From Tele-presence to Tele-mobility: Exploring the Design Space for Robotic Communication Products

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ABSTRACT
The last two decades have seen the emergence of a new family of communication products—telepresence robots—that bridges research and development on media spaces, telepresence, teleoperation, and robotics. These products offer remote users *mobility* as well as *embodiment* in a local environment and thus promise improvements in communication and collaboration among distributed work teams. While the early prototypes of telepresence robots date back to the late 90s, the recent emergence of commercial applications and increasingly widespread adoption by organizations have spurred an exploration of the rich design space for these products. This abstract outlines this design space, presents two studies that explore this space, focusing on aspects of mobility and embodiment, and discusses directions for future research.

Author Keywords
Computer-supported collaborative work; computer-mediated communication; robotics; teleoperation; telepresence

ACM Classification Keywords
H.4.3. Information Systems Applications: Communications Applications—*computer conferencing, teleconferencing, and videoconferencing*

INTRODUCTION
Telepresence robots are emerging as a new family of products designed to support computer-supported collaborative work (CSCW) [12]. These products bridge research and development in telepresence in CSCW [1, 3, 5, 9, 14, 15, 21] and teleoperation in robotics [7, 16] and offer a unique form of *mobility* and *embodiment* in remote collaboration. They enable remote users to control a video-based communication system that is placed on a mobile robot in order to navigate in a local environment and to communicate and collaborate with local users. Figure 1 illustrates the use of such a product.

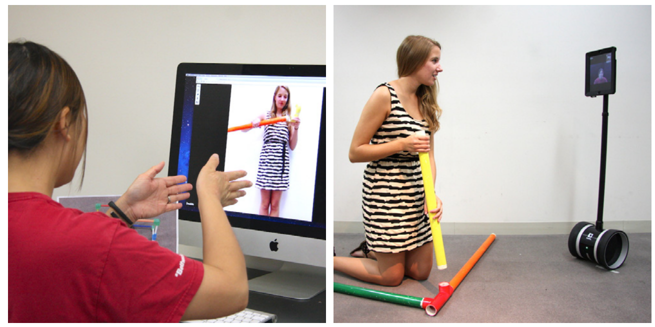

Figure 1. A remote user (left) is collaborating with a local user (right) on a construction task via a telepresence robot that provides the remote user with mobility and embodiment in the local environment. Displayed is the Double telepresence robot [2].

While explorations of robotic telepresence date back to as early as the mid 1950s [6], the first prototypes that introduced mobility were developed by Paulos and Canny [17], Fels et al. [4], and Jouppi [10] in the late 1990s and early 2000s. The prototypes developed by Paulos and Canny [17] included airborne robotic blimps equipped with one-way audio and video-based communication that enabled remote users to move in and observe the local environment. Later prototypes integrated ground robots and two-way video-based communication to not only enable remote users to move in and observe the local environment but also provide local users with an embodiment of the remote users. By incorporating a movable camera atop the robot and a simple arm that extends from its torso, these prototypes enabled remote users to direct their gaze and point toward information in the local environment.

The PEBBLES prototypes developed by Fels et al. [4] similarly integrated a two-way video-based communication system and a mobile robot base to enable home- or hospital-bound children to attend school. To better integrate the telepresence robot into the classroom environment, the prototypes had mechanisms—a light in early prototypes and a simple arm in later prototypes—that helped the student gain the teacher's attention. The BiReality system developed by Jouppi et al. [11], which extended the capabilities of an earlier prototype called Mutually Immersive Mobile Telepresence by Jouppi [10], introduced many features that provided local and remote users with a more immersive experience. These features included multiple video displays arranged in a circle that displayed the remote user's head from different angles and an immersive "display cube" that provided the remote user with a seamless 360-degree video feed of the local environment. Additionally, the telepresence robot automatically adjusted its height and gaze direction based on the height and gaze direction of the remote user. The projections of the local environment in the display cube were also automatically adjusted to match the height of the remote user.

These early prototypes and advancements in computing technology and infrastructure have spurred the development of a number of consumer products with varying capabilities for

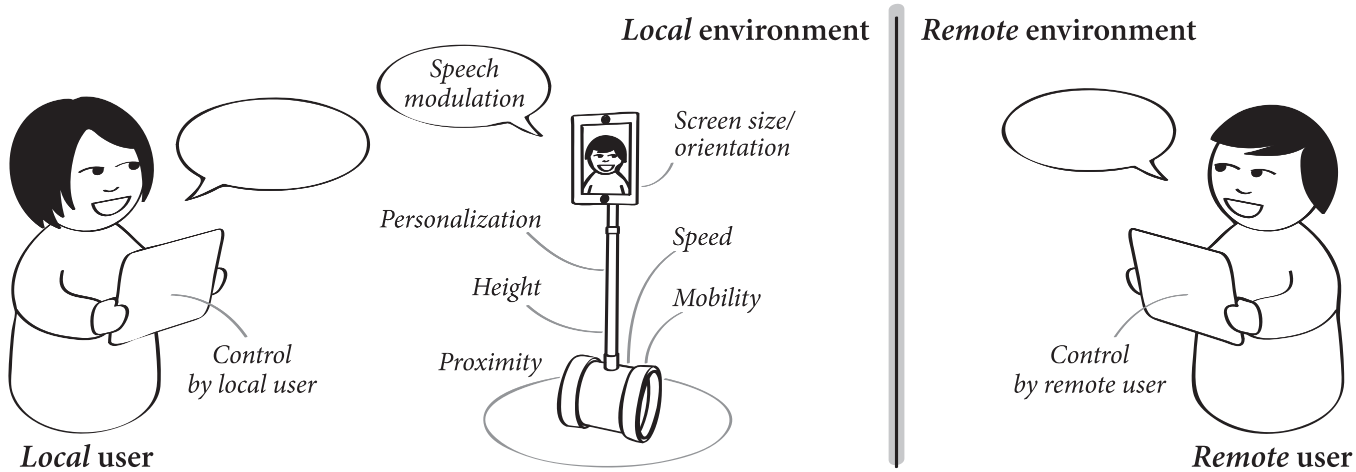

Figure 2. An illustration of some of the variables in the design space for robotic communication products.

mobility and embodiment (see Kristoffersson et al. [12] for a review), which in turn have found increasingly widespread adoption among distributed work teams. While little is known about the adoption and day-to-day use of these products, an early study by Lee and Takayama [13] has suggested that the mobility and embodiment afforded by these products provide remote users with a greater sense of presence in the local environment and opportunities for informal communication when compared to stationary video displays. The mobility enables the emergence of specific "places," as discussed by Harrison and Dourish [8], such as hallways in which informal conversations take place. Similar to what Dourish et al. [3] found in the use of media spaces, new practices and social norms emerge in the use of these products, such as local users opening doors for the telepresence robot to enter or exit rooms.

DESIGN SPACE FOR TELEPRESENCE ROBOTS

The early prototypes and studies of telepresence robots point toward a rich design space for supporting communication and collaboration among distributed teams. Figure 2 illustrates some of the key variables in this space. While some of these variables have been explored in the design of video-based telepresence systems, such as screen orientation [1], or the design of early prototypes of telepresence robots, such as the adjustment of the height of the robot to match that of the remote user [11], many aspects of this design space, particularly design elements that are unique to telepresence robots, such as mobility, control, and embodiment, remain largely unexplored. Research in the last few years across a small number of research groups has initiated such an exploration. The two studies below illustrate our group's work in this space, focusing particularly on aspects of robot mobility and embodiment.

Embodiment and Local Control Improve Trust

The first study explored how aspects of embodiment and mobility affected trust between local and remote users in a collaborative work scenario [19]. In a dyadic study, two naive participants, one located in a local environment and one remotely located user connecting to the local environment from a distance of 3,000 miles, collaborated in a social dilemma task. To study effects of embodiment, we compared the use of a telepresence robot to videoconferencing using a tablet computer. To better understand how different forms of mobility affected interpersonal trust, we compared whether the local users or the remote users controlled the mobility of the telepresence robot. The results from the dyadic analysis showed an increase in how much trust was gained between the collaborators when they used the telepresence robot to collaborate over the use of videoconferencing. Additionally, we found that more trust was gained when the local user controlled the mobility of the robot than when the remote user had control. An individual-level analysis showed that participants trusted their collaborators more when their collaborators had control over the mobility of the telepresence robot as opposed to when they had control of the robot.

The results of the study provide evidence for the argument that the "strong telepresence" afforded by the robotic embodiment would improve the overall experience of the remote user [17]. Our data showed that the stronger embodiment afforded by the telepresence robot improved how much remote users gained trust toward their collaborators, while there were no differences in trust gain among local users between the use of videoconferencing and the telepresence robot. Additionally, results on how control over mobility affected interpersonal trust confirm findings from management research [20]; placing remote users in a position of vulnerability by handing over the control of the mobility of the telepresence robot fostered trust between the two users. On the other hand, handing the control of the telepresence robot over to remote users provided them with more independence and collaborators with fewer opportunities to establish trust. These results suggest that the strong embodiment afforded by telepresence robots improve trust among collaborators and that who has control over the mobility of the robot has an effect on user trust.

Mobility Improves Presence but Hurts Task Performance

The second study explored the premise that the mobility afforded by telepresence robots would provide remote users with an increased sense of presence and facilitate collaboration in tasks that demand high mobility [18]. In the study, remote users collaborated with a local confederate in a construction task that was manipulated to demand low or high mobility. In the low-mobility task, participants constructed a tinker toy on a table, while they constructed a pipe structure on the floor in the high-mobility task. The study also manipulated the mobility of the telepresence robot to be stationary, facing the task space, or to be mobile, being controlled by the remote user. The results showed that remote users had a stronger sense of presence in the local environment when the robot was mobile, particularly when the task demanded greater mobility. On the other hand, mobility decreased task performance in measures of task time and number of errors.

These results are consistent with the design goal of the early telepresence robot prototypes of offering remote users a more immersive experience of the local environment [11, 17]. Our data shows that the ability to move improved remote users' feelings of presence in the local environment and that utilizing this ability due to task demands further strengthened these feelings. While we predicted that mobility would improve performance in tasks that demanded high mobility, our data shows the opposite. Our qualitative observations indicate that the decrease in task performance was a product of two factors. First, controlling the robot increased cognitive load and the need for situational awareness in remote users. Second, the telepresence robot used in the study lacked intuitive control mechanisms to support mobility in a remote environment. This finding further underlines the need for exploring the design space for control interfaces for telepresence robots.

DISCUSSION AND CONCLUSION

While the early and recent work reviewed above underline the promise of robotic communication products for remote communication and collaboration and highlight a rich space for their design, research on the design and use of these products is far from extensive. Future research efforts must include both studies of the real-world adoption and use of these products in domestic and organizational settings and explorations of the design of robot capabilities and embodiments as well as control mechanisms. Although new commercial products are frequently introduced and their use in schools, hospitals, and industrial settings is featured in popular press, very little is known about how these products are integrated into these settings and how they shape communication and communication in the real world. Design explorations and experimental studies of telepresence robots are gaining momentum, although many aspects that are critical to the success of these products, such as effective control interfaces that support remote users' awareness of the local environment, remain unexplored. Advances in these directions would contribute to the design and development of successful future products and provide us with a better understanding of how they shape communication and collaboration.

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