VROOM: Virtual Robot Overlay for Online Meetings

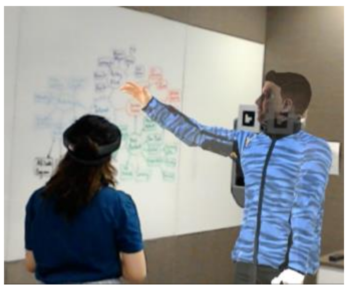

Figure 1: A local (left) and remote (right) user using VROOM to collaborate on a whiteboard.

Brennan Jones
University of Calgary &
Microsoft Research
Cambridge
bdgjones@ucalgary.ca

Yaying Zhang
Microsoft Vancouver
yayzhang@microsoft.com

Priscilla N. Y. Wong
University College London &
Microsoft Research
Cambridge
ngoi.wong.13@ucl.ac.uk

Sean Rintel
Microsoft Research
Cambridge
serintel@microsoft.com

CHI'20 Extended Abstracts, April 25–30, 2020, Honolulu, HI, USA

ACM ISBN 978-1-4503-6819-3/20/04.
https://doi.org/10.1145/3334480.3382820

Abstract

Telepresence robots allow users to freely explore a remote space and provide a physical embodiment in that space. However, they lack a compelling representation of the remote user in the local space. We present VROOM (Virtual Robot Overlay for Online Meetings), a two-way system for exploring how to improve the social experience of robotic telepresence. For the local user, an augmented-reality (AR) interface shows a life-size avatar of the remote user overlaid on a telepresence robot. For the remote user, a head-mounted virtual-reality (VR) interface presents an immersive 360° view of the local space with mobile autonomy. The VR system tracks the remote user's head pose and hand movements, which are applied to an avatar. This provides the remote user with an identifiable self-embodiment and allows the local user to see the remote user's head direction and arm gestures.

Author Keywords

Telepresence; remote collaboration; video communication; mixed reality; augmented reality; virtual reality; remote embodiment; avatar; awareness

CSS Concepts

• **Human-centered computing~Mixed / augmented reality**

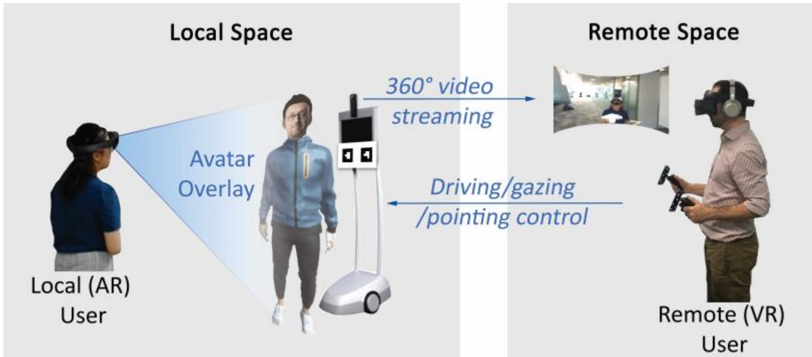

Figure 2: An overview of the VROOM system.

Introduction

Video communication has enabled global lifestyle and distributed access to a range of services. However, traditional 2D video communication constrains our abilities to achieve common ground [18], maintain awareness and control [12,18], and share experiences [23]. People work around these constraints, but the physical and spatial limitations are inescapable. There are currently two ways to add physical and spatial experiences into video communication. The first is to use telepresence robots (e.g., [25,41,42]) — effectively video-chat-on-wheels. These are increasingly common in the workplace (e.g., [43]) but are not yet widely adopted in domestic contexts. The second is to use augmented reality (AR) systems in which users wear head-mounted displays (HMDs) to see one another as 3D avatars in their respective local spaces (e.g., [44]). These avatars scale in realism from cartoonish to photorealistic, scale in animation from manual to parametric, and have some level of 'canned' procedural animations to fill in representational gaps, such as idle, moving, gestural, or facial animations.

Both methods are a step ahead of traditional video communication, but they still have limitations. Telepresence robots allow for autonomous mobility, but they have similar limitations on conveying bodily gestures as traditional video communication [22] because users are still locked into 2D screens and constrained fields of view. AR systems enable 3D bodily views at all endpoints, and while 3D avatars are currently still quite crude, users can freely use large gestures and spatial bodily arrangements. However, an AR avatar cannot roam around a remote location by itself at any time. AR systems require a meeting instance with at least one person per endpoint, and avatar mobility is limited to the physical area seen in the view of the HMD at each endpoint.

The question, then, is whether combining robotic telepresence with an AR avatar will provide the 'best of both worlds'? To answer this, we designed *VROOM* (*Virtual Robot Overlay for Online Meetings*; Figures 1 and 2). To enhance the remote user's sense of immersion we provide a 360° view of the local activity space, and to enhance their self-projection into that space we provide a first-person view of their own avatar. To enhance the local user's sense of co-location with the remote user, a full-size full-body avatar of the remote user overlays the telepresence robot.

Background

As well as enabling more distributed work and personal activities, improvements in video communication and allied infrastructure such as Wi-Fi and mobile data are empowering greater inclusion for people who cannot travel due to responsibilities, disabilities, or financial reasons, or those who do not wish to travel for reasons of sustainability or quality of life.

However, video communication is rife with inequalities. For example, in hybrid meetings [32], remote users are often restricted to the view from a static room camera. The lack of viewpoint control makes it difficult for remote users to contribute [12]. While some activities are not hampered by such issues, remote participation becomes more difficult as physicality increases (e.g., sketching on whiteboards or using sticky notes [10], referring to objects [7], or using bodily gestures [7]). Solutions exist in both research and products, such as giving users the ability to refer to objects in the other space [2,4,5,6,8,15], giving people richer or wider views into the space [11,13,35], and giving users more control of their viewpoint with mechanical or digital movable cameras or automated field of view framing [16,17]. However, these are acute fixes for a chronic problem, forever hampered by the basic architecture of traditional 2D video communication.

Telepresence robots and AR systems change the nature of distributed presence, albeit with some limitations of their own. Telepresence robots (e.g., [25,41,42]) are remotely-controlled movable robots with a screen, speakers, microphone, and at least one camera. Telepresence robots afford *physical autonomy* to explore a remote environment and a *physical embodiment* in that remote environment [30]. Both remote and local users thus have places that belong to them in the local activity space. Usage of telepresence robots has been studied by researchers in collaborative and social contexts such as museum visits [31], remotely attending academic conferences [22,29], outdoor activities [9], and long-distance relationships [39,40]. Telepresence robots are still hampered by their obviously robotic appearance, their lack of physical methods for deictic indication (and, indeed, lack of manipulators for interacting with physical objects), and their constrained representation of the remote user on a small 2D screen.

The field of view is critical in telepresence. The widest field of view is that of 360° cameras, which have been explored for video conferencing [13,19,20,35] and telepresence robots [9,11]. Viewing a 360° live video through a VR HMD can lead to a higher sense of immersion and emotional investment in the remote location [3], which could result in a remote user contributing more to, or getting more out of, a shared activity in that space. However, simply adding a larger field of view for a remote user does not provide a way for local users to know where a remote person is looking in the local activity space [35].

Mixed reality (MR), including AR and virtual reality (VR), provides ways to improve the communicative presence of remote collaborators by showing 3D full or half- body avatars, which have the concomitant advantages of being able to represent deictic gesture as well as other head and bodily gestures [21,24,36]. However, as we noted in our introduction, the lack of mobile physical autonomy in a remote is a common limit in pure AR systems.

Overcoming such limitations is the province of the Telexistence field, arising out of robotics, which explores immersive methods for humans to interact naturally in remote environments [33,37,38]. Telexistence and VR share three requirements: life-size spatiality, real-time interaction, and self-projection. Telexistence has explored both one-way and mutual telexistence [34]. Mutual telexistence research tends to explore the experience of symmetrical systems at each endpoint, but recent research has also explored using asymmetrical technologies at each endpoint. Piumsomboon et al. explored adding a mini avatar of the remote user to the local space, viewable through an AR HMD [26] and attaching a mini avatar to a 360° camera with a tracker, providing immersion in the local activity space to the remote user via a VR HMD [27].

System Design

We built VROOM as an asymmetrical system to enhance the mutual experience of telepresence for both local (AR) and remote (VR) users.

Avatar Representation

We created an avatar representing the remote user's appearance. This avatar is displayed in both the local (AR) user's view (Figure 3), and remote (VR) user's view (Figure 4). In the local user's view, the avatar is overlaid on a telepresence robot using marker tracking. In the remote user's view, the avatar is seen in first-person (shoulders, arms, torso, legs, and feet), mimicking the user's view of their own body.

Figure 3: Avatar representation in the local (AR) user's view.

Figure 4: Avatar representation in the remote (VR) user's view.

The avatar's appearance and actions are mapped to the remote user. A 2D image of the remote user's face is mapped onto a 3D avatar's head (Figure 5). The avatar is rigged to respond to the remote user's head and body actions. The head pans and tilts as the remote user's head does, detected by the gyroscope in the HMD. The head's mouth flaps in time with speech. A blink animation is applied periodically. The hands and arms are articulated to move as the user moves Windows Mixed Reality controllers. Driving the robot triggers a full body walk animation. An idle animation is applied when no locomotion or arm gesture input is detected. The avatar's movements in both the local and remote views are synchronized (Figure 6), so where the remote user looks or points maps to where the avatar looks and points. This full-body avatar is meant to heighten the local user's sense that the remote user is present in the activity space with them. At the same time, the remote user's first-person view of their avatar body immersed in a 360° view of the space is intended to heighten the sense that the remote user is present with the local user in the activity space.

Local Activity Space

Local (AR) User Interface: The local user wears a Microsoft HoloLens, through which they can see the remote user's avatar representation overlaid on the telepresence robot. Pointing by the remote user is limited to arm gestures (Figure 7).

Robot*:* The telepresence robot has fiducial markers for tracking [14] and a 360° camera attached to it to stream a view to the remote user. The markers are tracked by a HoloLens app to overlay the avatar on the robot in the AR view. In this version we used front and rear markers to enable to avatar to face in the same direction as the robot. This worked reasonably well, but future versions might include more markers for smoother tracking. We used a telepresence robot with a screen so that we could run a comparison between standard robotic telepresence and VROOM (to be reported in a future paper), but the screen would be unnecessary if all local users wore HMDs. A future iteration could use any driveable robot with a 360° camera on a pole reaching head-height.

Remote Space

Remote User (VR) Interface: The remote user wears a Windows Mixed Reality HMD. This displays the 360°

Figure 5: The avatar's appearance is made from a 2D image of the remote user's face.

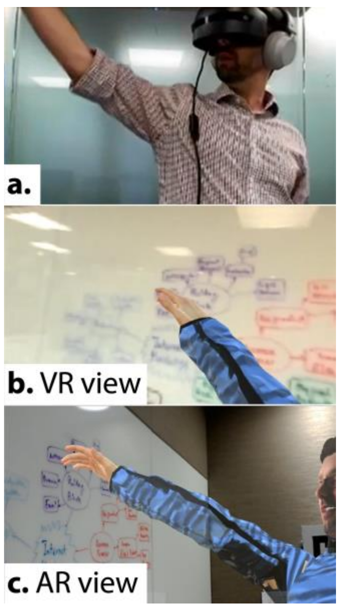

Figure 6: The remote user gesturing at a white board. **a.** Remote (VR) user's action. **b.** Remote (VR) user's view. **c.** Local (AR) user's view.

view from the perspective of the robot, as well as a first-person view of the avatar. The user also holds Windows Mixed Reality controllers in each hand. One thumbstick drives the robot. Standard tracking of both controllers animates the avatar's arm gestures. Since the remote user's hands are holding controllers, fully-articulated hand pose is not available to enable finger pointing or other fine-grained hand gestures.

Robot: We used the built-in audio and driving capabilities of the Beam telepresence robot. When using VROOM, since the remote user was wearing a HMD, they could not use the Beam's visual driving UI in which downward-facing view shows blue lines to indicate the projected direction of travel. We replaced these in the VR view with a white arrow that was locked to the forward direction of the robot.

Implementation

VROOM was constructed largely from existing technologies. In the local space, we use a Microsoft HoloLens (version 1) AR headset, running a custom Unity application. This application tracks the robot and overlays the avatar. The avatar's head is made from an image of the user's face, using the *Avatar Maker Pro* Unity library [45], and attached to an animated human-body model available as a standard asset in Unity. To track the robot, the HoloLens app uses the HoloLensARToolKit library [1,28] to track fiducial marker patterns that we printed and placed on the robot (Figure 8). The robot we use is a BeamPro telepresence robot [42]. On this robot, we attached a RICOH Theta V 360° camera [46], connected to a small laptop attached to the base of the robot. This laptop runs another application that streams the 360° video from the camera to the VR application running on the remote side. On the remote side, we implemented the VR application with Unity and using an HP Windows Mixed Reality headset and controller set [47] connected to a Windows desktop PC. This application displays the 360° live video in the headset, and a first-person view of the avatar. The VR application also sends the remote user's head orientation and hand position data to the AR application via HTTP polling. In addition, we implemented another application, running on the PC in the remote space, allowing the user to drive the robot using a thumbstick on one of the Windows Mixed Reality hand controllers. This app sends the controller commands to the Beam's normal controller app.

Usage Scenario

Amy is a design director in a motorcycle manufacturing company. She is in Seattle, USA, but she has teammates in Shanghai, China. With VROOM, she has a virtual 'key to the door' of the Shanghai studio, engaging with the office on her own timetable and without the need to organize meeting with a particular Shanghai colleague. Her colleagues, each wearing a HoloLens, can see her avatar present in any room, moving around the building, and if they call out when behind her, as she looks back over her shoulder in VR they can see her avatar's head naturally back over its shoulder too. Amy can 'walk' around the studio to check project progress from team to team, hold a 1:1s in her manager's office, and engage in ad hoc 'watercooler' conversations with people she comes across. In a specific design session, a team shows several life size clay maquettes of new motorcycle designs. Amy and her colleagues are all able to move around the room discussing the designs, huddling around each model and pointing at various design elements. As people move, Amy is always able to know

Figure 7: The remote user can express meaning with gazing and arm gestures.

Figure 8: An earlier version of the robot setup with the marker pattern (bottom) and 360° camera (top).

whether others are looking at her, where others are looking, and can also direct her attention to anything else in the room. At the end of the session, as everyone exits the room and returns to their desks, Amy continues conversations with a couple of colleagues on the move. At the end of that days' visit, Amy docks the robot ready for another user. An hour later Red, who works in the Brisbane, Australia, office, calls into the robot and can move around like Amy. Although the robot itself is identical, all of Robert's Shanghai colleagues are able to know it is him at a glance because they can see his avatar is different to Amy's.

Future Work

We are interested in understanding how VROOM affects social and spatial presence for remote and local users. A future paper will report on an exploratory study comparing standard robotic telepresence with VROOM. Questions to be answered include:

- How does VROOM affect users' collaborative and social interactions, compared to standard robotic telepresence?
- How do remote users make use of VROOM to explore and make sense of the environment?
- How do local users understand and perceive the remote user while using VROOM?

Although VROOM places a lot of value on access to shared physical reality in the local activity space, a shared virtual workspace (similar to [44]) would also be a very useful and straightforward addition. Both remote and local users should be able to spawn and use virtual objects (such as 3D models, documents, etc.) that could be pinned to locations in the real environment or decoupled from the physical environment as necessary.

Although we only illustrated one local user and one remote user, VROOM might also be used in scenarios with multiple local and remote users. Scaling up the number of robots would be the largest expense, but as both VR and AR HMDs become cheaper and more comfortable the biggest issues may be logistical and organizational ROI. It would be also be interesting to consider whether two users could share one robot at once. More explorations can be done looking at how multiple users interact with each other, how to have multiple remote users see each other's avatars, and how to reduce cost with cheaper robots.

Finally, it might be also be interesting to consider more exotic asymmetrical immersion technologies, such as room-scale tracking and matching, treadmill locomotion, or 3D reconstructions of remote spaces. These would increase the complexity and cost of building a flexible system, but they would be valuable in considering how to increase the physical activity levels of remote users, and improve remote user's sense of self-projection into local activity space. VROOM robots could also provide remote users with augmented capabilities (e.g. sensors for light outside the visible spectrum, RFID sensors etc.), which might have AR animated representations so that local users could know when a remote user was using them.

Acknowledgements

We thank our fellow Microsoft colleagues who have helped us tremendously with this work: James Scott, Xu Cao, He Huang, Minnie Liu, Zhao Jun, Matthew Gan, and Leon Lu.

References

[1] Ehsan Azimi, Long Qian, Nassir Navab, and Peter Kazanzides. 2018. Alignment of the Virtual Scene to the 3D Display Space of a Mixed Reality Head-Mounted Display. *arXiv preprint arXiv:1703.05834*.

[2] Omid Fakourfar, Kevin Ta, Richard Tang, Scott Bateman, and Anthony Tang. 2016. Stabilized Annotations for Mobile Remote Assistance. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, ACM, 1548–1560.

[3] Diana Fonseca and Martin Kraus. 2016. A Comparison of Head-mounted and Hand-held Displays for 360° Videos with Focus on Attitude and Behavior Change. *Proceedings of the 20th International Academic Mindtrek Conference*, ACM, 287–296.

[4] Susan R. Fussell, Leslie D. Setlock, Jie Yang, Jiazhi Ou, Elizabeth Mauer, and Adam D. I. Kramer. 2004. Gestures over Video Streams to Support Remote Collaboration on Physical Tasks. *Hum.-Comput. Interact.* 19, 3: 273–309.

[5] Steffen Gauglitz, Cha Lee, Matthew Turk, and Tobias Höllerer. 2012. Integrating the Physical Environment into Mobile Remote Collaboration. *Proceedings of the 14th International Conference on Human-computer Interaction with Mobile Devices and Services*, ACM, 241–250.

[6] Steffen Gauglitz, Benjamin Nuernberger, Matthew Turk, and Tobias Höllerer. 2014. World-stabilized Annotations and Virtual Scene Navigation for Remote Collaboration. *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology*, ACM, 449–459.

[7] William W. Gaver, Abigail Sellen, Christian Heath, and Paul Luff. 1993. One is Not Enough: Multiple Views in a Media Space. *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems*, ACM, 335–341.

[8] Carl Gutwin and Reagan Penner. 2002. Improving Interpretation of Remote Gestures with Telepointer Traces. *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work*, ACM, 49–57.

[9] Yasamin Heshmat, Brennan Jones, Xiaoxuan Xiong, et al. 2018. Geocaching with a Beam: Shared Outdoor Activities Through a Telepresence Robot with 360 Degree Viewing. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, ACM, 359:1–359:13.

[10] Hiroshi Ishii and Minoru Kobayashi. 1992. ClearBoard: A Seamless Medium for Shared Drawing and Conversation with Eye Contact. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, 525–532.

[11] Steven Johnson, Irene Rae, Bilge Mutlu, and Leila Takayama. 2015. Can You See Me Now?: How Field of View Affects Collaboration in Robotic Telepresence. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, ACM, 2397–2406.

[12] Brennan Jones, Anna Witcraft, Scott Bateman, Carman Neustaedter, and Anthony Tang. 2015. Mechanics of Camera Work in Mobile Video Collaboration. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, ACM, 957–966.

[13] Shunichi Kasahara and Jun Rekimoto. 2015. JackIn Head: Immersive Visual Telepresence System with Omnidirectional Wearable Camera for Remote Collaboration. *Proceedings of the 21st ACM Symposium on Virtual Reality Software and Technology*, ACM, 217–225.

[14] Anuroop Katiyar, Karan Kalra, and Chetan Garg. 2015. Marker based augmented reality. *Advances*

in Computer Science and Information Technology (ACSIT) 2, 5: 441–445.

[15] David Kirk and Danae Stanton Fraser. 2006. Comparing Remote Gesture Technologies for Supporting Collaborative Physical Tasks. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 1191–1200.

[16] Sven Kratz, Daniel Avrahami, Don Kimber, Jim Vaughan, Patrick Proppe, and Don Severns. 2015. Polly Wanna Show You: Examining Viewpoint-Conveyance Techniques for a Shoulder-Worn Telepresence System. *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI 2014), Industrial Case Studies*, ACM.

[17] Sven Kratz, Don Kimber, Weiqing Su, Gwen Gordon, and Don Severns. 2014. Polly: Being there through the parrot and a guide. *Proceedings of the 16th international conference on Human-computer interaction with mobile devices & services*, ACM, 625–630.

[18] Robert E. Kraut, Susan R. Fussell, Susan E. Brennan, and Jane Siegel. 2002. Understanding effects of proximity on collaboration: Implications for technologies to support remote collaborative work. *Distributed work*: 137–162.

[19] Zhengqing Li, Shio Miyafuji, Toshiki Sato, Hideki Koike, Naomi Yamashita, and Hideaki Kuzuoka. 2018. How Display Shapes Affect 360-Degree Panoramic Video Communication. *Proceedings of the 2018 Designing Interactive Systems Conference*, ACM, 845–856.

[20] Zhengqing Li, Shio Miyafuji, Erwin Wu, Hideaki Kuzuoka, Naomi Yamashita, and Hideki Koike. 2019. OmniGlobe: An Interactive I/O System For Symmetric 360-Degree Video Communication. *Proceedings of the 2019 on Designing Interactive Systems Conference*, ACM, 1427–1438.

[21] Andrew Maimone, Xubo Yang, Nate Dierk, Andrei State, Mingsong Dou, and Henry Fuchs. 2013. General-purpose telepresence with head-worn optical see-through displays and projector-based lighting. *2013 IEEE Virtual Reality (VR)*, 23–26.

[22] Carman Neustaedter, Gina Venolia, Jason Procyk, and Daniel Hawkins. 2016. To Beam or Not to Beam: A Study of Remote Telepresence Attendance at an Academic Conference. *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing*, ACM, 418–431.

[23] Kenton O'Hara, Alison Black, and Matthew Lipson. 2006. Everyday Practices with Mobile Video Telephony. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 871–880.

[24] Sergio Orts-Escolano, Christoph Rhemann, Sean Fanello, et al. 2016. Holoportation: Virtual 3D Teleportation in Real-time. *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, ACM, 741–754.

[25] Eric Paulos and John Canny. 2001. Social Tele-Embodiment: Understanding Presence. *Autonomous Robots* 11, 1: 87–95.

[26] Thammathip Piumsomboon, Gun A. Lee, Jonathon D. Hart, et al. 2018. Mini-Me: An Adaptive Avatar for Mixed Reality Remote Collaboration. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, ACM, 46:1–46:13.

[27] 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. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, ACM, 228:1–228:17.

[28] Long Qian. 2019. qian256/HoloLensARToolKit. .

[29] Irene Rae and Carman Neustaedter. 2017. Robotic Telepresence at Scale. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, ACM, 313–324.

[30] Irene Rae, Leila Takayama, and Bilge Mutlu. 2013. In-Body Experiences: Embodiment, Control, and Trust in Robot-Mediated Communication. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, 1921–1930.

[31] Irene Rae, Gina Venolia, John C. Tang, and David Molnar. 2015. A Framework for Understanding and Designing Telepresence. *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, ACM, 1552–1566.

[32] Banu Saatçi, Roman Rädle, Sean Rintel, Kenton O'Hara, and Clemens Nylandsted Klokmose. 2019. Hybrid Meetings in the Modern Workplace: Stories of Success and Failure. *Collaboration Technologies and Social Computing*, Springer International Publishing, 45–61.

[33] Susumu Tachi. 2015. Telexistence. In G. Brunnett, S. Coquillart, R. van Liere, G. Welch, and L. Váša, eds., *Virtual Realities: International Dagstuhl Seminar, Dagstuhl Castle, Germany, June 9-14, 2013, Revised Selected Papers*. Springer International Publishing, Cham, 229–259.

[34] Susumu Tachi, Naoki Kawakami, Masahiko Inami, and Yoshitaka Zaitsu. 2004. Mutual telexistence system using retro-reflective projection technology. *International Journal of Humanoid Robotics* 01, 01: 45–64.

[35] Anthony Tang, Omid Fakourfar, Carman Neustaedter, and Scott Bateman. 2017. Collaboration with 360° Videochat: Challenges and Opportunities. *Proceedings of the 2017 Conference on Designing Interactive Systems*, ACM, 1327–1339.

[36] 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. *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*, Association for Computing Machinery, 161–174.

[37] Kouichi Watanabe, Ichiro Kawabuchi, Naoki Kawakami, Taro Maeda, and Susumu Tachi. 2008. TORSO: Development of a Telexistence Visual System Using a 6-d.o.f. Robot Head. *Advanced Robotics* 22, 10: 1053–1073.

[38] Xingyu Xia, Chi-Man Pun, Di Zhang, et al. 2019. A 6-DOF Telexistence Drone Controlled by a Head Mounted Display. *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 1241–1242.

[39] Lillian Yang, Brennan Jones, Carman Neustaedter, and Samarth Singhal. 2018. Shopping Over Distance Through a Telepresence Robot. *Proc. ACM Hum.-Comput. Interact.* 2, CSCW: 191:1–191:18.

[40] Lillian Yang, Carman Neustaedter, and Thecla Schiphorst. 2017. Communicating Through A Telepresence Robot: A Study of Long Distance Relationships. *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, ACM, 3027–3033.

[41] Double Robotics - Telepresence Robot for Telecommuters. Retrieved December 17, 2019 from https://www.doublerobotics.com/.

[42] Suitable Technologies Beam Smart Presence System. Retrieved March 18, 2016 from https://suitabletech.com/beam/.

[43] R&D Lab - Microsoft Research. Retrieved December 21, 2019 from https://suitabletech.wistia.com/medias/eg82wq4x

5b?embedType=iframe&seo=false&videoWidth=560?wtime=0.

[44] Spatial - Collaborate from anywhere in Augmented Reality. Retrieved February 11, 2020 from https://spatial.io/.

[45] Avatar Maker Pro - 3D avatar from a single selfie - Asset Store. Retrieved January 4, 2020 from https://assetstore.unity.com/packages/tools/modeling/avatar-maker-pro-3d-avatar-from-a-single-selfie-134800.

[46] Product | RICOH THETA V. Retrieved December 21, 2019 from https://theta360.com/en/about/theta/v.html.

[47] HP Windows Mixed Reality Headset | HP® Official Site. Retrieved December 21, 2019 from https://www8.hp.com/us/en/campaigns/mixedrealityheadset/overview.html.