TableBot: Getting a Handle on Hybrid Collaboration by Negotiating Control of a Tabletop Telepresence Robot

Maja Dybboe*
dybboe@cs.au.dk
Aarhus University
Aarhus, Denmark

Johannes Ellemose*
ellemose@cs.au.dk
Aarhus University
Aarhus, Denmark

Alexander Langagergaard Vastrup
Alexanderv1997@gmail.com
Aarhus University
Aarhus, Denmark

Andriana Boudouraki
andriana.boudouraki@nottingham.ac.uk
University of Nottingham
Nottingham, United Kingdom

Sean Rintel
serintel@microsoft.com
Microsoft Research
Cambridge, United Kingdom

Marianne Graves Petersen
mgraves@cs.au.dk
Aarhus University
Aarhus, Denmark

Jens Emil Sloth Grønbæk
jensemil@cs.au.dk
Aarhus University
Aarhus, Denmark

Clemens Nylandsted Klokmose
clemens@cs.au.dk
Aarhus University
Aarhus, Denmark

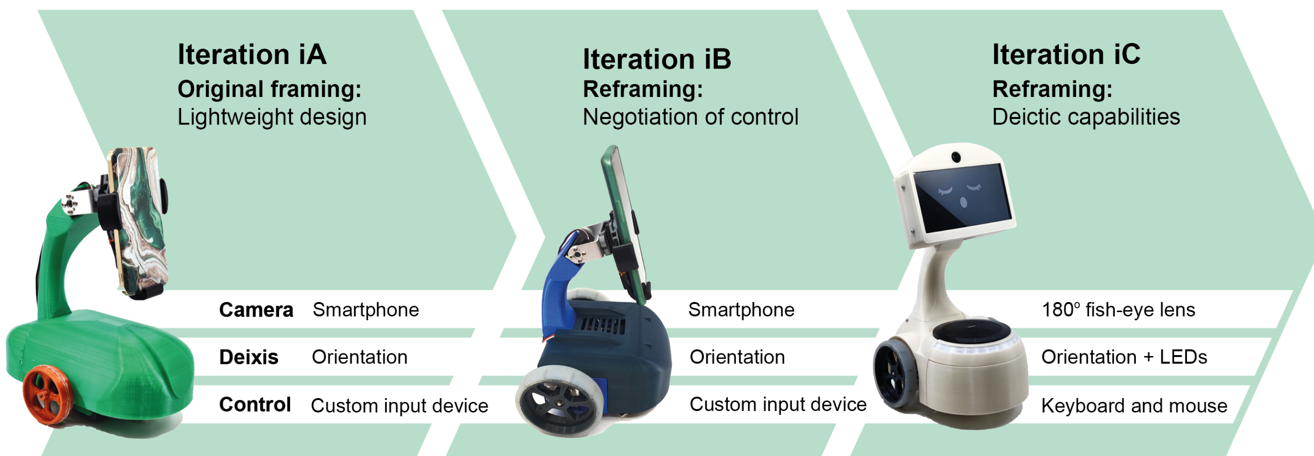


Figure 1: An overview of the iterations of TableBot and the framing used in the design process: Iteration 1 (*iA*) framed the design in terms of a lightweight design. Iteration 2 (*iB*) reframed the design to focus on negotiation of control. Iteration 3 (*iC*) reframed the design again, to focus on deictic capabilities in hybrid settings. Limitations and opportunities in the design space were identified through explorative studies, which motivated the reframings.

ABSTRACT

Mobile Remote telePresence robots (MRPs) have been explored as a promising approach to strengthen the agency and presence of remote participants in hybrid work settings. Despite the need and interest in how they might better support hybrid collaboration, substantial challenges remain in terms of their price, availability, and successful application in meeting room contexts. In response to these challenges, this paper explores the opportunities for designing lightweight telepresence robots supporting negotiation of control in hybrid meeting contexts. This paper describes a serial Research-through-Design process, exploring three iterations of design and evaluation of TableBot, a novel tabletop telepresence robot. Based on this work, we present the design of TableBot, and articulate the design space of telepresence robots for hybrid meetings in terms of three trade-offs and a framework for analysing telepresence systems regarding negotiation of control.

*Equal contribution.

NordiCHI 2024, October 13–16, 2024, Uppsala, Sweden

ACM ISBN 979-8-4007-0966-1/24/10
https://doi.org/10.1145/3679318.3685350

CCS CONCEPTS

• **Human-centered computing** → **Collaborative and social computing devices**; **Empirical studies in collaborative and social computing**.

KEYWORDS

Hybrid Collaboration, Telepresence Robots, Research through Design, Non-human design, Robomorphism, Negotiation of control

ACM Reference Format:

Maja Dybboe, Johannes Ellemose, Alexander Langagergaard Vastrup, Andriana Boudouraki, Sean Rintel, Marianne Graves Petersen, Jens Emil Sloth Grønbæk, and Clemens Nylandsted Klokmose. 2024. TableBot: Getting a Handle on Hybrid Collaboration by Negotiating Control of a Tabletop Telepresence Robot. In *Nordic Conference on Human-Computer Interaction (NordiCHI 2024), October 13–16, 2024, Uppsala, Sweden.* ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3679318.3685350

1 INTRODUCTION

Hybrid meetings have emerged as a compromise between telecommunication and traditional co-located collaboration [19, 47]. Having one or more participants connect via videoconferencing enables more flexible collaboration for distributed teams, but is not without problems; asymmetries regarding social behaviour, cultural expectations, and technical limitations affect outcomes for all parties [16, 57, 61, 68]. Videoconferencing research has addressed these asymmetries through a variety of techniques for imitating the physical presence of remote people, albeit often through complex and expensive hardware and software combinations, such as specialised rooms with visual illusions of co-presence [50], altered methods for viewing people in spatial configurations [38, 60], projection [25, 30, 35], and physical proxies of remote people, including using robots [3, 29, 54].

Of these varied solutions, Mobile Remote telePresence (MRP) is especially promising because it creates a sense of embodiment and physical presence for remote participants in hybrid settings, while providing strong agency and autonomy for remote users [23, 28, 49, 56, 64, 68]. Studies have showed how remote participants using MRPs feel engaged and express a high feeling of presence [45, 55]. For co-located meeting participants, even simple, small movements can convey a sense of presence from a remote participant using an MRP [69].

However, the high price and one-size-fits-all design means that existing physical settings must be adapted to the MRPs, rather than them being adopted in the varied settings of hybrid collaboration [9, 11, 36, 53]. Further, while MRPs are designed for roaming around potentially large physical areas (typically one or more floors in buildings), they are mostly used in meeting settings [13, 50]. Here, they are a poor fit, as they are clunky and hard to manoeuvre around furniture. They are cumbersome for the co-located meeting participants to move around due to their weight and size, so the co-located participants can mostly assist by moving furniture out of the way [11]. Also, it can be perceived as inappropriate for the co-located participants to interact with the robot body, even when the remote participant is exhibiting a lack of spatial and situational awareness [36, 64]. When digital tools such as shared documents or digital whiteboards are used, the MRP becomes less useful as the embodiment does not assist in the collaboration [13].

The shortcomings of MRPs in meeting settings motivates our design rationale for a MRP system with the following characteristics: (1) accessibility through a physically and technically lightweight design, (2) focus on meeting contexts where access to the physical tabletop is important, and (3) promote local assistance of the remote participant by designing for shared control of the robot. To explore this design space, we have designed TableBot: A tabletop telepresence robot in three prototype iterations (*iA*, *iB* and *iC*). TableBot embraces the asymmetries of MRP through a non-human 'cute' design, and promotes shared control through a novel 'neck'-handle that affords co-located participants the ability to lift and move the robot. TableBot is designed for a hub-satellite configuration of hybrid meetings, where one participant is remote (satellite) and the remaining are co-located (hub) [62]. We have adopted a serial Research-through-Design (RtD) approach [33, 70] for the iterative design of TableBot. This process started from a no-knowledge perspective, which also impacted the design direction of TableBot [51]. This design process is characterised by iterative framings and reframings [71] which direct the progression of the design and focus in the accompanying qualitative studies (see Figure 1). In this process, the framing and refraimings are central in both the actions and outcomes of the design process [71].

Through all iterations of TableBot we aim to illustrate the potentials of tabletop MRP in hybrid meeting settings, by embracing the unique design opportunities of tabletop telepresence systems. We explore the design space for shared control and the *negotiation of control* over the robot. We further explore how non-verbal communication, such as deictic gesturing and direction of focus, is expressed and understood when using a robot representation. Finally, we underline a bias in existing research on telepresence systems on to how control of the system is negotiated. All these explorations emerge from the continuous focus shift of framing and reframing of TableBot during the design and evaluation process.

In line with existing research, we use the terms 'remote participants', and 'co-located participants' when discussing hybrid collaboration. To refer to the remote participant who is piloting our telepresence robot, TableBot, we use the term 'pilot', to distinguish it from other research.

This paper first presents an overview of the existing research into telepresence systems and hybrid communication. We then present TableBot, our iteratively designed tabletop telepresence robot as well as our method for designing and experimentally studying our designs. Next we present our findings, and analyse them through three identified design trade-offs and finally discuss the perception of TableBot and the pilot on the possibilities for negotiated control through a proposed framework that encapsulates the trade-offs.

With this paper we make the following contributions:

- TableBot, a novel, lightweight, non-humanoid tabletop telepresence robot with a handle to encourage shared control.
- Based on a serial RtD process guided by several reframings, Negotiation of Control is proposed as a focus area for future tabletop telepresence robot research.
- An analysis of trade-offs in the design of tabletop telepresence systems derived from the serial RtD process.

- A framework, based on the trade-offs, for designing telepresence systems that support negotiation of control.

2 RELATED WORK

In this section we present an outline of social practices in hybrid communication, followed by an overview of different approaches to designing telepresence robots. Finally, we explore non-verbal language and deixis in hybrid collaborative settings, and how different views affect the use of telepresence robots.

2.1 Social Practices in Hybrid Collaboration

Hybrid communication relies on various technologies to mediate remote participants. This often hinders their ability to precisely express themselves compared to the co-located participants, as implicit meanings easily get lost in the mediation [16, 40]. To further complicate hybrid communication, Saatçi et al. [57] found that the social and cultural norms of each participant affect the success of hybrid meetings, as there may be disagreements between spaces regarding how to do turn-taking or if interruptions are acceptable. Others have provided additional insights and vocabulary to describe hybrid collaboration, emphasising technological asymmetries as either an obstacle [50], an opportunity [31, 67] or an unavoidable design challenge [40, 41]. Common for all these approaches is that asymmetries need to be addressed for hybrid communication to be successful.

Communication mediated through technology limits many communicative cues, that leads to remote participants being overlooked or under-utilised [22, 46, 57]. Bos et al. [10] found that in hybrid groups, remote participants were often delegated to supporting roles while co-located participants performed the most influential tasks among themselves. The text-based communication in Bos et al.'s study limited the ability for the remote participants to get attention, which made it easy for the co-located participants to overlook them. Almeida et al. [2] suggest presence to be a key contributor for successful collaboration, having both remote and co-located participants continuously acknowledging each other, similarly to other works [15, 52] which explore transferring existing social procedures to a hybrid space. Boudouraki et al. suggest that presence in hybrid should not be understood as the illusion of 'being there', but rather "a remote user's ability to participate and successfully 'gear into' everyday social interaction" [12, p. 63]. In either case, designing for presence is complex and success relies on the social structure of the group and the task to perform, leaving designers with little control of anything but how to represent the remote participants.

With TableBot, we provide a remote participant with a physical proxy in the co-located space. This provides the remote participant with enhanced presence in that space, and its affordances allow the remote participant to take a greater part in certain activities in the space.

2.2 Mobile Robotic telePresence

One way of achieving presence through a physical representation is through a MRP which is characterised by their imitation of human size and walking speed [17, 56]. MRPs allow the pilot to roam a space, enabling access to physical spaces not otherwise available [29, 49]. The ability to change views has been found by Nakanishi et al. [45] and Rae et al. [55] to be engaging for the pilot and improve the sense of being there. Additionally, Nakanishi et al. [45] found that having no control of the changing views had a negative influence on engagement of the remote participant. Studies of long-term impact of using MRPs, both in office environments [36, 64] and at home [53, 68], has found that the physical representation is supportive for a sense of mutual presence.

One limitation of MRPs is their size. They are difficult to position comfortably around a meeting table, and they are easily in they way of co-located participants, while their weight makes it cumbersome for co-located participants to reposition them [13, 36]. Smaller tabletop telepresence robots can address some of these issues, but have not been studied to the same extend as human-sized MRPs. MeBot explore gesturing and advanced input devices [1], while others explore swarm-style systems [37] or leverage the size asymmetry through cute designs [43, 63].

Using telepresence robots for hybrid collaboration present unique challenges. Schouten et al. [59] coined the term *Robomorphism* to describe when people apply robotic traits to a telepresence robot mediated interlocutor, perceiving them as both a human and robot simultaneously. This can often lead to social breakdowns [64], but also present opportunities in the non-human abilities these systems afford [37].

TableBot is a standalone tabletop MRP system designed for the meeting table. Through non-human traits, like a handle which affords co-located participants to reposition TableBot through grabbing it around its 'neck', TableBot attempts to leverage Robomorphism into a positive, rather than negative, quality.

2.3 Supporting Deixis and Gestures for Telepresence Robots

The typical physical design of MRPs does not include explicit tools for non-verbal communication beyond the general orientation of the robot. In a collaborative setting non-verbal communication is key to inform intent, meaning, and referencing using deixis [6]. The gestures used for this will vary in complexity depending on the message [21]. Several researchers have explored the use of non-verbal language in hybrid settings, ranging from simple solutions [20, 32, 34] to immersive, albeit complicated solutions [3, 28, 30, 35]. However, other studies have found that the orientation of a system alone can be very expressive [58, 69] especially with the support of verbal relational deixis to indicate specific areas of interest [44, 65].

To support these deictic capabilities the remote participant must have a good understanding of the space they navigate, motivating a wide field of view (FOV). However, too wide view can make the pilot overwhelmed, but with a too narrow view the understanding of the space is limited by what Johnson et al. calls *the keyhole effect* [26]. A compromise of 180° provides a comfortable view while encouraging changing orientation [5, 26].

TableBot explores how to convey deixis through a tabletop telepresence robot in a social setting through the orientation of the screen, inspired by Sakashita et al. [58]. *iC* expands this exploration to encompass different FOVs and their influence on participation, as well as simple tools to convey non-verbal deixis.

3 THE TABLEBOT CONCEPT

TableBot is a tabletop telepresence robot with a focus on a lightweight construction. We understand lightweight as having two parallel meanings: the physical system should be light and small to easily be moved and carried, while also being technologically lightweight and designed with affordable components. Although three iterations of the TableBot system were build, all iterations follow a simple combination of features. Variations in design are attributed to the serial RtD approach we adopted.

At its core, TableBot is a tabletop proxy for the pilot, representing them through a video call on a robot body. It is designed for a meeting setting with a hub-satellite configuration [62], where the pilot can roam a tabletop and orient towards those speaking or the relevant task space.

Common for all TableBot prototypes is a base with wheels to move the robot using differential steering and the ability for the attached camera and screen, used for facilitating a video call, to tilt up and down (see Figure 1). This camera and screen, whether as a smartphone or integrated into the design, is held by an arm connecting it to the base, lifting the camera and screen up to a comfortable height for conversation for both parties. The arm is shaped as a handle, providing the novel feature of allowing the co-located participants to grab, and thus lift and move, TableBot for a shared control of the robot, and of the pilot's view into the co-located space. Only the first iteration of TableBot included sensors to prevent the robot from driving off the edge of the table. They were removed in later iterations as they were not essential to the use of the robot or the studies.

Standing between 35 and 45 cm tall, depending on iteration, TableBot is small enough to be looked over by the co-located participants, but large enough to grab attention when moving. TableBot is made from low-cost, off-the-shelf components, connected by a 3D printed body to maintain a lightweight design (estimated price of components for *iA* $130, for *iB* $150 and for *iC* $490 US, *iA* and *iB* is excluding the needed smartphone).

4 METHODOLOGY AND DESIGN PROCESS

Prior to starting this work, few of the authors had prior knowledge with designing MRP systems. This allowed the design process to be explored from a position of partial and no knowledge about the domain [51], allowing the unforeseen to guide the design alongside observations. To structure the iterative exploration, we adopted a serial RtD approach [4, 8, 33, 70] where each iteration acted as a design experiment. These were explored over the span of 1.5 years, with each design experiment including an iteration of the tabletop telepresence robot as well as a study to systematically explore the qualities of the design. Each experiment provided insights through qualitative studies of the design iteration in a social context.

The RtD design process enables exploration of a research domain through rapid prototyping, frequent formal studies, and drifting [33], based on the findings from those studies. The serial approach enabled adapting each design according to those findings from the previous experiment, connecting all experiments as a serial progression towards our understanding of the design space. The process also enables the initial framing to evolve and be reframed as one experiment drift in an unexpected direction [71]. The process is often messy and difficult to present [18], but it is in the iterative reframing that the process and design space is revealed [71]. The reframing from one experiment to another forces restrictions to the process, as not all limitations and presented questions in the design process can be explored. Through the prioritisation of certain elements, the process is further shaped.

In this work we map the driftings in our design process, and the changes in both focus and designed artefacts this has resulted in, as the RtD process has framed and reframed the problem [71]. The framing and reframing of the RtD process is difficult to replicate, and thus difficult to generalise. However the RtD contribution is in the repeated themes of the experiments and findings from the supporting qualitative studies [51]. The contribution of the reframing process consist of an outline of an authentic design exploration of which the reframings were an organic design evolution, essential to the findings of this paper [71].

In the remaining section we present the RtD process of TableBot with the progression of driftings, and how this approach enabled us to produce informed designs through structured explorations. The section is structured based on the framings and reframings to illustrate the progression and repetition of themes in the design process. Each framing presents the design progression as well as the accompanying study.

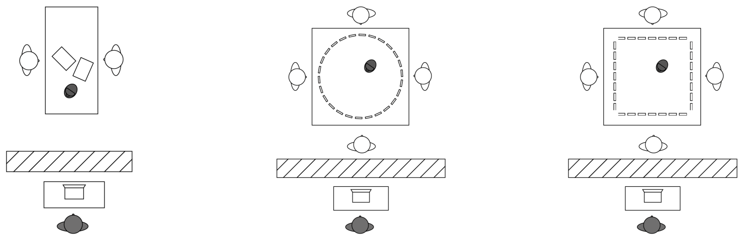
All user studies were conducted from a convenience population of primarily university students. A total of 43 participants (17 female, 26 male) were recruited, aged 20–58 (M 25.81, SD 6.05). We collected informed consent from participants before each study, and explained the study and its purpose to the participants. All collected data was stored in compliance with GDPR. We found no ethical issues in conducting any of the studies, and the studies were not submitted to any ethics board for review.

4.1 Framing: Lightweight design

The first iteration of TableBot (*iA*) was motivated by autoethnographic observations [39]. These were performed during the COVID-19 pandemic by three of the authors regarding hybrid, collaborative, product design processes. We observed that the remote participants wished to be able to autonomously control the camera orientation and position, to participate in design activities. This inspired an interest in MRP systems and their application in collaborative settings, as they exhibit these abilities. Another observation was the benefit of allowing co-located participants to easily relocate the remote participant's mediation to different tables or rooms as an activity evolved. Based on these observations, we wanted to explore designs which afforded autonomy to the remote participants, while utilizing the situational awareness of the co-located participants to benefit collaboration. Since our observations were partly based on our own practices, we decided on an autobiographical design approach [48], supported by existing literature on MRP and hybrid meetings.

To address our observations, we decided to model *iA* as a lightweight system, that lives on the tabletop, rather than on the floor like traditional MRP-systems do. Based on these system goals, we chose to use a smartphone as the medium for the video-call.

4.1.1 Evaluation. *Study* 1_{iA} was a proof of concept study. The goal of the study was to explore if the concept of a lightweight and



(a) Study 1_{iA} **(b) Study 2_{iB}** **(c) Study 3_{iC}**

Figure 2: Setup of all three studies with TableBot. The pilots and iterations of TableBot are annotated with grey.

Parameters	Study 1_{iA}	Study 2_{iB}	Study 3_{iC}
Iteration	*iA*	*iB*	*iC*
Framing	Lightweight design	The handle as tool for negotiation of control	Deictic capabilities for the pilot
Purpose	Pilot study: Proof of concept of a lightweight telepresence robot	Exploring the robot in a high paced social setting and sharing control with the handle	Exploring the pilots understanding of a social context vs being understood
Task	Design a poster	Play a board game	Play a board game
Participants	2 groups of 3 (6)	4 groups of 5 (20)	4 groups of 5 (20)
Duration	20 minutes	3 x 20 minutes	3 x 20 minutes
Key Finding	The concept is feasible, but provides uneven power distribution	A constructive negotiation of control between all participants leads to easy participation of the pilot	The wide FOV was preferred, but the deictic tool did not work in a social context

Table 1: Overview of the studies conducted with TableBot

accessible telepresence robot was feasible, and to provide direction for future work (see Table 1). Three participants, two co-located and one pilot, were tasked to collaboratively create a promotional poster using printed materials and art supplies in the co-located space (see Figure 2a). The participants were introduced to the telepresence robot, its controls, and the open-ended task, as a group. No instructions were given regarding the division of labour or how to structure the task. The pilot was chosen by the group and escorted to an adjacent room along with the controller, marking the start of the task. Both spaces, pilot and co-located, were observed by the authors, and the co-located space was video recorded. After 20 minutes the task concluded with a focus group interview of around 20 minutes with all participants. The interview was conducted by three of the authors, where one was delegated to note taking. The interviews focused on how the participants structured the work, how the co-located participants experienced the robot and the pilot, and how the pilot experienced the collaboration. Two rounds of study were conducted. The interview responses were used in conjunction with the video recording and observations to evaluate the design by the same three authors, by reviewing key moments noted during the task for insights.

4.2 Reframing: Negotiation of Control

The next iteration, *iB*, was designed to address the primary shortcoming of *iA* found in *study* 1_{iA}: *iA* was too slow to follow a conversation. We replaced the stepper motors used in *iA*[1] with faster motors[2], which required some redesign of the implementation and the 3d-printed body to accommodate their larger size.

In study 1, the participants expressed unease and lack of comfort in how to respond when the pilot performed actions through the robot that disrupted the collaborative task. This motivated *study* 2_{iB} to further explore negotiation of control in a hybrid setting with a tabletop telepresence robot. In *study* 1_{iA}, the handle had not been used due to the uneven power distribution and was thus a point of interest to us. With iB, we wanted to address the handle, as a novel part of our design, by designing a task which explored role distribution and negotiation of control through the use of the handle.

4.2.1 Evaluation. *Study* 2_{iB} had a twofold purpose; to understand what happens when TableBot was placed in a high-paced social

[1]Stepper motors in *iA*: 28BYJ-48 5V
[2]Stepper motors in *iB*: Nema 17HS4401

setting, and how participants communicate and negotiate a shared control of the telepresence robot and thus the view into the co-located space for the pilot (see Table 1). The task for *iB* was inspired by the boardgame Codenames[3] and required the pilot and four co-located participants to collaboratively choose the correct words positioned in a circle around the table to score points (see Figure 2b. The task was designed to challenge as many aspects of the robot as possible.

No instruction on how to move the robot was provided to the co-located participants, and all participants were encouraged to freely interpret the rules of the task. The negotiation of control was explored by each round having different parties control the view of the pilot; full control to the pilot, full control to the co-located participants, or shared between both parties. These three conditions were examined in a within subject manner, with the first two rounds being counter balanced and the final round being shared control.

After three rounds of the game each taking 20 minutes, a focus group interview of around 20 minutes with each participant group concluded the study. The interviews focused on the negotiation of control between participants and how it was experienced from either end of the video call, and were conducted by two of the authors. Four rounds of study were conducted.

All rounds of study were video recorded from both the remote and co-located space, robot movements were logged, and the focus group interviews were transcribed and analysed using a thematic analysis [14], with a focus on how the robot was perceived. The video recordings were analysed with regards to patterns of movement in relation to the task. Interesting episodes were further analysed with a focus on robot movements, conversation, and inclusion of the pilot, by mapping who spoke and to whom, how much the robot moved, and when the co-located assisted the pilot. These analyses were performed by the same authors who conducted the interviews.

4.3 Reframing: Deictic Capabilities

Study 2_{iB} provided valuable insights which motivated the design of *iC*: The narrow FOV of *iB* was helpful to understand the locus of attention (LOA) of the pilot, but limited the pilots ability to understand and navigate the co-located space. The findings of *study* 2_{iB} suggest that a wider FOV would result in increased autonomy and engagement for the pilot. Additionally, the better spatial understanding provided by a wide FOV could provide the pilot with a better position in the negotiation of control as the pilot could have an improved sense of capabilities and needs. However, as mentioned, the narrow FOV also provided benefits to both the pilot and co-located participants: The pilot's LOA was very clear to the co-located participants.

To address these benefits and drawbacks into one design, we considered ways of providing the pilot with a blurred periphery, providing spatial awareness, while maintaining a clear LOA of the pilot for the co-located participants. Our solution centres around the graphical user interface provided to the pilot in which the videofeed is presented. A variety of customizable CSS layers on top of the video feed, which can be toggled on of off, allow control of the FOV and application of a blurred filter to provide a blurry periphery, with a focused area in the centre (see Figure 3). Using the mouse and a click-and-drag interaction, the user can move the blurry CSS layer and thus the focused area. The width of the video feed is directly mapped to the LED's along the curved front of the robot, meaning that any point in the width of the video feed corresponds to a set of LEDs. Moving the focused area activates the LED's corresponding to the direction, implicitly indicating where the pilot is looking to the co-located participants, by integrating it into the interaction itself. With this design, our intend was to provide a way for the pilot to show their LOA to the co-located participants, while at the same time giving the pilot greater spatial and situational awareness compared to a standard FOV video feed.

Figure 3: A screenshot showing the dynamic filter applied to *iC*. The area of the view around the cursor (left side) is in focus, while the rest is blurred. Clicking causes TableBot to rotate to move the clicked area to the center of the screen.

To provide a wide FOV, we replaced the smartphone previously used to facilitate the video call, with an integrated wide FOV camera[4], a conference speaker system[5], and an integrated 7" display.

During *study* 2_{iB}, the participants expressed being afraid that the robot would break from being handled and carried. To address this, the robot body was completely redesigned to convey a sense of polish and robustness in the design, while keeping it soft and approachable, maintaining a grab-able handle. This was done alongside the redesign needed to accompany the new components.

4.3.1 Evaluation. The purpose of *study* 3_{iC} was thus to examine how different FOVs and the inclusion of the dynamic filter affect the feeling of presence for both the pilot and the co-located participants, and if the LED-strip attached to *iC* could establish reciprocal understanding of the pilot's LOA.

We initially performed a set of minor lab experiments to examine the readability of a dynamic, blurry filter and LED strips. The experiments suggested the LEDs were readable as deictic indicators, and that the filter did not excessively restrict the remote participant. Based on these initial findings, we chose a setting with a medium intensity of the blur (12 pixel radius gaussian blur), with the unblurred area being equal to 10% of the width of the view, since these were the expressed preferences. Three LEDs were chosen to indicate the pilot's LOA on the robot, since it was the slightly better performer than other settings explored.

We used the same setup for the user study as in *study* 2_{iB}, and performed the same data collection. Three conditions were examined within subject; a standard 60° video FOV similar to that of

[3]Codenames official website: https://codenamesgame.com/

[4]Fish-eye lens camera on *iC*: ELP-USBFHD01M-L180

[5]Speaker and microphone in *iC*: Jabra Speak 510

study 1_{iA} and 2_{iB}, a 146° wide FOV which was the widest view possible, and a 146° wide FOV with a dynamic filter applied. Four rounds of study were conducted with counterbalanced conditions, alternating between the 60° FOV and the wide view with applied dynamic filter, always finishing with the wide view with no filter. We reused the task from *study* 2_{iB}, using the same setup, and number and distribution of participants to allow for comparative analyses between the two iterations (see Figure 2c).

Participants were presented to the robot and it's capabilities, instructed in the task, and chose who among them should be the pilot. A focus group interview of around 20 minutes with each participant group concluded each round study, conducted by three of the authors. These interviews focused on how the different FOVs and the LED-strip were experienced by the pilot and co-located participants. Recordings of the study were reviewed for interesting episodes, which were analysed with regards to robot movement, conversation, use of the LOA indicator, and inclusion of the pilot. Interview responses were transcribed and analysed though a thematic analysis [14] by the same authors who conducted the studies and interviews.

5 FINDINGS

In this section we present the findings from all studies performed to evaluate the design of each iteration of TableBot. The findings of each study were explored separately and used as reason for the reframings of TableBot. The limited variation in the concept of TableBot, and the consistent study setting, enabled the studies to be comparable. Through a thorough comparison of the findings from all studies, a set of recurring themes evolved, highlighting different challenges found in the concept of TableBot. In the following we present these three themes supported by observations and quotes. Each theme includes a short observed episode from a specific study, emphasising the theme.

5.1 Indication of Focus

When the pilot of *iC* had a wide FOV into the co-located space, it became difficult for the co-located participants to understand where the pilot's focus were. While our initial, minor lab experiments found that the LED's deictic abilities are easily readable, in the exploratory study the LED's was often overlooked or ignored. Rather, we observed in *study* 3_{iC} the co-located participants using the screen orientation to read the pilot's LOA, although this was not necessarily precise when the pilot had access to a wide FOV.

When referring to artefacts, the participants had to rely on verbal explanations to ensure the same artefact was discussed. In contrast, in *study* 2_{iB}, the limited view of *iB* was used as an anchor point for verbal deictic references, and was transformed into a benefit for an intimate, personal side-interaction between a co-located participant and the pilot:

Dance session: *While waiting for the next round to start, the pilot changes view from one participant to another. The person being switched to reacts excited to having the attention on them, and expresses this first with an exaggerated facial expression which is followed up by a small dance. The pilot responds by participating in the dance. After a few seconds of dancing, the pilot asks "can the others see me dancing as well?", to which they all respond "no" followed by laughter and small-talk as the dancing ends.*

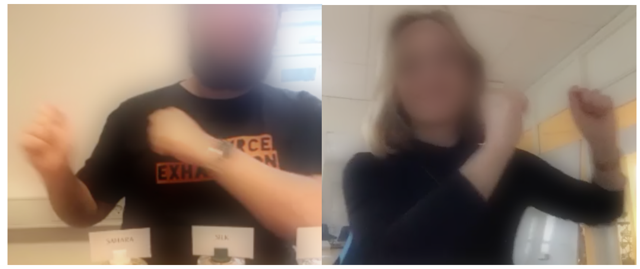


Figure 4: The dance session where the pilot and one co-located participant initiated a small dance during the task.

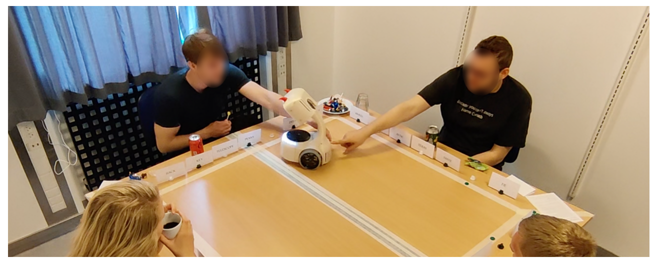


Figure 5: The robot glitching episode where technical limitations in *iC* encouraged the co-located participants to support the pilot.

While this dance session illustrates the potential benefits of a narrow, limited FOV, *study* 3_{iC} found that all participants, remote and co-located, prefer a wide FOV, which provided the best sense of presence for both parties.

This presents a design trade-off, balancing the situational awareness of a wide FOV with the clear indication of focus with a limited FOV, which is elaborated on in 6.2.1.

5.2 Getting Attention

The various studies conducted with TableBot indicate the ability to grab attention is uneven depending on the context and number of co-located participants. *Study* 1_{iA} indicated that TableBot easily could attract attention from the co-located participants, simply by moving. In the larger study setting of *study* 2_{iB} and 3_{iC} the remote participants found it harder to get attention, especially non-verbally. Interviews indicate that the amount of movement the robot did corresponded with the amount of attention given to the pilot, as in *study* 2_{iB}, when the pilot was not allowed to move the robot, the pilot was more likely to be excluded than when being able to move the robot, as expressed by one pilot: "It was very challenging to be unable to control [the view]. I did not feel as much a part of [the task]."

The most notable way in which TableBot was able to grab attention was during breakdowns, such as when a motor got stuck, resulting in noise and jittering that was distracting to the co-located participants. An example of this happened in *study* 3_{iC} (see Figure 5):

Robot glitching: *After navigating the space a bit, the motors on TableBot get stuck, causing a jittering motion which catch the attention of the co-located participants. The pilot asks 'am I stuck?' to which one co-located participant replies 'where do you want to go?' while another give the robot a small push to see if it helps release the motors. The pilot is able to move for a bit, before the motors get stuck once more. This causes the co-located participants to give the robot another small push which is not enough. The pilot then asks 'can you lift it a bit? Can you lift me?' as a way to alleviate the issue of being unable to move properly. A final large push seems to fix the motors for the pilot, who exclaims 'thats it!' and resumes roaming the task-space.*

In the above episode both the co-located participants and the pilot is affected by glitches as it distracts from the task. The attention to limitations made the co-located participants interact with the robot in ways ranging from requests to suggestive actions, yet none were deemed inappropriate by the pilot who continued with the task. This hints to a trade-off in the design, both providing a sturdy design that does not disrupt conversations, but also encouraging exhibiting the limitations of the system to motivate supporting the pilot, further elaborated on in 6.2.2. Other findings from our studies show how designing for negotiation of control can be a negative for the remote participant, which are presented next.

5.3 Negotiating Control of the Robot

Negotiation of control is a central design focus of TableBot, however it was not always a successful experience for the participants. The narrow FOV of iteration *iB* made the perceived distance to participants seem greater than what with the wide view of iteration *iC*. A co-located participant in *study* 3_{iC} noted: "[The robot] sometimes comes all the way into your private sphere," while the pilot's perspective was different: "[I] don't really think I [the robot] came too close to them [the co-located participants]." Despite this, in the focus-group interviews in *study* 2_{iB}, the co-located participants expressed that moving the robot felt like a violation of the remote participant's space and would rather not do it. However, when the robot exhibited technical glitches, visible through shaking motions, we observed the co-located participants quickly supporting the pilot without being asked. They expressed that TableBot in these cases was perceived less as the pilot and more as a robot, and thus it was easier to grab it: "I did not see [the pilot] or something [human], so it was not that bad [to move the robot]." Iteration *iC* exhibited only technical glitches in one group, where the co-located participants quickly moved the robot to support the pilot. In no other group during *study* 3_{iC} did the co-located participants support the pilot as they expected the pilot to not need any support due to the polished design, and lack of verbal requests from the pilot: "Not even once did I consider that we could actually move [the pilot]." Another participant found the shape of the handle enticing, but did not grab it since the pilot seemed mobile enough: "[The pilot] seemed very mobile [...], but I wanted to do it [move the robot], because the neck looked very comfortable to hold." This glitching episode also illustrate how the perception of the pilot and TableBot is dynamic, similarly to the findings of Takayama and Go [64]. Depending on the situation and context, the co-located participants might see TableBot as an intentional proxy of the pilot, or as a piece of equipment that happens to be mediating the pilot.

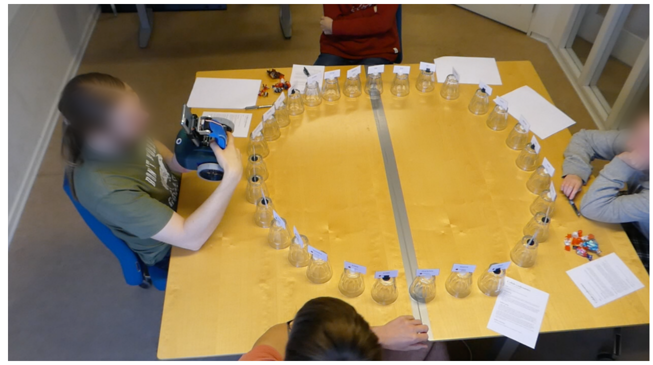


Figure 6: The hostage episode where one co-located participant lifted TableBot and thereby removed the pilots control.

In *study* 2_{iB} one of the pilots was very explicit about needs from the co-located participants and boundaries, which encouraged the co-located participants to support the pilot even when not explicitly asked. This group was the most successful in sharing the control, and the best performing group with regards to the integration of the pilot. Another group in the same study (*study* 2_{iB}), however, experienced an episode in which a co-located participant 'took control' of the pilot's view by grabbing and keeping a hold of the robot, shown in Figure 6:

Hostage episode: *At the beginning of their third game, where participants could share control of the robot's view, the co-located participants decide to place TableBot near the edge of the table. This allows the pilot to move around and see all the points which are only visible from the outside of the circle of words, and thereby get the highest score for the team. Due to the pilot's lack of spatial awareness the pilot is unaware of how close the robot is to the edge of the table. The co-located participants get anxious for the robot to drive over the edge and asks the pilot to be careful. As the pilot moves a bit backwards towards the table edge, it becomes too stressful for one of the co-located participants, who picks up the robot and playfully holds it in front of their face, as if to reprimand the pilot for the recklessness, exclaiming that if the remote participant can not take care of themselves they would have to be taken care of. After a few minutes the robot is returned to the centre of the table and the task resumes.*

In the focus-group interview following the hostage situation, the remote participant said that they felt like being taken hostage by the co-located participant, which was an annoying experience and even expressed it as uncomfortable: *[Remote participant] "It was a bit annoying when [the co-located participant] just picked me up and just held me, kind of hostage. I had just gained some freedom, and now it was taken away from me."*

Summary of Findings

This section illustrates how each design decision has had both positive and negative consequences for the participants. In the following, we summarise the contingencies and trade-offs involved in designing tabletop telepresence robots which were exposed through the serial RtD process of TableBot.

A wide field of view was desirable by all participants in *study* 3_{iC}. However *study* 2_{iB} indicates the value of a readable indication of the remote participant's gaze and/or LOA, from the orientation of the TableBot, which was a result of a limited field of view.

Our findings from *study* 1_{iA} indicate that TableBot can easily grab attention in small spaces. However, *study* 2_{iB} and 3_{iC} suggest that when the pilot is greatly outnumbered by co-located participants, they have a hard time grabbing attention in a meaningful way. Furthermore, telepresence robots might inadvertently grab attention due to technical issues as *iA* and the *glitching episode* demonstrate.

The ability for both the pilot and co-located participants to move the robot is a central design feature of TableBot. Findings from *study* 2_{iB} show that co-located participants tend to be uncomfortable moving the robot, while the pilot in turn is not negatively affected by it. However, issues might still arise when the co-located participants are willing to move the robot, as shown in the *hostage episode*, where the boundaries of the pilot were not adhered to.

6 DISCUSSION

In this section we discuss the design of TableBot and findings from the studies. We first discuss the influence of reframing on the focus shift to negotiation of control. Afterwards, we discuss three design trade-offs that emerged from the findings regarding designing tabletop telepresence robotics. Finally, the trade-offs are applied as a foundation for a framework for positioning hybrid communication systems in terms of negtiation of control.

6.1 The Design of TableBot

The novel feature of TableBot is the handle, which was not considered an asset for the design until the second iteration. TableBot was a product of a serial RtD process in which intentional driftings were formed through reframings of the design process. The handle design on TableBot was a bi-product of the limited knowledge based RtD process in which the design goal of a lightweight design had motivated the use of a smartphone for video-call facilitation. To allow the smartphone to tilt, the phone would have to be suspended on an arm which was eventually designed as a handle to "see what would happen". Following the pilot *study* 1_{iA}, the technological limitations of *iA* indicated a need for collaboration between the co-located and the pilot to best include the pilot. Throughout all design experiments, the conceptual design of TableBot was mostly unchanged. However, in the reframing, the focus was shifted from element to element (see Table 1). The reframing of *iB* is an outlier, as this reframing did not require a design change, but rather a change in perspective on an existing design element. The purpose of the handle transformed thus from a suggestive design opportunity to an instrument for not only sharing the control, but primarily negotiating it.

Study 2_{iB} was an attempt to explore the handle as an instrument in a social context, of which the findings indicated that the handle was valuable in the negotiation of control. It was easy to grab, while the pilot did not experience the grabbing as invasive as it was outside of their periphery. The degree of interaction varied between studies and groups, with some participants being more comfortable with interacting with the robot than others. The participant's reactions suggest the novelty of the robot produced an exaggerated care for the system. This was evident in some participants in both *study* 1_{iA} and *study* 3_{iC} curiously and carefully touching it briefly with their fingertips when the shared attention was placed elsewhere. The design of the robot and handle thus had influence on the confidence in interacting with the robot, as further elaborated on in the following section.

6.2 Identifying trade-offs of tabletop telepresence robotics

The three themes presented in our findings indicate design trade-offs for tabletop telepresence robots, which are simultaneously opportunities to further frame the design space of MRPs: Wide Field of View vs. Clear Locus of Attention, Polished Design vs. Expressing Limitations, and Autonomy vs. Assistance. Below we elaborate on each trade-off through reflections on their opportunities and limitations.

6.2.1 *Wide Field of View vs. Clear Locus of Attention.*

In face-to-face conversation people can understand each others LOA through head orientation and gaze [69]. While conveying gaze is difficult through telepresence robots, our findings indicate that the orientation of the screen and camera is a clear indication of pilot's direction of attention.

The narrow FOV of *iB* made the pilot's LOA unambiguous for the co-located participants, providing the opportunity for unique and intimate social constellations [42]. This facilitated the *Dance Session episode.* The lack of ambiguity led to less reliance on repeated verbal explanations of deixis, as the colocated participants related the pilot's reference to the robot's orientation.

The narrow FOV supports these valuable social interactions, but our findings also indicate that a wide FOV eases the mental workload of the pilot, and increases social presence and co-presence in line with existing literature [2, 5, 26]. Participants in *study* 3_{iC} experienced higher social presence [2] with a wide FOV, and less with a narrow FOV. *iC* was designed to provide a wide FOV to the pilot, while using LEDs to maintain the clear indication of LOA. Our design proved unsuccessful as the screen orientation dominated the co-located participants' understanding of LOA, while the LEDs were mostly ignored. This led to breakdowns where the co-located participants expected the pilot to look inappropriately at them, while the pilot was actually looking in a different direction, indicated by the LEDs.

The trade-off here is between providing a small FOV that clearly conveys LOA to the co-located participants vs. a wide FOV that provides higher levels of situational awareness and mental ease for the pilot.

6.2.2 *Polished Design vs. Expressing Limitations.*

The aesthetics of TableBot in the different experiments also affected the experience and use of the system, and the willingness of the co-located participants to assist the pilot. During *Study* 2_{iB} the co-located participants were initially reluctant to move the robot due to fear of damaging the system. This motivated the sturdy and polished design of *iC*, which had an unexpected consequence: The co-located participants thought that since the robot looked and moved smooth and polished, the pilot would not need any help from them.

The polished system expressed autonomy and stability, making the co-located participants inclined to leave all control to the pilot. However, inclusion of the pilot requires collaboration, as we further elaborate on with the next trade-off. As seen in the *glitching episode* glitches such as motor jamming effectively conveyed technical limitations to the co-located participants. It was obvious that this was not the intended action of the pilot, which led to conversations about the pilot's needs and suggestions for support. Thus, the presentation of limitations acted as encouragement to the co-located participants, motivating a collaborative effort.

This analysis indicates a trade-off between designing a system that is polished enough to bestow confidence in its stability, but simultaneously expresses limitations, making them obvious to the co-located participants, and inviting them to assist the remote participant when needed.

6.2.3 Autonomy vs. Assistance. The goal of TableBot is to enable the remote participant to roam around on a tabletop, while being supported by the co-located participants for actions and movements, which are difficult or impossible to accomplish by the pilot. So, as we saw in the studies, in order to complete the tasks, the pilot will sometimes need to be moved by the co-located participants.

Being moved is inherently an act of negotiation between the co-located participants needing to physically move the robot, and the remote participant having their view changed by being moved around. Based on our findings, we present this negotiated control as a spectrum with five defining categories, illustrated in Figure 7: (a) The pilot has full control of the robot: This is entirely an action within the remote participant's control, done by the remote participant, for the remote participant. The co-located participants are not affected by the action, except whenever breakdowns occur, such as in the *glitching episode*. (b) The pilot asks for help from the co-located participants: The action is dictated by the pilot, but executed by the co-located participants. (c) The co-located participants move the robot with consent: The co-located participants identify potential issues or needs, but seek consent from the pilot before performing any actions. (d) The co-located participants move the robot without consent: The co-located participants act on identified potential issues or needs without seeking the remote participant's consent. (e) The co-located participants have full control of the robot: The action is performed without consent and without obvious benefit to the pilot, such as the *hostage episode*.

The different categories of negotiated control should be understood as dynamic, as seen in the *glitching episode*. Here the control oscillated between the pilot asking for help (b), the co-located participants suggesting help (c) and the co-located participants automatically moving the robot when issues occurred (d). This oscillation however can result in breakdowns, as the *hostage episode* shows. Here the co-located participants suggested helping the pilot to avoid an accident (c), but was rejected by the pilot. This led to the co-located participants removing control (e).

The handle is a novel design feature of TableBot, inviting the co-located participants to directly control the pilot's view. It positions TableBot in an interaction space between the autonomy and control of a MRP, and the collaborative efforts of changing the view in a video call using a tablet or laptop to mediate a remote person. However, the pilots and co-located participants had very different views on moving or being moved in the studies. While the co-located participants mostly expressed it as feeling invasive of the pilot's personal space, similar to grabbing someone's body, the pilots did not experience the act of being moved as negative. Rather, they expressed being moved as helpful in most situations, and even comfortable. We return to this differing perception of the pilot in 6.3.

In *study* 2_{iB} and 3_{iC}, the groups who actively shared the control of the robot were the best performing based on the integration of the pilot in the task. This points to the potential advantage of negotiating the control of the robot.

Designing for negotiated control is a trade-off between the autonomy of the pilot and the co-located participants assisting the pilot. While the pilot mostly retained control in our studies, there were instances where they needed assistance, such as in the *glitching episode*. However, as the *hostage episode* illustrates, it is important that the remote participant can clearly indicate non-consent to being moved. Figure 8 shows a low-fidelity exploration of expressing non-consent using spikes along the handle to make lifting TableBot physically uncomfortable. This and other designs can potentially leverage the non-human aspects of telepresence robots to creatively convey information to the co-located participants to avoid breakdowns.

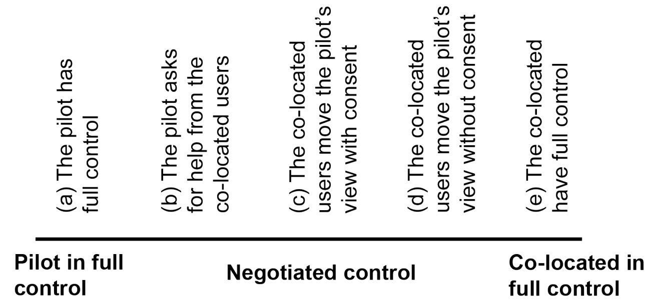


Figure 7: The spectrum of negotiated control based on findings from all studies

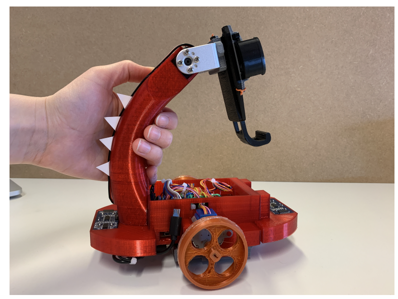


Figure 8: Spikes on the handle to convey non-consent to being moved. This design would move the control of the robot towards the pilot due to the handle losing it's grabability.

6.3 A framework for the Negotiation of Control

The three trade-offs identified above are design challenges which do not only affect the pilot, but also the co-located participants. Each trade-off highlight a separate challenge, however they also compliment each other in highlighting the varying ways of perceiving the pilot as mediated through the robot. In the *glitching episode* the pilot refers to the robot both as ‘it’ and ‘me’. This is a clear indication of robomorphism [59], where the co-located participants’ perception of the pilot, or the pilot’s perception of themselves, are at the same time as human and as something robotic. The co-located participants would primarily refer to the robot as a human or a container with a human inside. Many participants argued that this made it uncomfortable for them to grab or touch the robot as it felt like crossing a boundary. However, when technical glitches appeared, the perception of the robot changed. It’s robotic qualities came in focus, motivating the co-located participants to support the pilot without being asked. Thereby, the dynamic perception of the robot, oscillating between being a human or a robot, affected the willingness of the co-located participants to move it.

Takayama and Go [64] present five metaphors for describing the perception of a person mediated through a telepresence robot: A person, a person with disabilities, an object or container for a person, a communications medium with a person, and a non-human robot. When discussing the *hostage episode* in the focus group interviews, participants’ descriptions of the robot changed as the story progressed. Initially, they referred to the robot by the pilot’s name and pronoun, but as their experience got more tense, they changed their descriptions to ’it’ and ’the robot’. This aligns with Takayama and Go’s metaphors, as the perception of the pilot changed dynamically within a short span of time.

The findings from all three iterations of TableBot suggest robomorphism as an important factor of successful negotiation of control of a tabletop telepresence robot. We can therefore get a better understanding of negotiated control by analysing who is in control of the system in relation to the spectrum of robomorphism. In Figure 9 we lay out a framework, mapping our findings between the spectrum of robomorphism, represented by Takayama and Go’s [64] five metaphors, as seen from the co-located space and the spectrum of negotiated control identified in Figure 7. The episodes described in section 5 are positioned based on findings from observations and interviews.

As identified above, when the co-located participants perceive the robot as a human or even as a container for a human, moving the robot feels like crossing a boundary. However, when the robot is perceived as an object, moving it is not an issue. This connection follows a diagonal area in the framework, spanning the top-left square to bottom-right square, marked with a red ellipse in Figure 9. Along this downward diagonal, the Robomorphic perception supports the negotiation of control of the system, encouraging the co-located participants to assist the remote participant, without dehumanising the remote participant. The interaction is comfortable for the co-located participants, reducing the possibility of breakdowns. Breakdowns are likely to occur above the diagonal for both pilot and co-located participants: Because the pilot is perceived as a person, having little control will be frustrating for the pilot, while the co-located participants are uncomfortable. Below the diagonal the systems have few human traits, which makes it less problematic for the co-located participants to assist and take control of them, but potentially difficult to include the remote participant. To design for negotiated control, the diagonal in the framework can act as a guideline. It motivates designing for variations within the spectrum of negotiated control, allowing both the co-located and remote participants to control the system. It is not necessary for a successful negotiation of control to use the full spectrum, but designing for variety allows the participants to appropriate the system depending on the context.

6.4 Designing negotiated hybrid communication systems

The negotiating of control of TableBot enables it to span multiple cells within the framework. This motivated a curiosity for how existing work is positioned in regards to negotiation of control. We have plotted relevant literature in the framework, to illustrate a bias in related work towards the pilot having complete control of the telepresence system. At the same time, the related work shows a tendency for mediating the remote participant as a person, often with some technological limitations, with the goal of imitating a co-located presence. In highlighting these tendencies, we illustrate potential areas for future research in the field of MRP. Just a few systems are designed for negotiation of control between the co-located and remote participants, such as Asteroids [37] and Mirrorblender [22]. These systems are not static within the framework, due to their negotiating qualities, but are positioned based on their primary design goals.

Our intention is not to suggest that systems designed for negotiation of control should map to only a single cell in the framework. Rather, we suggest that these systems should be dynamic, capable of moving between the cells in the framework, similarly to how TableBot spans several cells. As the type of control oscillates, the perception of the system alters to fit the type of control or vice versa, all in an effort to make the shared control of the remote participant’s mediation as tension free as possible. Asteroids [37] is an example of this, having a swarm-style telepresence robot system where there are more remote participants than robots. The remote participants are able to ‘hop’ between robots to change their view or move a robot if they are in control of it. However, the co-located participant can direct the view of all robots or force all remote participants into a single robot. This control is negotiated as the task progress, with the co-located participant having dominant control over the system, but must choose when to use it to enhance the collaboration. The non-human abilities of robot hopping leads Asteroids to utilise the full spectrum of negotiation of control.

While we consider Asteroids to be a successful application of negotiated of control over the telepresence system, many others do not share our enthusiasm for non-human interactions. Much literature on telepresence attempt to emulate a human presence, by giving the remote participant human abilities or characteristics, such as gesticulating arms, an articulating neck or a humanoid shape [1, 3, 7, 20, 28–30, 50, 66]. In addition, a lot of systems treats the mediation as something which should be solely under the remote participant’s control [1, 3, 20, 27–29, 31, 50, 58]. Often, the focus is on providing a presence similar to a co-located person,

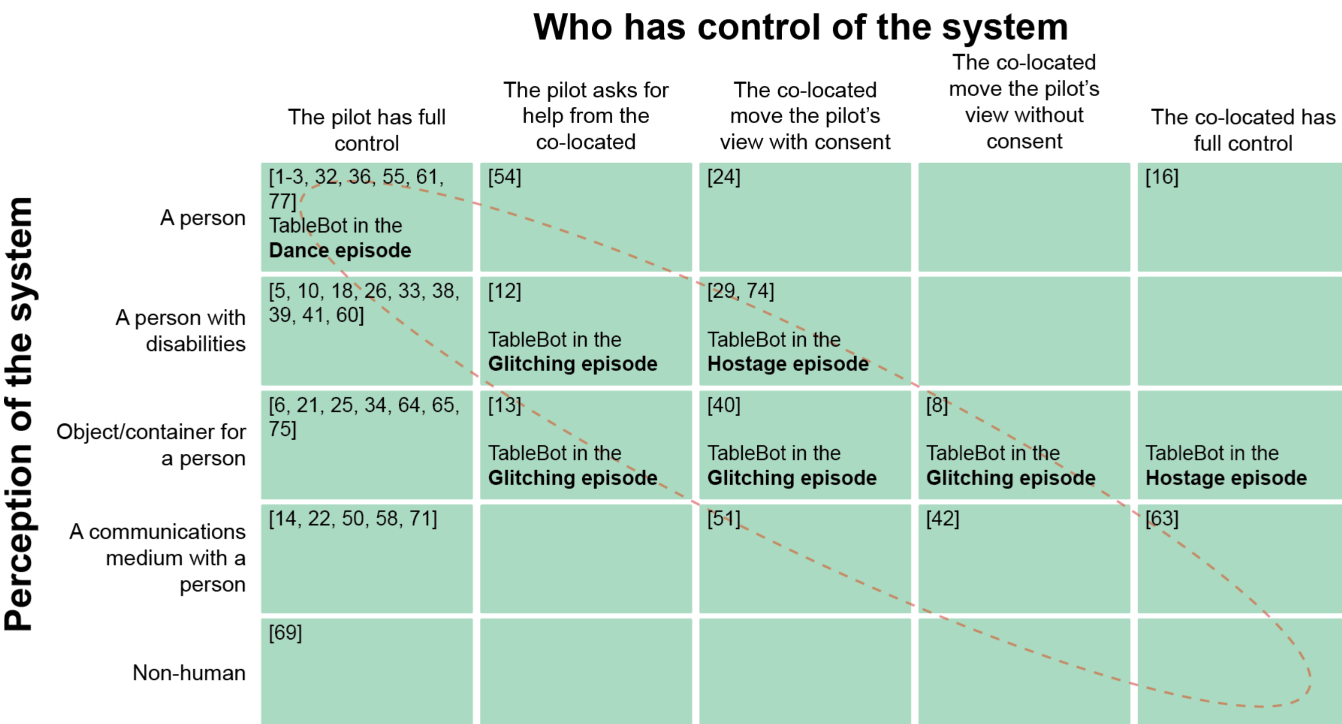


Figure 9: A framework for exploring how the pilot is perceived [64] in relation to who has control of the robot (negotiation of control, see Figure 7). Robomorphism [59] lies in the perception of a remote participant not as a person, but neither as completely non-human. The area within the red dotted line indicate a dynamic range where we find the combination of negotiated control and a Robomorphic perception can be beneficial to both remote and co-located participants.

where the goal is to treat the mediated participant the same as the co-located participants. This work remains important for improving hybrid collaboration, and only more so in the post-pandemic era. However, it also presents a limitation, as little work explores the remote and co-located participants negotiating control of a system, or where the system is designed to alter the perception of itself, to facilitate shared control or assistance from the co-located participants. The many empty cells of the framework underline this point. We believe there are many opportunities to explore alternative designs, in which the control of the remote participants' mediation also can be controlled by the co-located participants to better include remote participants in the activity, and promote engagement and understanding of limitations in hybrid collaboration settings.

With the framework, we wish to bring focus on the many opportunities that exist for designing for negotiation of control, in combination with considerations of how participants mediated through a system is perceived. The framework can be used as a reflective lens to see new design proposals through, to evaluate the success of designing for negotiated control of telecommunications systems.

While the framework can be used to reflect on and critique designs, it does not act as a design guide for how to actually achieve successful negotiation of control. Rather we suggest turning to the trade-offs as guidelines for what to consider when designing for negotiated control, and how it might affect a design's position in the framework. Neither does our framework help with determining which combinations of negotiated control and perceptions of the system would lead to successful negotiation of control. We suggest that designing along the downwards diagonal allows the perception of the remote participant and the distribution of control to be aligned with user expectations. However there remains possibilities for designing systems which do not adhere to this alignment, and we encourage further design explorations in these areas.

With TableBot we have identified a useful connection between Robomorphism and who has control of the system, however we have in this paper only done preliminary work on how to design for different and changing robomorphic perceptions. Opportunities remain to lean further into different asymmetries, and explore how they affect hybrid collaboration, and how future systems can be designed to increase engagement and presence.

Future work could lean further into the non-human aspects that telepresence systems often emanate, in order to achieve a robomorphic perception. Additionally, augmenting the remote participant with abilities beyond what is possible for a human body [24] would allow the remote participant to still be partially perceived as a human, but with non-human qualities. The idea of using spikes, illustrated in Figure 8, is an examples of this. The pilot is able to express through non-human means, that they do not consent to being moved at this point, reclaiming control of their non-human representation. Non-human abilities encourage the co-located participants to dynamically oscillate their perceptions between a human and something not human. As our finding suggest, this could make it easier to perform actions, such as grabbing the pilot, allowing for successful negotiation of control.

LIMITATIONS

There are several factors that limit the generalisability of our findings to all meeting situations. TableBot is a small robot compared to an MRP, which possibly affect the impression of the pilot's authority. All studies with TableBot are designed to ensure equal power distribution among all participants to examine the pilot's ability to be integrated in a social setting as an equal peer. Therefore, this work does not account for possible uneven power distributions among participants in, e.g. a corporate hybrid meeting, and for how this might affect the negotiation of control. To ease possible tensions arising from introducing a novel piece of technology, we adopted a playful setting and task for all of our exploratory studies. While this yielded unique findings, the setting and task does not match conventional meeting settings. Not all findings are thus transferable to a traditional work related hybrid meeting. All participants in the studies were recruited through the authors' networks, meaning some of the participants had existing relationships. While this has been identified as having influence on the social dynamics of the groups, the direct affect has not been examined. This also applies to how different personality types can express comfort in moving the robot while others are reserved.

7 CONCLUSION

Traditional MRP robots are not designed to let the co-located participants assist the pilot. Furthermore, these systems are pricey, clunky, and not made specifically for the meeting setting, where they are mostly used. Instead they are designed for roaming office spaces, and provide a human-like representation of the pilot to the co-located participants.

In this paper we have presented TableBot, a lightweight, simple tabletop telepresence robot with a novel handle to address these shortcomings. Based on a serial Research-through-Design approach, the focus area of the research shifted from the lightweight tabletop telepresence robot to investigate how to design for negotiation of control and providing deictic capabilities for the pilot. As a result of this process, the design was changed through reframings of TableBot, resulting in three conceptually similar iterations. These iterations were explored across three studies, each providing findings on the remote and co-located participants' roles in a collaborative setting. Through these studies, negotiation of control came to be a central focus area of the RtD process and based on the findings we have outlined three trade-offs for designing tabletop telepresence systems. These include trading off a) a wide field of view of the pilot versus offering a clear locus of attention; b) polished design versus expressing limitations in the design, and c) designing for autonomy versus assistance of the tabletop robot. The trade-offs emphasise that there is no one-design-fits-all approach.

Finally we draw upon previous research into robomorphism and the trade-offs we identified in the studies of TableBot to present a framework for negotiating control. The framework indicates that allowing co-located participants to assist the pilot can result in better integration of the pilot into the space, in particular when both the pilot and co-located participant share a common perception of the robot as a medium for the pilot. It additionally highlights a bias in the existing literature regarding hybrid communication towards providing the pilot with as much control as possible. It further emphasises a tendency to present the remote participant as something as close to physically "being there" as possible. Based on the framework, we suggest further exploration and design experimentation of the spectrum of negotiation of control and robomorphism to include remote participants in new ways. We suggest using the trade-offs to explore design opportunities in the design space of hybrid communication systems, while using the framework to position the work in terms of collaborative qualities.

REFERENCES

[1] Sigurdur Orn Adalgeirsson and Cynthia Breazeal. 2010. MeBot: A robotic platform for socially embodied telepresence. In *2010 5th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, Osaka, Japan, 15–22. https://doi.org/10.1109/HRI.2010.5453272

[2] Luis Almeida, Paulo Menezes, and Jorge Dias. 2022. Telepresence Social Robotics towards Co-Presence: A Review. *Applied Sciences* 12, 11 (2022), 36 pages. https://doi.org/10.3390/app12115557

[3] Dimitra Anastasiou, Christoph Stahl, and Thibaud Latour. 2019. *The Role of Gesture in Social Telepresence Robots—A Scenario of Distant Collaborative Problem-Solving*. Springer International Publishing, Cham, 61–83. https://doi.org/10.1007/978-3-030-17107-0_4

[4] Anne Louise Bang and Mette Agger Eriksen. 2014. Experiments all the Way in Programmatic Design Research. *Artifact: Journal of Design Practice* 3, 2 (2014), 4.1–4.14. https://doi.org/10.14434/artifact.v3i2.3976/art.3.2.4.1_1

[5] Federica Bazzano, Fabrizio Lamberti, Andrea Sanna, and Marco Gaspardone. 2019. The Impact of Field of View on Robotic Telepresence Navigation Tasks. In *Computer Vision, Imaging and Computer Graphics – Theory and Applications*, Ana Paula Cláudio, Dominique Bechmann, Paul Richard, Takehiko Yamaguchi, Lars Linsen, Alexandru Telea, Francisco Imai, and Alain Tremeau (Eds.). Springer International Publishing, Cham, 66–81.

[6] Mathilde M. Bekker, Judith S. Olson, and Gary M. Olson. 1995. Analysis of Gestures in Face-to-Face Design Teams Provides Guidance for How to Use Groupware in Design. In *Proceedings of the 1st Conference on Designing Interactive Systems: Processes, Practices, Methods, & Techniques* (Ann Arbor, Michigan, USA) *(DIS '95)*. Association for Computing Machinery, New York, NY, USA, 157–166. https://doi.org/10.1145/225434.225452

[7] Jacob T. Biehl, Daniel Avrahami, and Anthony Dunnigan. 2015. Not Really There: Understanding Embodied Communication Affordances in Team Perception and Participation. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing* (Vancouver, BC, Canada) *(CSCW '15)*. Association for Computing Machinery, New York, NY, USA, 1567–1575. https://doi.org/10.1145/2675133.2675220

[8] Thomas Binder and Johan Redström. 2006. Exemplary Design Research. In *Wonderground - DRS International Conference 2006*, K. Friedman, T. Love, E. Corte-Real, and C. Rust (Eds.). Design Research Society, Lisbon, Portugal, 14 pages. https://dl.designresearchsociety.org/drs-conference-papers/drs2006/researchpapers/51

[9] Patrik Björnfot, Joakim Bergqvist, and Victor Kaptelinin. 2018. Non-technical users' first encounters with a robotic telepresence technology: An empirical study of office workers. *Paladyn, Journal of Behavioral Robotics* 9, 1 (2018), 307–322. https://doi.org/doi:10.1515/pjbr-2018-0022

[10] Nathan D. Bos, Ayse Buyuktur, Judith S. Olson, Gary M. Olson, and Amy Voida. 2010. Shared Identity Helps Partially Distributed Teams, but Distance Still Matters. In *Proceedings of the 2010 ACM International Conference on Supporting Group Work* (Sanibel Island, Florida, USA) *(GROUP '10)*. Association for Computing Machinery, New York, NY, USA, 89–96. https://doi.org/10.1145/1880071.1880086

[11] Andriana Boudouraki, Joel E. Fischer, Stuart Reeves, and Sean Rintel. 2021. "I Can't Get Round": Recruiting Assistance in Mobile Robotic Telepresence. *Proc. ACM Hum.-Comput. Interact.* 4, CSCW3, Article 248 (jan 2021), 21 pages. https://doi.org/10.1145/3432947

[12] Andriana Boudouraki, Joel E. Fischer, Stuart Reeves, and Sean Rintel. 2023. "Being in on the Action" in Mobile Robotic Telepresence: Rethinking Presence in Hybrid Participation. In *Proceedings of the 2023 ACM/IEEE International Conference on Human-Robot Interaction* (Stockholm, Sweden) *(HRI '23)*. Association for Computing Machinery, New York, NY, USA, 63–71. https://doi.org/10.1145/3568162.3576961

[13] Andriana Boudouraki, Stuart Reeves, Joel Fischer, and Sean Rintel. 2023. "There is a Bit of Grace Missing": Understanding Non-Use of Mobile Robotic Telepresence in a Global Technology Company. In *Proceedings of the First International Symposium on Trustworthy Autonomous Systems* (Edinburgh, United Kingdom) *(TAS '23)*. Association for Computing Machinery, New York, NY, USA, Article 15,

10 pages. https://doi.org/10.1145/3597512.3599710

[14] Virginia Braun and Victoria Clarke. 2012. Thematic Analysis. In *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological.* American Psychological Association, Washington, DC, Chapter 4, 57–71. https://doi.org/10.1037/13620-004

[15] Bill Buxton. 2009. *Mediaspace – Meaningspace – Meetingspace.* Springer London, London, 217–231. https://doi.org/10.1007/978-1-84882-483-6_13

[16] Mao-Lin Chiu. 2002. An organizational view of design communication in design collaboration. *Design Studies* 23, 2 (2002), 187–210. https://doi.org/10.1016/S0142-694X(01)00019-9

[17] 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, Woburn, MA, USA, 15–20. https://doi.org/10.1109/TEPRA.2011.5753474

[18] Audrey Desjardins and Cayla Key. 2020. Parallels, Tangents, and Loops: Reflections on the 'Through' Part of RtD. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference* (<conf-loc>, <city>Eindhoven</city>, <country>Netherlands</country>, </conf-loc>) *(DIS '20).* Association for Computing Machinery, New York, NY, USA, 2133–2147. https://doi.org/10.1145/3357236.3395586

[19] Melanie Duckert, Louise Barkhuus, and Pernille Bjørn. 2023. Collocated Distance: A Fundamental Challenge for the Design of Hybrid Work Technologies. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23).* Association for Computing Machinery, New York, NY, USA, Article 612, 16 pages. https://doi.org/10.1145/3544548.3580899

[20] Naomi T. Fitter, Youngseok Joung, Zijian Hu, Marton Demeter, and Maja J. Matarić. 2019. User Interface Tradeoffs for Remote Deictic Gesturing. In *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN).* IEEE, New Delhi, India, 1–8. https://doi.org/10.1109/RO-MAN46459.2019.8956354

[21] Aaron Genest and Carl Gutwin. 2011. Characterizing Deixis over Surfaces to Improve Remote Embodiments. In *ECSCW 2011: Proceedings of the 12th European Conference on Computer Supported Cooperative Work, 24-28 September 2011, Aarhus Denmark*, Susanne Bødker, Niels Olof Bouvin, Volker Wulf, Luigina Ciolfi, and Wayne Lutters (Eds.). Springer London, London, 253–272.

[22] Jens Emil Grønbæk, Banu Saatçi, Carla F. Griggio, and Clemens Nylandsted Klokmose. 2021. MirrorBlender: Supporting Hybrid Meetings with a Malleable Video-Conferencing System. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21).* Association for Computing Machinery, New York, NY, USA, Article 451, 13 pages. https://doi.org/10.1145/3411764.3445698

[23] Yasamin Heshmat, Brennan Jones, Xiaoxuan Xiong, Carman Neustaedter, Anthony Tang, Bernhard E. Riecke, and Lillian Yang. 2018. Geocaching with a Beam: Shared Outdoor Activities through a Telepresence Robot with 360 Degree Viewing. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18).* Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3173574.3173933

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

[25] Hiroshi Ishii and Minoru Kobayashi. 1992. ClearBoard: A Seamless Medium for Shared Drawing and Conversation with Eye Contact. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Monterey, California, USA) *(CHI '92).* Association for Computing Machinery, New York, NY, USA, 525–532. https://doi.org/10.1145/142750.142977

[26] Steven Johnson, Irene Rae, Bilge Mutlu, and Leila Takayama. 2015. Can You See Me Now? How Field of View Affects Collaboration in Robotic Telepresence. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15).* Association for Computing Machinery, New York, NY, USA, 2397–2406. https://doi.org/10.1145/2702123.2702526

[27] Brennan Jones, Jens Maiero, Alireza Mogharrab, Ivan A. Aguliar, Ashu Adhikari, Bernhard E. Riecke, Ernst Kruijff, Carman Neustaedter, and Robert W. Lindeman. 2020. FeetBack: Augmenting Robotic Telepresence with Haptic Feedback on the Feet. In *Proceedings of the 2020 International Conference on Multimodal Interaction* (Virtual Event, Netherlands) *(ICMI '20).* Association for Computing Machinery, New York, NY, USA, 194–203. https://doi.org/10.1145/3382507.3418820

[28] 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* (Honolulu, HI, USA) *(CHI EA '20).* Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3334480.3382820

[29] Norman P. Jouppi. 2002. First Steps towards Mutually-Immersive Mobile Telepresence. In *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work* (New Orleans, Louisiana, USA) *(CSCW '02).* Association for Computing Machinery, New York, NY, USA, 354–363. https://doi.org/10.1145/587078.587128

[30] Kibum Kim, John Bolton, Audrey Girouard, Jeremy Cooperstock, and Roel Vertegaal. 2012. TeleHuman: Effects of 3d Perspective on Gaze and Pose Estimation with a Life-Size Cylindrical Telepresence Pod. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI '12).* Association for Computing Machinery, New York, NY, USA, 2531–2540. https://doi.org/10.1145/2207676.2208640

[31] Ryohei Komiyama, Takashi Miyaki, and Jun Rekimoto. 2017. JackIn Space: Designing a Seamless Transition between First and Third Person View for Effective Telepresence Collaborations. In *Proceedings of the 8th Augmented Human International Conference* (Silicon Valley, California, USA) *(AH '17).* Association for Computing Machinery, New York, NY, USA, Article 14, 9 pages. https://doi.org/10.1145/3041164.3041183

[32] Sven Kratz and Fred Rabelo Ferriera. 2016. Immersed remotely: Evaluating the use of Head Mounted Devices for remote collaboration in robotic telepresence. In *2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN).* IEEE, New York, NY, USA, 638–645. https://doi.org/10.1109/ROMAN.2016.7745185

[33] Peter Gall Krogh, Thomas Markussen, and Anne Louise Bang. 2015. Ways of Drifting—Five Methods of Experimentation in Research Through Design. In *ICoRD'15 – Research into Design Across Boundaries Volume 1*, Amaresh Chakrabarti (Ed.). Springer India, New Delhi, 39–50.

[34] Hideaki Kuzuoka, Shinya Oyama, Keiichi Yamazaki, Kenji Suzuki, and Mamoru Mitsuishi. 2000. GestureMan: A Mobile Robot That Embodies a Remote Instructor's Actions. In *Proceedings of the 2000 ACM Conference on Computer Supported Cooperative Work* (Philadelphia, Pennsylvania, USA) *(CSCW '00).* Association for Computing Machinery, New York, NY, USA, 155–162. https://doi.org/10.1145/358916.358986

[35] Hideaki Kuzuoka, Jun Yamashita, Keiichi Yamazaki, and Akiko Yamazaki. 1999. Agora: A Remote Collaboration System That Enables Mutual Monitoring. In *CHI '99 Extended Abstracts on Human Factors in Computing Systems* (Pittsburgh, Pennsylvania) *(CHI EA '99).* Association for Computing Machinery, New York, NY, USA, 190–191. https://doi.org/10.1145/632716.632836

[36] Min Kyung Lee and Leila Takayama. 2011. "Now, i Have a Body": Uses and Social Norms for Mobile Remote Presence in the Workplace. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver, BC, Canada) *(CHI '11).* Association for Computing Machinery, New York, NY, USA, 33–42. https://doi.org/10.1145/1978942.1978950

[37] Jiannan Li, Maurício Sousa, Chu Li, Jessie Liu, Yan Chen, Ravin Balakrishnan, and Tovi Grossman. 2022. ASTEROIDS: Exploring Swarms of Mini-Telepresence Robots for Physical Skill Demonstration. In *CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22).* Association for Computing Machinery, New York, NY, USA, Article 111, 14 pages. https://doi.org/10.1145/3491102.3501927

[38] 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. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (San Diego, CA, USA) *(DIS '19).* Association for Computing Machinery, New York, NY, USA, 1427–1438. https://doi.org/10.1145/3322276.3322314

[39] Andrés Lucero. 2018. Living Without a Mobile Phone: An Autoethnography. In *Proceedings of the 2018 Designing Interactive Systems Conference* (Hong Kong, China) *(DIS '18).* Association for Computing Machinery, New York, NY, USA, 765–776. https://doi.org/10.1145/3196709.3196731

[40] Paul Luff, Christian Heath, Hideaki Kuzuoka, Jon Hindmarsh, Keiichi Yamazaki, and Shinya Oyama. 2003. Fractured Ecologies: Creating Environments for Collaboration. *Human–Computer Interaction* 18, 1-2 (2003), 51–84.

[41] Paul K. Luff, Naomi Yamashita, Hideaki Kuzuoka, and Christian Heath. 2015. Flexible Ecologies And Incongruent Locations. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15).* Association for Computing Machinery, New York, NY, USA, 877–886. https://doi.org/10.1145/2702123.2702286

[42] Paul Marshall, Yvonne Rogers, and Nadia Pantidi. 2011. Using F-Formations to Analyse Spatial Patterns of Interaction in Physical Environments. In *Proceedings of the ACM 2011 Conference on Computer Supported Cooperative Work* (Hangzhou, China) *(CSCW '11).* Association for Computing Machinery, New York, NY, USA, 445–454. https://doi.org/10.1145/1958824.1958893

[43] Reo Matsumura, Masahiro Shiomi, Kayako Nakagawa, Kazuhiko Shinozawa, and Takahiro Miyashita. 2016. A Desktop-Sized Communication Robot: "robovie-mR2". *Journal of Robotics and Mechatronics* 28, 1 (2016), 107–108. https://doi.org/10.20965/jrm.2016.p0107

[44] Helena M. Mentis, Kenton O'Hara, Abigail Sellen, and Rikin Trivedi. 2012. Interaction Proxemics and Image Use in Neurosurgery. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Austin, Texas, USA) *(CHI '12).* Association for Computing Machinery, New York, NY, USA, 927–936. https://doi.org/10.1145/2207676.2208536

[45] Hideyuki Nakanishi, Yuki Murakami, Daisuke Nogami, and Hiroshi Ishiguro. 2008. Minimum Movement Matters: Impact of Robot-Mounted Cameras on Social Telepresence. In *Proceedings of the 2008 ACM Conference on Computer*

Supported Cooperative Work (San Diego, CA, USA) *(CSCW '08)*. Association for Computing Machinery, New York, NY, USA, 303–312. https://doi.org/10.1145/1460563.1460614

[46] Thomas Neumayr, Mirjam Augstein, and Bettina Kubicek. 2022. Territoriality in Hybrid Collaboration. *Proc. ACM Hum.-Comput. Interact.* 6, CSCW2, Article 332 (nov 2022), 37 pages. https://doi.org/10.1145/3555224

[47] Thomas Neumayr, Banu Saatci, Sean Rintel, Clemens Nylandsted Klokmose, and Mirjam Augstein. 2021. What was Hybrid? A Systematic Review of Hybrid Collaboration and Meetings Research. https://doi.org/10.48550/ARXIV.2111.06172

[48] Carman Neustaedter and Phoebe Sengers. 2012. Autobiographical Design in HCI Research: Designing and Learning through Use-It-Yourself. In *Proceedings of the Designing Interactive Systems Conference* (Newcastle Upon Tyne, United Kingdom) *(DIS '12)*. Association for Computing Machinery, New York, NY, USA, 514–523. https://doi.org/10.1145/2317956.2318034

[49] 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. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (San Francisco, California, USA) *(CSCW '16)*. Association for Computing Machinery, New York, NY, USA, 418–431. https://doi.org/10.1145/2818048.2819922

[50] Kenton O'hara, Jesper Kjeldskov, and Jeni Paay. 2011. Blended Interaction Spaces for Distributed Team Collaboration. *ACM Trans. Comput.-Hum. Interact.* 18, 1, Article 3 (may 2011), 28 pages. https://doi.org/10.1145/1959022.1959025

[51] Doenja Oogjes and Ron Wakkary. 2022. Weaving Stories: Toward Repertoires for Designing Things. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (<conf-loc>, <city>New Orleans</city>, <state>LA</state>, <country>USA</country>, </conf-loc>) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 98, 21 pages. https://doi.org/10.1145/3491102.3501901

[52] Rieks op den Akker, Dennis Hofs, Hendri Hondorp, Harm op den Akker, Job Zwiers, and Anton Nijholt. 2009. Supporting Engagement and Floor Control in Hybrid Meetings. In *Cross-Modal Analysis of Speech, Gestures, Gaze and Facial Expressions*, Anna Esposito and Robert Vích (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 276–290.

[53] Andrea Orlandini, Annica Kristoffersson, Lena Almquist, Patrik Björkman, Amedeo Cesta, Gabriella Cortellessa, Cipriano Galindo, Javier Gonzalez-Jimenez, Kalle Gustafsson, Andrey Kiselev, Amy Loutfi, Francisco Melendez, Malin Nilsson, Lasse Odens Hedman, Eleni Odontidou, Jose-Raul Ruiz-Sarmiento, Mårten Scherlund, Lorenza Tiberio, Stephen von Rump, and Silvia Coradeschi. 2016. ExCITE Project: A Review of Forty-Two Months of Robotic Telepresence Technology Evolution. *Presence: Teleoperators and Virtual Environments* 25, 3 (12 2016), 204–221. https://doi.org/10.1162/PRES_a_00262 arXiv:https://direct.mit.edu/pvar/article-pdf/25/3/204/1622021/pres_a_00262.pdf

[54] Kazuhiro Otsuka. 2016. MMSpace: Kinetically-augmented telepresence for small group-to-group conversations. In *2016 IEEE Virtual Reality (VR)*. 19–28. https://doi.org/10.1109/VR.2016.7504684

[55] Irene Rae, Bilge Mutlu, and Leila Takayama. 2014. Bodies in Motion: Mobility, Presence, and Task Awareness in Telepresence. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 2153–2162. https://doi.org/10.1145/2556288.2557047

[56] Irene Rae, Gina Venolia, John C. Tang, and David Molnar. 2015. A Framework for Understanding and Designing Telepresence. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing* (Vancouver, BC, Canada) *(CSCW '15)*. Association for Computing Machinery, New York, NY, USA, 1552–1566. https://doi.org/10.1145/2675133.2675141

[57] 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. In *International Conference on Collaboration and Technology*. Springer, Springer Nature, Kyoto, Japan, 45–61.

[58] Mose Sakashita, E. Andy Ricci, Jatin Arora, and François Guimbretière. 2022. RemoteCoDe: Robotic Embodiment for Enhancing Peripheral Awareness in Remote Collaboration Tasks. *Proc. ACM Hum.-Comput. Interact.* 6, CSCW1, Article 63 (apr 2022), 22 pages. https://doi.org/10.1145/3512910

[59] Alexander P. Schouten, Tijs C. Portegies, Iris Withuis, Lotte M. Willemsen, and Komala Mazerant-Dubois. 2022. Robomorphism: Examining the effects of telepresence robots on between-student cooperation. *Computers in Human Behavior* 126 (2022), 106980. https://doi.org/10.1016/j.chb.2021.106980

[60] Abigail Sellen, Bill Buxton, and John Arnott. 1992. Using Spatial Cues to Improve Videoconferencing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Monterey, California, USA) *(CHI '92)*. Association for Computing Machinery, New York, NY, USA, 651–652. https://doi.org/10.1145/142750.143070

[61] Solace Shen, Hamish Tennent, Houston Claure, and Malte Jung. 2018. My Telepresence, My Culture? An Intercultural Investigation of Telepresence Robot Operators' Interpersonal Distance Behaviors. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3173574.3173625

[62] David Sirkin, Gina Venolia, John Tang, George Robertson, Taemie Kim, Kori Inkpen, Mara Sedlins, Bongshin Lee, and Mike Sinclair. 2011. Motion and Attention in a Kinetic Videoconferencing Proxy. In *Human-Computer Interaction – INTERACT 2011*, Pedro Campos, Nicholas Graham, Joaquim Jorge, Nuno Nunes, Philippe Palanque, and Marco Winckler (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 162–180.

[63] Michael Suguitan and Guy Hoffman. 2021. You Are (Not) The Robot: Variable Perspective Motion Control of a Social Telepresence Robot. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, Article 181, 4 pages. https://doi.org/10.1145/3411763.3451571

[64] Leila Takayama and Janet Go. 2012. Mixing Metaphors in Mobile Remote Presence. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work* (Seattle, Washington, USA) *(CSCW '12)*. Association for Computing Machinery, New York, NY, USA, 495–504. https://doi.org/10.1145/2145204.2145281

[65] Anthony Tang and Omid Fakourfar. 2017. Watching 360 ° Videos Together. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 4501–4506. https://doi.org/10.1145/3025453.3025519

[66] Anthony Tang, Michel Pahud, Kori Inkpen, Hrvoje Benko, John C. Tang, and Bill Buxton. 2010. Three's Company: Understanding Communication Channels in Three-Way Distributed Collaboration. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work* (Savannah, Georgia, USA) *(CSCW '10)*. Association for Computing Machinery, New York, NY, USA, 271–280. https://doi.org/10.1145/1718918.1718969

[67] Amy Voida, Stephen Voida, Saul Greenberg, and Helen Ai He. 2008. Asymmetry in Media Spaces. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (San Diego, CA, USA) *(CSCW '08)*. Association for Computing Machinery, New York, NY, USA, 313–322. https://doi.org/10.1145/1460563.1460615

[68] Lillian Yang and Carman Neustaedter. 2018. Our House: Living Long Distance with a Telepresence Robot. *Proc. ACM Hum.-Comput. Interact.* 2, CSCW, Article 190 (nov 2018), 18 pages. https://doi.org/10.1145/3274459

[69] Cristina Zaga, Roelof A.J. de Vries, Jamy Li, Khiet P. Truong, and Vanessa Evers. 2017. A Simple Nod of the Head: The Effect of Minimal Robot Movements on Children's Perception of a Low-Anthropomorphic Robot. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 336–341. https://doi.org/10.1145/3025453.3025995

[70] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through Design as a Method for Interaction Design Research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07)*. Association for Computing Machinery, New York, NY, USA, 493–502. https://doi.org/10.1145/1240624.1240704

[71] John Zimmerman, Aaron Steinfeld, Anthony Tomasic, and Oscar J. Romero. 2022. Recentering Reframing as an RtD Contribution: The Case of Pivoting from Accessible Web Tables to a Conversational Internet. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (<conf-loc>, <city>New Orleans</city>, <state>LA</state>, <country>USA</country>, </conf-loc>) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 541, 14 pages. https://doi.org/10.1145/3491102.3517789

A CODE, 3D-MODELS AND ASSEMBLY INSTRUCTIONS

The parts-list, 3D-models, assembly instructions, alongside installation and cofiguration guides for the final iteration of TableBot are available here: https://github.com/Aldermoore/TableBot, As well as under supplemental material online.

Received 20 February 2023; revised 12 March 2024; accepted 5 June 2029