloLens (v1) headset [22] running a custom Unity app that displays the avatar and virtual objects over the environment. This app also allows the LU to open the virtual gift boxes. We also used an Android phone to run a similar app that can view the space, but does not allow interaction. The avatar's head is made from a photo of the RU's face, using the Avatar Maker Pro library [44], and attached to a Microsoft RocketBox [11,36] avatar body of the RU's choice.

In the local space, we attached a RICOH Theta V 360° camera [41] to a tripod and connected it to a laptop running an app that streams the 360° video to the VR app on the remote side. A Christmas tree with lights was plugged in to a Kasa IoT smart plug [19]. Another server app, made with Home Assistant API [2], receives requests from the VR app, which uses the Home Assistant's Unity client [12] to turn on the smart plug.

On the **remote side**, we implemented the VR app with Unity and using Oculus Quest (v1/2) [45]. This app displays the 360° live video, a first-person view of the avatar, and virtual objects overlaid on the live video. We used a room-scan 3D model of the living room (Fig. 2-b.1), scanned by the HoloLens, and aligned it with the 360° video to apply physics and occlusion, and synchronize the virtual objects for the remote and local applications. We used the MoveBox [10,35] library to apply the RU's controller and finger movements detected by the Quest onto the avatar. The RU can use the left thumbstick to switch between the modes of *spawn gift*, *spawn decoration*, and *light up tree*. With the right controller pointer, the RU can manipulate virtual objects. Before the experience, the RU can pre-upload pictures to a server, which she can then select from in a menu during the experience (Fig. 2-a.1) when spawning gifts.

The synchronization of video streaming and events such as avatar updates, virtual object updates (e.g., object spawning/moving), and IoT switch on/off commands was achieved using multiple peer-to-peer WebRTC connections and data channels established using a signaling server implemented in Node.js.

4 USER INSIGHTS AND FUTURE WORK

To understand preliminarily how XRmas can influence an RU's experience, during Christmas 2020, two of the authors used XRmas as LUs to connect with a remote family member as the RU (who had one month experience with VR gaming). The trial lasted ~25 minutes, and the authors and RU tried all system features. Afterward, the authors and RU re-watched a video of the experience together (with the AR and VR views synced and playing side-by-side). During the re-watch, the RU paused the video to describe her thoughts on how XRmas felt different from video-conferencing and in-person Christmas gatherings, while the authors asked follow-up questions to understand her experience.

We found that the *multi-agency space* provided the RU with a feeling of increased agency and belonging in the space, but that this was hampered by slight asymmetries between the LUs' and RU's experiences. The RU said she felt like she was *"there"* because she could *"interact with [the] space,"* especially when she found she could turn on the IoT tree. However, she also felt that the virtual objects were *"in a separate space"* from the physical objects. She suspected this could be due to small differences in how she saw the virtual objects compared to how the LUs saw them. E.g., the LUs could move around and discover gift boxes dropped behind the counter, but the RU thought they disappeared because she could not see them from her fixed perspective. However, the RU felt an increased sense of presence when the LUs mirrored her arm movements (e.g., raising arms for cheering), because it reminded her that she could be seen in the room. We also found the *'magical'* experience made the activity more *memorable* to the RU than in-person gatherings:

> *"[XRmas] felt more significant. [...] Because the way that I did it [turned on the tree], it was more interesting and more memorable than just physically turning on the lights. The magic powers! [...] I think that something as simple as just having an animation made it feel more like I was there."*

Overall, we feel the multi-agency space increased the RU's influence and agency, and creating a 'magical' experience triggered meaningful memories that reflect a higher sense of belonging and agency. In the future, we are interested in conducting more in-depth user studies to further understand the potential of multi-agent spaces and the 'magical' effect.

REFERENCES

[1] AltspaceVR. Virtual Reality Church. Retrieved February 24, 2020 from https://account.altvr.com/channels/VRChurch

[2] Home Assistant. Home Assistant. Home Assistant. Retrieved June 1, 2021 from https://www.home-assistant.io/

[3] Jed R. Brubaker, Gina Venolia, and John C. Tang. 2012. Focusing on shared experiences: moving beyond the camera in video communication. In Proceedings of the Designing Interactive Systems Conference, ACM, 96–105.

[4] Xiang Cao, Abigail Sellen, A.J. Bernheim Brush, David Kirk, Darren Edge, and Xianghua Ding. 2010. Understanding family communication across time zones. In Proceedings of the 2010 ACM conference on Computer supported cooperative work (CSCW '10), Association for Computing Machinery, New York, NY, USA, 155–158. DOI:https://doi.org/10.1145/1718918.1718947

[5] Maayan Cohen, Kody R. Dillman, Haley MacLeod, Seth Hunter, and Anthony Tang. 2014. OneSpace: shared visual scenes for active freeplay. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14), Association for Computing Machinery, New York, NY, USA, 2177–2180. DOI:https://doi.org/10.1145/2556288.2557117

[6] Microsoft Corporation. Remote Assist | Microsoft Dynamics 365. Retrieved June 1, 2021 from https://dynamics.microsoft.com/en-us/mixed-reality/remote-assist/

[7] Omid Fakourfar, Kevin Ta, Richard Tang, Scott Bateman, and Anthony Tang. 2016. Stabilized Annotations for Mobile Remote Assistance. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), Association for Computing Machinery, New York, NY, USA, 1548–1560. DOI:https://doi.org/10.1145/2858036.2858171

[8] Danilo Gasques, Janet G. Johnson, Tommy Sharkey, Yuanyuan Feng, Ru Wang, Zhuoqun Robin Xu, Enrique Zavala, Yifei Zhang, Wanze Xie, Xinming Zhang, Konrad Davis, Michael Yip, and Nadir Weibel. 2021. ARTEMIS: A Collaborative Mixed-Reality System for Immersive Surgical Telementoring. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21), Association for Computing Machinery, New York, NY, USA, 1–14. DOI:https://doi.org/10.1145/3411764.3445576

[9] Steffen Gauglitz, Benjamin Nuernberger, Matthew Turk, and Tobias Höllerer. 2014. World-stabilized annotations and virtual scene navigation for remote collaboration. In Proceedings of the 27th annual ACM symposium on User interface software and technology (UIST '14), Association for Computing Machinery, New York, NY, USA, 449–459. DOI:https://doi.org/10.1145/2642918.2647372

[10] Mar Gonzalez-Franco, Zelia Egan, Matthew Peachey, Angus Antley, Tanmay Randhavane, Payod Panda, Yaying Zhang, Cheng Yao Wang, Derek F. Reilly, Tabitha C Peck, Andrea Stevenson Won, Anthony Steed, and Eyal Ofek. 2020. MoveBox: Democratizing MoCap for the Microsoft Rocketbox Avatar Library. In 2020 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR), 91–98. DOI:https://doi.org/10.1109/AIVR50618.2020.00026

[11] Mar Gonzalez-Franco, Eyal Ofek, Ye Pan, Angus Antley, Anthony Steed, Bernhard Spanlang, Antonella Maselli, Domna Banakou, Nuria Pelechano, Sergio Orts-Escolano, Veronica Orvalho, Laura Trutoiu, Markus Wojcik, Maria V. Sanchez-Vives, Jeremy Bailenson, Mel Slater, and Jaron Lanier. 2020. The Rocketbox Library and the Utility of Freely Available Rigged Avatars. Front. Virtual Real. 1, (2020). DOI:https://doi.org/10.3389/frvir.2020.561558

[12] Harrie de Groot. 2021. harriedegroot/HA.Unity. Retrieved June 1, 2021 from https://github.com/harriedegroot/HA.Unity

[13] Jim Hollan and Scott Stornetta. 1992. Beyond Being There. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '92), ACM, New York, NY, USA, 119–125. DOI:https://doi.org/10.1145/142750.142769

[14] Kori M. Inkpen. 2013. Kids & Video: Playing with Friends at a Distance. In Connecting Families: The Impact of New Communication Technologies on Domestic Life, Carman Neustaedter, Steve Harrison and Abigail Sellen (eds.). Springer, London, 95–123. DOI:https://doi.org/10.1007/978-1-4471-4192-1_6

[15] JBrentJ. Connect IoT data to HoloLens 2 with Azure Digital Twin and Unity - Learn. Retrieved June 1, 2021 from https://docs.microsoft.com/en-us/learn/modules/connect-iot-hololens-azure-digital-twins-unity/

[16] Brennan Jones, Yaying Zhang, Priscilla N. Y. Wong, and Sean Rintel. 2020. VROOM: Virtual Robot Overlay for Online Meetings. In Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI EA '20), Association for Computing Machinery, New York, NY, USA, 1–10. DOI:https://doi.org/10.1145/3334480.3382820

[17] Brennan Jones, Yaying Zhang, Priscilla N. Y. Wong, and Sean Rintel. 2021. Belonging There: VROOM-ing into the Uncanny Valley of XR Telepresence. Proc. ACM Hum.-Comput. Interact. 5, CSCW1 (April 2021), 59:1-59:31. DOI:https://doi.org/10.1145/3449133

[18] Sasa Junuzovic, Kori Inkpen, Tom Blank, and Anoop Gupta. 2012. IllumiShare: sharing any surface. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12), Association for Computing Machinery, New York, NY, USA, 1919–1928. DOI:https://doi.org/10.1145/2207676.2208333

[19] KasaSmart.com. Smart Plugs – Kasa Smart. Retrieved June 1, 2021 from https://www.kasasmart.com/us/products/smart-plugs

[20] David S. Kirk, Abigail Sellen, and Xiang Cao. 2010. Home video communication: mediating "closeness." In Proceedings of the 2010 ACM conference on Computer supported cooperative work (CSCW '10), Association for Computing Machinery, New York, NY, USA, 135–144. DOI:https://doi.org/10.1145/1718918.1718945

[21] David Ledo, Bon Adriel Aseniero, Saul Greenberg, Sebastian Boring, and Anthony Tang. 2013. OneSpace: shared depth-corrected video interaction. In CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13), Association for Computing Machinery, New York, NY, USA, 997–1002. DOI:https://doi.org/10.1145/2468356.2468534

[22] mattzmsft. HoloLens (1st gen) hardware. Retrieved June 1, 2021 from https://docs.microsoft.com/en-us/hololens/hololens1-hardware

[23] Sergio Orts-Escolano, Christoph Rhemann, Sean Fanello, Wayne Chang, Adarsh Kowdle, Yury Degtyarev, David Kim, Philip L. Davidson, Sameh Khamis, Mingsong Dou, Vladimir Tankovich, Charles Loop, Qin Cai, Philip A. Chou, Sarah Mennicken, Julien Valentin, Vivek Pradeep, Shenlong Wang, Sing Bing Kang, Pushmeet Kohli, Yuliya Lutchyn, Cem Keskin, and Shahram Izadi. 2016. Holoportation: Virtual 3D Teleportation in Real-

time. In Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16), Association for Computing Machinery, Tokyo, Japan, 741–754. DOI:https://doi.org/10.1145/2984511.2984517

[24] Thammathip Piumsomboon, Gun A. Lee, Jonathon D. Hart, Barrett Ens, Robert W. Lindeman, Bruce H. Thomas, and Mark Billinghurst. 2018. Mini-Me: An Adaptive Avatar for Mixed Reality Remote Collaboration. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18), Association for Computing Machinery, Montreal QC, Canada, 1–13. DOI:https://doi.org/10.1145/3173574.3173620

[25] Thammathip Piumsomboon, Gun A. Lee, Andrew Irlitti, Barrett Ens, Bruce H. Thomas, and Mark Billinghurst. 2019. On the Shoulder of the Giant: A Multi-Scale Mixed Reality Collaboration with 360 Video Sharing and Tangible Interaction. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, 1–17. Retrieved June 1, 2021 from https://doi.org/10.1145/3290605.3300458

[26] Thammathip Piumsomboon, Youngho Lee, Gun Lee, and Mark Billinghurst. 2017. CoVAR: a collaborative virtual and augmented reality system for remote collaboration. In SIGGRAPH Asia 2017 Emerging Technologies (SA '17), Association for Computing Machinery, New York, NY, USA, 1–2. DOI:https://doi.org/10.1145/3132818.3132822

[27] Iulian Radu, Tugce Joy, and Bertrand Schneider. 2021. Virtual Makerspaces: Merging AR/VR/MR to Enable Remote Collaborations in Physical Maker Activities. In Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, 1–5. Retrieved May 30, 2021 from https://doi.org/10.1145/3411763.3451561

[28] Taehyun Rhee, Stephen Thompson, Daniel Medeiros, Rafael dos Anjos, and Andrew Chalmers. 2020. Augmented Virtual Teleportation for High-Fidelity Telecollaboration. IEEE Transactions on Visualization and Computer Graphics 26, 5 (May 2020), 1923–1933. DOI:https://doi.org/10.1109/TVCG.2020.2973065

[29] Kimberly Tee, A. J. Bernheim Brush, and Kori M. Inkpen. 2009. Exploring communication and sharing between extended families. International Journal of Human-Computer Studies 67, 2 (February 2009), 128–138. DOI:https://doi.org/10.1016/j.ijhcs.2008.09.007

[30] Balasaravanan Thoravi Kumaravel, Fraser Anderson, George Fitzmaurice, Bjoern Hartmann, and Tovi Grossman. 2019. Loki: Facilitating Remote Instruction of Physical Tasks Using Bi-Directional Mixed-Reality Telepresence. In Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19), Association for Computing Machinery, New York, NY, USA, 161–174. DOI:https://doi.org/10.1145/3332165.3347872

[31] Nadir Weibel, Danilo Gasques, Janet Johnson, Thomas Sharkey, Zhuoqun Robin Xu, Xinming Zhang, Enrique Zavala, Michael Yip, and Konrad Davis. 2020. ARTEMIS: Mixed-Reality Environment for Immersive Surgical Telementoring. In Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI EA '20), Association for Computing Machinery, New York, NY, USA, 1–4. DOI:https://doi.org/10.1145/3334480.3383169

[32] John P. Whitney, Tianyao Chen, John Mars, and Jessica K. Hodgins. 2016. A hybrid hydrostatic transmission and human-safe haptic telepresence robot. In 2016 IEEE International Conference on Robotics and Automation (ICRA), 690–695. DOI:https://doi.org/10.1109/ICRA.2016.7487195

[33] Svetlana Yarosh, Anthony Tang, Sanika Mokashi, and Gregory D. Abowd. 2013. "almost touching": parent-child remote communication using the sharetable system. In Proceedings of the 2013 conference on Computer supported cooperative work (CSCW '13), Association for Computing Machinery, New York, NY, USA, 181–192. DOI:https://doi.org/10.1145/2441776.2441798

[34] 2021. microsoft/Virtual-Robot-Overlay-for-Online-Meetings. Microsoft. Retrieved June 10, 2021 from https://github.com/microsoft/Virtual-Robot-Overlay-for-Online-Meetings

[35] 2021. microsoft/MoveBox-for-Microsoft-Rocketbox. Microsoft. Retrieved June 1, 2021 from https://github.com/microsoft/MoveBox-for-Microsoft-Rocketbox

[36] 2021. microsoft/Microsoft-Rocketbox. Microsoft. Retrieved June 1, 2021 from https://github.com/microsoft/Microsoft-Rocketbox

[37] Spatial: Virtual Spaces That Bring Us Together. Retrieved June 1, 2021 from https://spatial.io/

[38] Introducing Microsoft Mesh | Here can be anywhere. Retrieved June 1, 2021 from https://www.microsoft.com/en-us/mesh

[39] Hubs by Mozilla. Retrieved June 1, 2021 from /

[40] VRChat. VRChat. Retrieved June 1, 2021 from https://hello.vrchat.com

[41] Product | RICOH THETA V. Retrieved June 1, 2021 from https://theta360.com/en/about/theta/v.html

[42] Guardian® GT Force-Multiplying Dexterous Robotic System. Sarcos Robotics. Retrieved June 1, 2021 from https://www.sarcos.com/products/guardian-gt/

[43] Digital Twins – Modelling and simulations | Microsoft Azure. Retrieved June 1, 2021 from https://azure.microsoft.com/en-ca/services/digital-twins/

[44] Avatar Maker Pro - 3D avatar from a single selfie | Modeling | Unity Asset Store. Retrieved June 1, 2021 from https://assetstore.unity.com/packages/tools/modeling/avatar-maker-pro-3d-avatar-from-a-single-selfie-134800

[45] Oculus Quest 2: Our Most Advanced New All-in-One VR Headset | Oculus. Retrieved June 1, 2021 from https://www.oculus.com/quest-2/?utm_source=bing&utm_medium=d_ps&utm_campaign=407133826&utm_term=oculus+quest+2&utm_content&utm_parent=quest2&utm_ad=1363394943304446&utm_location=5044&utm_location2&utm_placement=kwd-85212471786018%3Aloc-4056&utm_adposition&utm_device=c&utm_matchype=e&utm_feed&msclkid=4f115a46b98d1813d7a23af04672a49f