Designing Re-embodiment and Telepresence metaphors for Augmented Reality facilitated Robotic Guidance

Yifei Zhu
Colorado School of Mines
Golden, CO, USA
zhu1@mines.edu

Tom Williams
Colorado School of Mines
Golden, CO, USA
twilliams@mines.edu

ABSTRACT

Robotic assistance has been demonstrated as an effective way to provide in-person assistance, while when human users need remote assistance, Augmented Reality Task Guidance (ARTG) has been shown to be intuitive and efficient. This study explores the extension of robotic assistance in scenarios where the human and robot are no longer co-located, specifically, we investigate the design possibilities and challenges of integrating robot assistants into ARTG systems. Our design process was inspired by Re-embodiment based and Telepresence-based identity designs, where our design goal is clear communication and understanding between users and their robot helpers in AR environments.

1 INTRODUCTION

Robots have the potential to help human interactants with a variety of fundamentally different tasks, such as helping teachers to give lessons in classrooms [3], guiding passengers in busy airports [25], and teaching cardiac patients to perform breathing exercises [12]. Across this previous work, human users and their robot assistants have been **co-located** in the same physical space, meaning they can see and hear each other. However, there are many use cases in which robots may need to assist users when they are no longer co-located, e.g., to answer questions, or to step in to re-walk a user through a technical problem. There is extensive literature on the ways these types of **remote requests** for assistance from non-robotic teammates (including human teammates or nonembodied AI systems) could be enabled using Augmented and Mixed Reality technologies, in the form of *Augmented Reality Task Guidance (ARTG)*, where human- or machine-selected visual cues are overlayed over a user's field of view using an Augmented Reality Head-Mounted Display (AR-HMD) to help the user resolve the problems they face.

We argue that ARTG can expand to include robot teammates as well; When a physical robot is near the human user, the robot can provide in-person assistance; and when the robot is no longer co-located with the user, remote robot assistance can be facilitated through AR. This extends the robot's ability to help and allows knowledge (and rapport) from previous in-person human-robot interactions to be naturally referenced and leveraged during remote assistance. We term this approach *Augmented Reality facilitated Robotic Guidance (ARRoG)*. However, ARRoG is not as simple as integrating an ARTG system with an existing robotic system. Specifically, we argue that continuing previous in-person interactions through AR requires clear communication of *who* the user is interacting with. Different AR design strategies may have nuanced impacts on users' understanding of *what is real and who is real* in their Mixed Reality environment [21]. Similarly, different ways of depicting a virtual avatar for a physical robot may lead to different understandings of *who* a user is interacting with and *what* they should expect from them. Thus, in this work, we present the process and outcome of a design workshop that explored this tension by considering two candidate designs inspired by existing interaction patterns in the HRI literature: a *re-embodiment* design in which a sense of *agent migration between physicality and virtuality* is conveyed, and a *telepresence* design in which a sense of *communication with a remote agent through virtuality* is conveyed.

2 AUGMENTED REALITY TASK GUIDANCE AND ROBOTIC GUIDANCE

Robots can offer task-related assistance from providing training and information to assisting, monitoring, and guiding task execution [26]. For example, robots have been used to assist upper-limb training for post-stroke patients with positive outcomes [11, 17, 28], have acted as museum guides by providing directions for visitors [14], and collaborative robots work alongside people [13, 29], executing tasks based on operator instructions [24], and learning skills from human demonstration to perform repetitive tasks [15].

While these approaches are typically designed for co-located users and robots, *remote* robot assistance may needed in many contexts. For example, in search and rescue tasks, the physical distances between rescuers may make it impractical for physical robots to accompany them at all times. In manufacturing, robots may be stationary and incapable of moving to a user in need of help. Additionally, there might simply not be enough robots to follow each human user who might need assistance. Across these scenarios, users may need assistance from *remote* robots. For instance, Lytridis et al. [19] presented a remote robot-assisted therapy tool that was able to effectively help children with Autism Spectrum Disorder during the COVID-19 pandemic [19], similarly, robot-assisted video-based interventions were able to promote observational learning for children with ASD [27]. Meanwhile, AR has been explored in the domain of navigation and guidance with promising outcomes [31]. Gerstweiler et al. [10] presented an AR indoor navigation system for novice users, while Debandi et al. [7] developed interactive MR navigation to improve user experience, adding informative visual elements such as the history of the location. In addition to providing navigation, AR has also been explored to assist and improve training and learning [5, 22] The user scenario we envision (ARRoG) might be able to reap the benefit of both ARTG and Robotics guidance and build on prior work that exists separately in each domain. However, ARRoG by definition requires us to carefully consider the design configuration between the physical and virtual agent.

3 DESIGNED-IDENTITY CANDIDATES: RE-EMBODIMENT AND TELEPRESENCE

Re-embodiment and Telepresence are two fundamentally different models of human-robot interaction that differ in how *identity* is conceptualized, managed, and depicted. While humans typically have a single personality or identity, robots and conversational agents can flexibly change the identities they perform within and between interactions. Researchers have explored *co-embodiment* (robotic agents simultaneously occupying the same robot body) [18], and *re-embodiment* (robots' identities migrating between bodies). Participants react positively to agents re-embodying and appearing across different settings [18], and perceive agents that uses re-embodiment to take different forms in different settings as beneficial [23].

Re-embodiment is a key tool for robot designers to shape users' mental models of robotic systems [30], even when "performative" (i.e., not necessarily accurate representation of the software), as multi-robot groups that "appear" to have one robot identity migrate between bodies encourage users to maintain a more consistent and manageable set of agent mental models. Various design cues can be used to convey these different robot identity performance strategies [1, 2], and the choice of these design cues can be highly consequential, as consistent design cues can effectively be used to maintain one identity across different embodiments [20]. Accordingly, we argue that performative re-embodiment in ARRoG needs to be carefully designed, and the intended metaphor needs to be precisely conveyed to users, to encourage users to view their interactions with robots' virtual avatars as continuing previous physical interactions.

On the other hand, performative re-embodiment could be construed as intentionally deceptive, and may mislead users as to the actual capabilities of the "re-embodied" agent within the local context [4]. Moreover, performative re-embodiment might encourage users to dissociate robots' bodies from their identities (which may or may not be something that designers wish to encourage) [30]. One alternative to re-embodiment that might not involve such deception is the metaphor of *telepresence*. While re-embodiment envisions an agent migrating into a new body, telepresence envisions an agent staying where they are, but using another body or system as an appendage they can use to remotely perceive and act. Most prior work in telepresence has sought to allow human users to achieve telepresence through a robot platform [8] (e.g., in contexts like tele-surgery [6] or tele-education [9, 16]). But we believe that telepresence may also serve as a useful metaphor for remote human-robot interactions in which the robot is depicted as merely viewing the human's local context through their AR-HMD. It is possible that this metaphor could be easier for users to grapple with and buy into, and less likely to result in false capability attributions. We then conduct a design workshop to identify: **What design cues can be used to best convey the metaphors of *re-embodiment* and *telepresence* in ARRoG?**

4 DESIGN WORKSHOP

4.1 Interaction Analysis

Our design workshop aimed to explore the space of possible design cues that could be used during ARRoG interactions, and to identify which of those design cues might most effectively be used to convey the metaphors of *re-embodiment* and *telepresence*, and invoke these metaphors' associated mental models of the ARRoG interaction.

To structure this workshop, we began by analyzing the necessary *Phases* of an ARRoG interaction, in which different design cues might be needed to maintain the intended interaction metaphor. Our analysis identified four key phases of ARRoG interactions:

- Phase One: *Requesting a Connection*, in which the user initiates a connection between the remote robot and their AR-HMD to request remote assistance)
- Phase Two: *Attempting a Connection*, during which it is shown that the requested connection is being established.
- Phase Three: *Establishing a Connection*, in which it is demonstrated to the user that a connection has been established.
- Phase Four: *Demonstrating the Connection*, during which the virtual avatar for the remote robot interacts with the user to actually provide assistance.

4.2 Scenario Design

To help workshop participants understand the nature of ARRoG interaction, we grounded our design workshop in a concrete scenario designed to demonstrate a context in which an ARRoG interaction might be necessary and beneficial:

Scenario: Company X makes parts for HVAC systems. The site has a team of specialized robots that work alongside employees, providing training and helping with production. The robots have knowledge about the manufacturing process and the steps involved. However, they are pretty hefty robots and usually don't leave their stations. R is a new employee at Company X. R just finished training with Robot X-01, and is now in her designated work area, which is in a separate area from the site where the robots are. R realizes she forgot about how to perform step 3, something she just went over with Robot X-01. She decided to call the robot with her Mixed Reality headset to get some help.

A visual depiction of this scenario is shown in Fig. 1.

Figure 1: Visual depiction of our envisioned use case. This visual was shown to participants during our design workshop.

4.3 Workshop Procedure

Four participants concurrently took part in our design workshop, with a researcher acting as moderator and notetaker. The workshop lasted 2.5 hours. Participants were first introduced to the concept of

ARRoG interactions and presented with interaction scenario. The visual used is shown in Fig. 1. Then, participants were introduced to the four identified interaction Phases and their overall task for the workshop. The four Phases and the Scenario text and graphic were displayed on an LCD screen during the workshop, and participants were given post-it notes on which they could write down their thoughts.

After making sure that participants understood the scenario and were ready to begin, we asked participants to use mind-mapping to brainstorm possible design cues for each Phase and to think about what different design choices might imply about the virtual robot's status. To further guide participants, we asked them to keep in mind the scenario they were introduced to earlier and to center that scenario in their ideas or comments. Workshop participants were asked to use the provided post-its to write down proposed design cues, and their thoughts about each potential design cue. As the workshop unfolded, a skeleton mind-map containing a single example cues for each of the four main phases was displayed on the LCD screen, and participants were made free to place post-its directly onto the screen to materially augment the virtual mind map. A photo taken during this process is shown in Fig. 2.

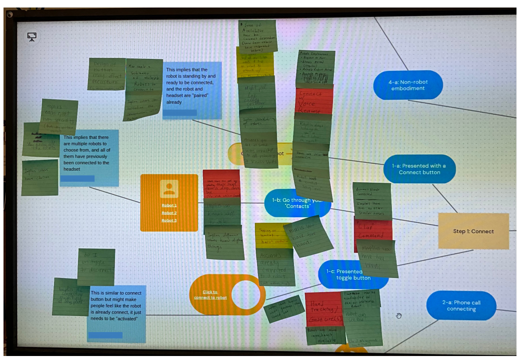

Figure 2: Photograph of part of design workshop brainstorming process

After completing this group ideation process, participants were presented with a list of all design cues ideated during the workshop, along with comments participants had made about each design cue during the workshop. Participants were then asked to fill out a questionnaire to indicate their general perception of each ideated design cue. This included questions such as:

"Does this suggest that there are multiple robots that can connect to this headset?"

"Does this suggest there's only one robot that can connect to this headset?"

"Does this suggest the physical robot will migrate to the headset?"

"Does this suggest the physical robot will not migrate but instead will talk through the headset?"

4.4 Workshop Results

Participants generated 24 total design cues. After removing four infeasible cues, 20 cues remained, which (unintentionally) were evenly distributed across the four Phases, for a result of five cues per Phase.

Next, the results of the post-workshop survey were used to choose cues from each phase that were most likely to be well-aligned with Re-embodiment or Telepresence. For example, the question "Does this suggest that the robot will migrate to the headset?" allowed us to identify design cues that might most effectively convey the metaphor of *re-embodiment*. Similarly, the question "Does this suggest ... talk through the headset" allowed us to identify design cues that might most effectively convey the metaphor of *telepresence*. In the vast majority of cases we were able to use these two questions alone to straightforwardly select design cues in each phase, using additional questions to break ties in only two cases. This thus produced a final set of design cues, with one cue selected for each of the four phases, for each of the two designs.

4.4.1 *Selected Cues: Telepresence.*

Phase One: Contact List. A "contacts list" visual shows possible robots that the headset could connect to, similar to a mobile phone contact list. Users can then select from this list to *request a connection.*

Phase Two: Calling Visual. A phone-call-like connection visual is shown while *attempting a connection.*

Phase Three: Chime Sound. A chime sound plays after *establishing a connection.*

Phase Four: Non-robot embodiment. The *connection is demonstrated* through interaction with a virtual (non-robotic) agent, such as a Siri-like orb.

4.4.2 *Selected Cues: Re-embodiment.*

Phase One: Contact Button. The user is simply presented with a "contact" button that allows them to immediately *request a connection* with the most recently interacted robot teammate.

Phase Two: Transfer Visual. A visual conveying movement, such as a glowing light moving across the screen, is shown while *attempting a connection* to convey that the physical robot is on their way.

Phase Three: "Hello, I'm Here". After *establishing a connection*, the robot teammate's voice is used to say "Hello, I'm here."

Phase Four: Full-size virtual robot. The *connection is demonstrated* through interaction with visualization of robot teammate that resembles the physical form, shown in the user's upper visual field.

5 CONCLUSION AND FUTURE WORK

In this paper, we defined a novel interaction pattern, *Augmented Reality Robot Guidance (ARRoG)*. We presented the results of a design workshop to explore the ways that two key HRI design patterns (re-embodiment and telepresence) could be used as metaphors to inform the design of ARRoG interactions. Future research can build on our results and interrogate the impacts of different design metaphors in actual AR environment. Furthermore, future work could explore an even wider space of ARRoG interaction designs (e.g., leveraging metaphors like co-embodiment and teleoperation).

About Authors:

Yifei Zhu is a PhD student at Colorado School of Mines.

Dr. Tom Williams is an Associate Professor of Computer Science at Colorado School of Mines.

REFERENCES

[1] Alexandra Bejarano, Samantha Reig, Priyanka Senapati, and Tom Williams. 2022. You Had Me at Hello: The Impact of Robot Group Presentation Strategies on Mental Model Formation. In *Proceedings of the 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*.

[2] Alexandra Bejarano and Tom Williams. 2023. No Name, No Voice, Less Trust: Robot Group Identity Performance, Entitativity, and Trust Distribution. In *IEEE International Symposium on Robot-Human Interactive Communication*, Vol. 2023. IEEE.

[3] Cynthia Breazeal and Andrea L Thomaz. 2008. Learning from human teachers with socially guided exploration. In *2008 IEEE International Conference on Robotics and Automation*. IEEE, 3539–3544.

[4] Ana Paula Chaves and Marco Aurelio Gerosa. 2018. Single or multiple conversational agents? An interactional coherence comparison. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.

[5] Po-Jung Chen, I-Wen Penn, Shun-Hwa Wei, Long-Ren Chuang, and Wen-Hsu Sung. 2020. Augmented reality-assisted training with selected Tai-Chi movements improves balance control and increases lower limb muscle strength in older adults: A prospective randomized trial. *Journal of Exercise Science & Fitness* 18, 3 (2020), 142–147.

[6] Paul J Choi, Rod J Oskouian, R Shane Tubbs, and Paul Joon Koo Choi. 2018. Telesurgery: past, present, and future. *Cureus* 10, 5 (2018).

[7] Federico Debandi, Roberto Iacoviello, Alberto Messina, Maurizio Montagnuolo, Federico Manuri, Andrea Sanna, and Davide Zappia. 2018. Enhancing cultural tourism by a mixed reality application for outdoor navigation and information browsing using immersive devices. In *IOP Conference Series: Materials Science and Engineering*, Vol. 364. IOP Publishing, 012048.

[8] Munjal Desai, Katherine M Tsui, Holly A Yanco, and Chris Uhlik. 2011. Essential features of telepresence robots. In *2011 IEEE Conference on Technologies for Practical Robot Applications*. IEEE, 15–20.

[9] Naomi T Fitter, Yasmin Chowdhury, Elizabeth Cha, Leila Takayama, and Maja J Matarić. 2018. Evaluating the effects of personalized appearance on telepresence robots for education. In *Companion of the 2018 ACM/IEEE international conference on human-robot interaction*. 109–110.

[10] Georg Gerstweiler, Emanuel Vonach, and Hannes Kaufmann. 2015. HyMoTrack: A mobile AR navigation system for complex indoor environments. *Sensors* 16, 1 (2015), 17.

[11] Leonard E Kahn, Peter S Lum, W Zev Rymer, and David J Reinkensmeyer. 2014. Robot-assisted movement training for the stroke-impaired arm: Does it matter what the robot does? *Journal of rehabilitation research and development* 43, 5 (2014), 619–630.

[12] Kyong Il Kang, Sanford Freedman, Maja J Mataric, Mark J Cunningham, and Becky Lopez. 2005. A hands-off physical therapy assistance robot for cardiac patients. In *9th International Conference on Rehabilitation Robotics*. IEEE, 337–340.

[13] Mario Kleindienst, Matthias Wolf, Christian Ramsauer, and Viktoria Pammer-Schindler. 2016. Industry 4.0: What workers need and what ICT can give-an analysis. In *16th International Conference on Knowledge Technologies and Data driven Business: 16th International Conference on Knowledge Technologies and Data-driven Business*.

[14] Yoshinori Kuno, Kazuhisa Sadazuka, Michie Kawashima, Keiichi Yamazaki, Akiko Yamazaki, and Hideaki Kuzuoka. 2007. Museum guide robot based on sociological interaction analysis. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. 1191–1194.

[15] Maria Kyrarini, Muhammad Abdul Haseeb, Danijela Ristić-Durrant, and Axel Gräser. 2019. Robot learning of industrial assembly task via human demonstrations. *Autonomous Robots* 43 (2019), 239–257.

[16] Ming Lei, Ian M Clemente, Haixia Liu, and John Bell. 2022. The acceptance of telepresence robots in higher education. *International Journal of Social Robotics* 14, 4 (2022), 1025–1042.

[17] Peter S Lum, Charles G Burgar, Peggy C Shor, Matra Majmundar, and Machiel Van der Loos. 2002. Robot-assisted movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke. *Archives of physical medicine and rehabilitation* 83, 7 (2002), 952–959.

[18] Michal Luria, Samantha Reig, Xiang Zhi Tan, Aaron Steinfeld, Jodi Forlizzi, and John Zimmerman. 2019. Re-Embodiment and Co-Embodiment: Exploration of social presence for robots and conversational agents. In *Proceedings of the 2019 on Designing Interactive Systems Conference*. 633–644.

[19] Chris Lytridis, Christos Bazinas, George Sidiropoulos, George A Papakostas, Vassilis G Kaburlasos, Vasiliki-Aliki Nikopoulou, Vasiliki Holeva, and Athanasios Evangeliou. 2020. Distance special education delivery by social robots. *Electronics* 9, 6 (2020), 1034.

[20] Alan Martin, Gregory MP O'hare, Brian R Duffy, Bianca Schön, and John F Bradley. 2005. Maintaining the identity of dynamically embodied agents. In *5th International Working Conference on Intelligent Virtual Agents (IVA)*. Springer, 454–465.

[21] Thomas K Metzinger. 2018. Why is virtual reality interesting for philosophers? *Frontiers in Robotics and AI* 5 (2018), 101.

[22] Ming Qian, John Nicholson, David Tanaka, Patricia Dias, Erin Wang, and Litao Qiu. 2019. Augmented reality (ar) assisted laryngoscopy for endotracheal intubation training. In *Virtual, Augmented and Mixed Reality. Applications and Case Studies: 11th International Conference, VAMR 2019, Held as Part of the 21st HCI International Conference, HCII 2019, Orlando, FL, USA, July 26–31, 2019, Proceedings, Part II 21*. Springer, 355–371.

[23] Samantha Reig, Michal Luria, Elsa Forberger, Isabel Won, Aaron Steinfeld, Jodi Forlizzi, and John Zimmerman. 2021. Social robots in service contexts: Exploring the rewards and risks of personalization and re-embodiment. In *Designing Interactive Systems Conference 2021*. 1390–1402.

[24] Casper Schou, Rasmus Skovgaard Andersen, Dimitrios Chrysostomou, Simon Bøgh, and Ole Madsen. 2018. Skill-based instruction of collaborative robots in industrial settings. *Robotics and Computer-Integrated Manufacturing* 53 (2018), 72–80.

[25] Rudolph Triebel, Kai Arras, Rachid Alami, Lucas Beyer, Stefan Breuers, Raja Chatila, Mohamed Chetouani, Daniel Cremers, Vanessa Evers, Michelangelo Fiore, et al. 2016. Spencer: A socially aware service robot for passenger guidance and help in busy airports. In *Field and Service Robotics: Results of the 10th International Conference*. Springer, 607–622.

[26] Konstantinos Tsiakas, Vangelis Karkaletsis, and Fillia Makedon. 2018. A taxonomy in robot-assisted training: current trends, needs and challenges. In *Proceedings of the 11th Pervasive Technologies Related to Assistive Environments Conference*. 208–213.

[27] Diego Antonio Urdanivia Alarcon, Sandra Cano, Fabian Hugo Rucano Paucar, Ruben Fernando Palomino Quispe, Fabiola Talavera-Mendoza, and María Elena Rojas Zegarra. 2021. Exploring the Effect of Robot-Based Video Interventions for Children with Autism Spectrum Disorder as an Alternative to Remote Education. *Electronics* 10, 21 (2021), 2577.

[28] Janne M Veerbeek, Anneli C Langbroek-Amersfoort, Erwin EH Van Wegen, Carel GM Meskers, and Gert Kwakkel. 2017. Effects of robot-assisted therapy for the upper limb after stroke: a systematic review and meta-analysis. *Neurorehabilitation and neural repair* 31, 2 (2017), 107–121.

[29] Ales Vysocky and Petr Novak. 2016. Human-robot collaboration in industry. *MM Science Journal* 9, 2 (2016), 903–906.

[30] Tom Williams, Daniel Ayers, Camille Kaufman, Jon Serrano, and Sayanti Roy. 2021. Deconstructed trustee theory: Disentangling trust in body and identity in multi-robot distributed systems. In *Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. 262–271.

[31] Meng-Lin Wu and Voicu Popescu. 2017. Efficient VR and AR navigation through multiperspective occlusion management. *IEEE transactions on visualization and computer graphics* 24, 12 (2017), 3069–3080.