Tele-Haptics: Remote Collaboration on Physical Objects

MAXIMILIAN LETTER, Berliner Hochschule für Technik, Germany

The need to work together at any time from any place in the world is constantly increasing. While the possibility to remotely collaborate on digital content has matured to the point where it manifested into daily used services, remote collaboration on physical objects has not left its early stages of prototypes and studies. The task is challenging because of multiple reasons that partly cause each other: (1) physical content is static and cannot be duplicated or transported like digital content; (2) the possibilities of capturing and digitizing physical content are yet limited and usually come with a loss of information; (3) interacting with representations of physical objects is unnatural and does not allow an experience similar to the interaction with real-world objects. In my work, I aim to research the latter of these challenges. The goal is to explore how working with physical objects that are remote can be digitally supported to enable collaborations independent of time or space. As this field of academia is comparably novel, numerous aspects can be looked at. I am most interested in asynchronous collaboration and mutual collaboration, as well as how to transport and emulate the properties of physical objects that go beyond the visual.

Additional Key Words and Phrases: Remote Collaboration, Tangible Interaction, Augmented Reality, Mixed Reality

ACM Reference Format:
Maximilian Letter. 2022. Tele-Haptics: Remote Collaboration on Physical Objects. In *AVI '22: International Conference on Advanced Visual Interfaces, June 6–June 10, 2022, Rome, Italy*. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/1122445.1122456

1 MOTIVATION

Remote collaboration allows people to work more flexible by choosing their own workplace. Thereby, traffic is reduced and travel-times, that are most often perceived as lost time, can be saved. The importance of remote collaboration increased constantly over the last decades and skyrocketed during the last two years of living in a global pandemic. As for the current state of remote collaboration, we work with colleagues on a daily basis through communication (video chat) and digital content production. The digital content we collaborate on is traditionally text-based, but collaborative drawing and 3D-modelling are also supported.

Working remotely on physical objects however (e.g. in product design, architecture, fashion design) seems far more challenging. This leads to one of two effects. One option is to have people rather working on virtual abstractions of physical objects (e.g. 3D modeling tools and CAD programs) that have the benefits of digital content, which however decouples work from the product it evolves around. The other way is to force a co-located collaboration, by getting both, people and objects, together in the same place. Therefore, workers have to travel extensively, or the physical content is transferred between locations by long post ways, both are costly, time-consuming, and harmful to the environment [15, 20].

The topic of remote collaboration on physical objects fits in the current trend of merging physical and digital world. It is of interest to research the challenges of working with digital representations of physical objects in a remote collaboration and to develop approaches to enable a seamless interaction. One crucial aspect of this interaction with digital representations is haptic sensation, that is lost with most currently employed technologies. My aim is to contribute towards a vision of remote collaboration that feels more natural, in pursue of enabling a connected and merged world that is neither locked behind screens nor limited to the boundaries of time and space.

2 KEY RELATED WORK AND RESEARCH GAPS

Multiple structured literature reviews can be found that touch on topics that are related to remote collaboration on physical objects, mainly collaborative mixed reality [3, 14, 19, 22, 25, 29]. While these surveys are related and partly include publications that study remote collaboration on physical objects, a comprehensive overview on the state of research in that area has not been done. In order to identify key related work, I conducted a structured literature review on remote collaboration on physical objects [17]. Led by the open research question of "what aspects of remote collaboration on physical objects have been studied in scientific literature?", 80 publications were analyzed and discussed.

Overall, a constant increase in popularity in research could be observed. Notable are spikes showing high amount of works followed by phases of low publication counts. These effects were possibly related to hardware releases in the same time frame. In line with the introductions of new hardware, the composition of applied technologies changed over time. It could be stated that currently, mobile devices as well as immersive virtual and augmented reality headsets are on the rise. The traditional 2D screen remained relevant over the complete time span.

As this area of research is relatively young, multiple research gaps could be identified. With 61 out of 80 publications, the majority of works did research synchronous collaborations that regard a guidance task. Consequential, asynchronous collaborations as well as mutual collaborative scenarios were identified as research gaps.

While some of the proposed prototypes could potentially be used in an asynchronous variant, only a few works actually investigated that form of collaboration [6, 12, 21, 27, 30]. The lack of research in that area is in line with related literature surveys [3, 22]. As asynchronous collaboration on physical objects is more difficult than working with digital content by the nature of physicality, it is an interesting research topic to delve into, providing versatile challenges. Similarly, the under-representation of mutual collaboration is due to the physicality of objects, which cannot be duplicated or easily transported. Therefore, equal access to an object is challenging to accomplish, while guiding a task where only one collaborator interacts with the physical content is much easier to achieve. However, multiple works studied a mutual remote collaboration on physical objects, showing the possibilities of this attempt [4, 5, 8, 10].

Further, it could be stated that there is a general lack of focus on the physicality of objects. Remote physical objects are visualized to collaborators [1, 7, 26] but seldom are properties beside appearance transmitted. The reason might come from a low amount of research in this field, as most publications study other aspects of the collaboration, like the communication through gestures [2, 11, 28] or the control of collaborators' viewpoints [13, 23, 24], than the object itself. The publications that address the haptic senses of collaborators are most often works that utilize the idea of tangible user interfaces [5, 21], frequently in conjunction with mixed reality technology [8, 16, 31].

Based on the results of the structured literature review, the following research questions can be derived:

(1) **asynchronous collaboration**: how can asynchronous changes on physical objects be represented, so that it benefits a collaboration?
(2) **mutual collaboration**: exploring use cases beyond guidance, how can mutual remote collaboration on physical objects be enabled?
(3) **physicality of objects**: how can the interaction with representations of real-world objects be improved due to appealing to more than the visual sense, and how does that benefit the collaboration?

3 COMPLETED AND ONGOING RESEARCH

I have laid the groundwork for future research in the field of remote collaboration on physical objects by conducting a structured literate review, the results of which are presented in section 2. The work was submitted to CSUR as a full paper [17] and is currently under review.

Based on the research gaps identified during the structured literature review, I selected asynchronous collaboration on physical objects as the first area to investigate. Therefore, I investigated how physical objects can be compared to virtual alternatives directly in the real world. As a result, the concept of Tangible Version Control (TVC) was developed. TVC is inspired by version control, commonly used in software development. Compared to traditional version control systems, information is no longer bound to a screen, but instead displayed directly on top of the physical artifact that is worked on. Supplementary digital information about the object's alternative versions are visualized with the use of augmented reality. Actions are performed by physically moving the object. The concept of TVC can be split in two logical parts: timeline and comparisons, which are displayed in figure 1.

The timeline is a representation of alternative versions, positioned and interacted with by moving the physical artifact. The current state in the timeline is displayed by highlighting the corresponding digital twin of the physical artifact, as well as compared against versions. Once two versions are compared with each other, visualizations are shown on the physical object itself. Three modes were selected during iterative development of the prototype: SideBySide, showing current and an alternative version next to each other; Overlay, superimposing the alternative version onto the current state; and Differences, highlighting color-coded differences between the two versions based on a part-based differing algorithm.

In order to spread the concept of an object-centered version control that utilizes augmented reality and foster discussion about such an approach, the work will appear in CHI22 as a poster in the Late-Breaking Work track [18].

Fig. 1. Prototype showing the concept of Tangible Version Control [18]. Left: a timeline of virtual versions can be explored by moving the physical artifact. Contextual information about ongoing comparisons and between physical and virtual content are marked by blue highlights. Right: comparisons between two versions are displayed directly on the physical artifact. In the image, the Differences-mode is used, in which differing parts of the physical object are highlighted by color-coded outlines.

The TVC concept is planned to be expanded in scope and evaluated in a formal user study. As extensions, more aspects of version control systems could be included, such as multi-branch repositories, merging, and commit intentions. For the study, we plan to compare TVC to currently used version control systems, such as Git, in the use case of iterating on a physical object.

4 VISUO-HAPTIC INTERACTION AND CONTRIBUTION TO THE WORKSHOP

Even with an approach such as TVC, that incorporates the physical artifact itself in the interaction, alternative versions are purely visual representations, thereby lacking immersion and realism. In a next step, it is planned to investigate into the physicality of objects and the low representation of their non-visual properties. This is particular important as it is currently difficult to imitate tangible surfaces of remote physical objects over distance.

One potential approach lies in the use of additional devices, such as gloves or finger-worn stimulators, that could go hand in hand with the augmented reality usage. Alternatively, passive haptics are of interest. Passive haptics generated by proxy objects potentially require a lot less technology once they are produced. In addition, they can be naturally interacted with just as with ordinary real-world objects. A third option could lie in the use of illusionary approaches, simulating haptic sensations rather than physically producing them.

The workshop on visuo-haptic interaction therefore appears as a great place to exchange ideas about improving the tangibility of virtual objects. I am specially interested in approaches that enable a seamless switch between natural occurring haptic interaction, for example with the physical artifact, and technology-enabled haptics that support virtual representations, for example remote objects. In turn, my expertise about collaborative scenarios could make an interesting addition to the workshop participants, as it brings an alternative view on the use and application areas of visuo-haptic interactions.

5 LONG-TERM VISION AND CONTEXT

The long-term vision for remote collaboration on physical objects for my work is the idea of seamless interaction, regardless of location, that feels as natural as co-located work. In order to match these qualities, representation and interaction of physical content must first break out of two-dimensional screens and user interfaces. Inspired by the vision Ishii proposed in his fight against the pixel empire [9], I aim to investigate into solutions that directly include the objects that are worked on in the collaborative process, while making the interaction with representations of remote objects as natural as possible.

I am researching remote collaboration on physical objects now for more than one and a half year at the Berliner Hochschule für Technik (BHT) in Berlin, Germany. My research is supervised by Katrin Wolf, BHT Berlin. My thanks go to Katrin Wolf for supporting and advising my research, as well as to the BHT for making my studies possible by funding the PhD program. I look forward to participating in the workshop on visuo-haptic interaction at AVI22.

REFERENCES

[1] Matt Adcock, Stuart Anderson, and Bruce Thomas. 2013. RemoteFusion: real time depth camera fusion for remote collaboration on physical tasks. In *Proceedings of the 12th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry - VRCAI '13*. ACM Press, Hong Kong, Hong Kong, 235–242. https://doi.org/10.1145/2534329.2534331

[2] Judith Amores, Xavier Benavides, and Pattie Maes. 2015. ShowMe: A Remote Collaboration System that Supports Immersive Gestural Communication. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*. ACM, Seoul Republic of Korea, 1343–1348. https://doi.org/10.1145/2702613.2732927

[3] Ryan Anthony J. de Belen, Huyen Nguyen, Daniel Filonik, Dennis Del Favero, Tomasz Bednarz, Ryan Anthony J. de Belen, Huyen Nguyen, Daniel Filonik, Dennis Del Favero, and Tomasz Bednarz. 2019. A systematic review of the current state of collaborative mixed reality technologies: 2013–2018. *AIMS Electronics and Electrical Engineering* 3, 2 (2019), 181–223. https://doi.org/10.3934/ElectrEng.2019.2.181

[4] Hrvoje Benko, Ricardo Jota, and Andrew Wilson. 2012. MirageTable: freehand interaction on a projected augmented reality tabletop. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*. ACM Press, Austin, Texas, USA, 199. https://doi.org/10.1145/2207676.2207704

[5] Scott Brave, Hiroshi Ishii, and Andrew Dahley. 1998. Tangible interfaces for remote collaboration and communication. In *Proceedings of the 1998 ACM conference on Computer supported cooperative work - CSCW '98*. ACM Press, Seattle, Washington, United States, 169–178. https:

//doi.org/10.1145/289444.289491

[6] Filipe Calegario, João Tragtenberg, Johnty Wang, Ivan Franco, Eduardo Meneses, and Marcelo M Wanderley. 2020. Open Source DMIs: Towards a Replication Certification for Online Shared Projects of Digital Musical Instruments. In *International Conference on Human-Computer Interaction*. Springer, 84–97.

[7] Lei Gao, Huidong Bai, Rob Lindeman, and Mark Billinghurst. 2017. Static local environment capturing and sharing for MR remote collaboration. In *SIGGRAPH Asia 2017 Mobile Graphics & Interactive Applications on - SA '17*. ACM Press, Bangkok, Thailand, 1–6. https://doi.org/10.1145/3132787.3139204

[8] Sebastian Günther, Florian Müller, Martin Schmitz, Jan Riemann, Niloofar Dezfuli, Markus Funk, Dominik Schön, and Max Mühlhäuser. 2018. CheckMate: Exploring a Tangible Augmented Reality Interface for Remote Interaction. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, Montreal QC Canada, 1–6. https://doi.org/10.1145/3170427.3188647

[9] Hiroshi Ishii. 2008. Tangible Bits: Beyond Pixels. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction* (Bonn, Germany) *(TEI '08)*. Association for Computing Machinery, New York, NY, USA, xv–xxv. https://doi.org/10.1145/1347390.1347392

[10] Sasa Junuzovic, Kori Inkpen, Tom Blank, and Anoop Gupta. 2012. IllumiShare: sharing any surface. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*. ACM Press, Austin, Texas, USA, 1919. https://doi.org/10.1145/2207676.2208333

[11] Seungwon Kim, Gun Lee, Mark Billinghurst, and Weidong Huang. 2020. The combination of visual communication cues in mixed reality remote collaboration. *Journal on Multimodal User Interfaces* 14, 4 (Dec. 2020), 321–335. https://doi.org/10.1007/s12193-020-00335-x

[12] Gerd Kortuem, Martin Bauer, and Zary Segall. 1999. NETMAN: The design of a collaborative wearable computer system. (1999), 10.

[13] Joel Lanir, Ran Stone, Benjamin Cohen, and Pavel Gurevich. 2013. Ownership and control of point of view in remote assistance. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, Paris France, 2243–2252. https://doi.org/10.1145/2470654.2481309

[14] Jean-François Lapointe, Heather Molyneaux, and Mohand Saïd Allili. 2020. A Literature Review of AR-Based Remote Guidance Tasks with User Studies. In *Virtual, Augmented and Mixed Reality. Industrial and Everyday Life Applications (Lecture Notes in Computer Science)*, Jessie Y. C. Chen and Gino Fragomeni (Eds.). Springer International Publishing, Cham, 111–120. https://doi.org/10.1007/978-3-030-49698-2_8

[15] David S Lee, David W Fahey, Piers M Forster, Peter J Newton, Ron CN Wit, Ling L Lim, Bethan Owen, and Robert Sausen. 2009. Aviation and global climate change in the 21st century. *Atmospheric environment* 43, 22-23 (2009), 3520–3537.

[16] Jae Yeol Lee, Gue Won Rhee, and Hyungjun Park. 2009. AR/RP-based tangible interactions for collaborative design evaluation of digital products. *The International Journal of Advanced Manufacturing Technology* 45, 7-8 (Dec. 2009), 649–665. https://doi.org/10.1007/s00170-009-2012-0

[17] Maximilian Letter, Ceenu George, and Katrin Wolf. 2022. A Survey of Computer-Supported Remote Collaboration on Physical Objects. (2022). ***Under Submission***.

[18] Maximilian Letter and Katrin Wolf. 2022. Tangible Version Control: Exploring a Physical Object's Alternative Versions. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. New Orleans, LA, USA. https://doi.org/10.1145/3491101.3519686

[19] Bibeg Hang Limbu, Halszka Jarodzka, Roland Klemke, and Marcus Specht. 2018. Using sensors and augmented reality to train apprentices using recorded expert performance: A systematic literature review. *Educational Research Review* 25 (Nov. 2018), 1–22. https://doi.org/10.1016/j.edurev.2018.07.001

[20] Liisa Mäkelä, Jussi Tanskanen, Hilpi Kangas, and Milla Heikkilä. 2021. International business travelers' job exhaustion: effects of travel days spent in short-haul and long-haul destinations and the moderating role of leader-member exchange. *Journal of Global Mobility: The Home of Expatriate Management Research* (2021).

[21] Florian Perteneder, Eva-Maria Grossauer, Yan Xu, and Michael Haller. 2015. Catch-Up 360: Digital Benefits for Physical Artifacts. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, Stanford California USA, 105–108. https://doi.org/10.1145/2677199.2680564

[22] Catlin Pidel and Philipp Ackermann. 2020. Collaboration in Virtual and Augmented Reality: A Systematic Overview. In *Augmented Reality, Virtual Reality, and Computer Graphics (Lecture Notes in Computer Science)*, Lucio Tommaso De Paolis and Patrick Bourdot (Eds.). Springer International Publishing, Cham, 141–156. https://doi.org/10.1007/978-3-030-58465-8_10

[23] 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*. ACM, Glasgow Scotland Uk, 1–17. https://doi.org/10.1145/3290605.3300458

[24] Troels A. Rasmussen and Weidong Huang. 2019. SceneCam: Using AR to improve Multi-Camera Remote Collaboration. In *SIGGRAPH Asia 2019 XR*. ACM, Brisbane QLD Australia, 36–37. https://doi.org/10.1145/3355355.3361892

[25] Alexander Schäfer, Gerd Reis, and Didier Stricker. 2021. A Survey on Synchronous Augmented, Virtual and Mixed Reality Remote Collaboration Systems. arXiv:2102.05998 [cs.HC]

[26] Franco Tecchia, Leila Alem, and Weidong Huang. 2012. 3D helping hands: a gesture based MR system for remote collaboration. In *Proceedings of the 11th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and its Applications in Industry - VRCAI '12*. ACM Press, Singapore, Singapore, 323. https://doi.org/10.1145/2407516.2407590

[27] 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*. ACM, New Orleans LA USA, 161–174. https://doi.org/10.1145/3332165.3347872

[28] Peng Wang, Shusheng Zhang, Xiaoliang Bai, Mark Billinghurst, Li Zhang, Shuxia Wang, Dechuan Han, Hao Lv, and Yuxiang Yan. 2019. A gesture- and head-based multimodal interaction platform for MR remote collaboration. *The International Journal of Advanced Manufacturing Technology* 105, 7-8 (Dec. 2019), 3031–3043. https://doi.org/10.1007/s00170-019-04434-2

[29] Peng Wang, Shusheng Zhang, Mark Billinghurst, Xiaoliang Bai, Weiping He, Shuxia Wang, Mengmeng Sun, and Xu Zhang. 2020. A comprehensive survey of AR/MR-based co-design in manufacturing. *Engineering with Computers* 36, 4 (Oct. 2020), 1715–1738. https://doi.org/10.1007/s00366-019-00792-3

[30] Te-Yen Wu, Jun Gong, Teddy Seyed, and Xing-Dong Yang. 2019. Proxino: Enabling Prototyping of Virtual Circuits with Physical Proxies. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*. ACM, New Orleans LA USA, 121–132. https://doi.org/10.1145/3332165.3347938

[31] Shun Yamamoto, Hidekazu Tamaki, Yuta Okajima, Kenichi Okada, and Yuichi Bannai. 2008. Symmetric Model of Remote Collaborative MR Using Tangible Replicas. In *2008 IEEE Virtual Reality Conference*. IEEE, Reno, NV, USA, 71–74. https://doi.org/10.1109/VR.2008.4480753