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Publication Date
2021-08-17

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Mobile Computing: The Role of Autonomous Features in Robot-Mediated Virtual Learning

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Abstract. Telerobots may function as robotic avatars in the physical world for people who are restricted to their homes due to high risk of infection or illness. Telerobots are mobile robot units that can be moved and controlled by a remote person (e.g., someone at home) in a local environment (e.g., office, classroom). These robots provide real-time audio and video exchange, with the person's face typically shown on the robot's "head" via face screen. The remote user is in control of the movement and behavior of the robot in the local environment. This control provides the remote user a degree of embodiment in the robot and the opportunity to be present and engage in the local environment. Currently available telepresence robots differ from each other in significant ways with different mobility, vision, and audio features. Many telerobots also have autonomous features that reduce cognitive load to facilitate an immersive experience for the user. In this chapter, we will review our studies on the use of telerobots for virtual learning and explore autonomous and semi-autonomous features that facilitate an immersive experiences for the remote user and the interactants (e.g., peers, colleagues interacting with the telerobot). We will evaluate issues of 1) function in existing systems and what is needed in future systems, 2) trust in autonomous features, and 3) need for interdisciplinary approaches to meet human needs. We will also explore social and ethical issues related to increased autonomous features in child-operated robots.

Keywords: Human-robot interaction, human-automation interaction, virtual learning.

1 Introduction and Background

Telerobots have recently been introduced as a way for children who are homebound due to medical conditions to attend their local schools. Each year, millions of children are homebound due to illness that requires limited exposure to other children and adults due to health risks [1]–[3]. How might physical robotic avatars be used to enrich social and developmental experiences? What role do autonomous features play in telerobot design? Fundamental developmental theories and theories of thriving make clear the importance of exposure to larger social settings for normative healthy human development [4], [5]. This chapter draws upon theories of human development to justify the importance of exposure to the kinds of experiences children normally receive in school settings for normative development. Theories related to virtual reality are also explored to evaluate the role that social presence, through robotic avatars, plays in providing homebound children with developmental experiences. Earlier work informs a theoretically supported framework for evaluating robot-mediated presence and the potential for autonomous telerobot features to improve social connectedness.

1.1 Medically Homebound Children

Understanding the population of homebound children and their social contexts of engagement not only provides insight into how children interact socially in schools via telerobots but also aids in developing more effective robotic systems for this population. There are a number of serious medical conditions that keep children from physically attending school (e.g., childhood cancer, chronic immune deficiency, heart disease, sickle cell disease, and HIV/AIDS). These and other medical conditions may make a child especially vulnerable to diseases that are commonly passed among children at school. With advancements in medicine that result in improved survival rates for these conditions, comes greater need for advancements in technology to ensure the quality of life for children living with serious medical conditions. Telerobots are a promising technology to address the needs of homebound children.

A foundational block of any, if not all, child–robot interaction work is a strong understanding of traditional childhood social and developmental experiences. Most homebound children in our studies are traditional learners until symptoms, diagnosis, or treatments of a medical condition require them to be homebound. Homebound children are physically segregated from school and other social settings for extended periods of time due to associated health risks. Although some homebound children experience physical challenges, many do not have an increase in cognitive challenges that prevent them from participating in social and academic activities [3], [6], [7].

For most homebound children, the need for equal access to the same learning outcomes, both academic and social, remains the same as that of their healthy peers. However, current homebound educational services do not provide children with the social and academic experiences necessary for positive long-term social or cognitive outcomes. In the United States, homebound children receive minimal home instruction services (typically 4–5 hr/week) [7], [8] even though research has shown that inclusive educational practices result in better social and academic outcomes for all children [9],

[10]. Being removed from school and losing contact with peers for significant periods of time likely undermine both healthy social and cognitive development, as well as create anxiety and fears about disrupted friendships and concerns about falling behind academically [11], [12].

1.2 Bioecological Systems Theory

Schools are places where children learn academic, emotional, and social lessons, all of which are intertwined. Many children experience loneliness and depression when homebound [13], [14]. Earlier work on telerobots was centered on what children needed from the design of robots to facilitate social experiences [6]. We are extending this work to explore robot-mediated development and social connectedness. Bronfenbrenner's bioecological framework for human development provides a foundation for highlighting the importance of remaining socially connected to peers, school, and community [5]. Bronfenbrenner formulated his bioecological systems theory to explain how the inherent qualities of children and their environments interact to influence how they grow and develop. Bronfenbrenner's theory emphasizes the importance of studying children in multiple environments, also known as ecological systems, in the attempt to understand their development [5], [15].

According to this theory, children typically find themselves enmeshed in various ecosystems, from the most intimate home ecological system to the larger school system, and then to the more expansive systems that include society, culture, and government/ social policy. Each of these ecological systems inevitably interacts with and influences each other in all aspects of the children's lives. Bronfenbrenner proposed that the microsystem is the smallest and most immediate environment in which children live. As such, the microsystem comprises the daily home, school or daycare, peer group, and community environment of the children.

Interactions within the microsystem typically involve personal relationships with family members, classmates, teachers, and caregivers. How these groups or individuals interact with the children will affect how they grow. But what happens when a child is homebound and these environmental supports, critical components of the microsystem, are removed? Can robot-mediated interactions reestablish these crucial environmental supports of the microsystem?

To illustrate what has traditionally taken place, Figure 1 represents a simplified view of the environmental supports in a traditional childhood microsystem. This microsystem of support is radically altered when a child becomes homebound. Figure 2 demonstrates a simplified view of the homebound experience: peers, school, and community are removed, and health care is introduced as a new environment in the child's microsystem. The homebound child is restricted to the physical environments of home and hospital for social experiences. All participants in this study reported the addition of regular interactions with a healthcare team and almost complete removal of their school, community, and peer activities when receiving homebound services without a robot. Very little is known about the long-term effects of this disruption to a child's social environment as there has not been an alternative to this traditional homebound experience. Recently, the use of telepresence robots provides a way to remain virtually connected to these supports throughout the homebound experience. Figure 3 illustrates the return of these supports, represented with the Wi-Fi symbol in the background, to signify that these supports are now experienced via digital means (i.e., robotic telepresence, Wi-Fi connectivity, and home device).

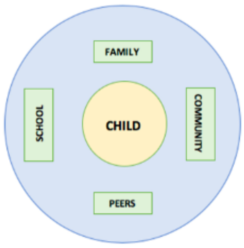

Figure 3. Traditional Microsystem.

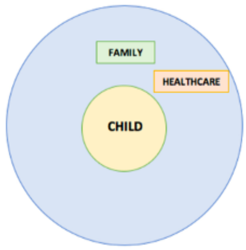

Figure 3. Homebound Microsystem.

Figure 3. Robot-mediated Microsystem.

2 Overview of Telerobots for Virtual Learning

2.1 Virtual Inclusion

The term "virtual inclusion" refers to educational practices that allow homebound children to attend school through the use of telerobots in such a way that they are able to interact with classmates, teachers, and other school personnel as if they were physically present [3]. Virtual inclusion is the user's compelling sense of being in a technology-mediated space (e.g., the classroom) and not where the physical body is located (e.g., the home) much like virtual reality where a remote person feels present in a virtual environment [16], [17]. Ideally, homebound children can feel as if they are in attendance at school and engaged in educational experiences along with peers. If so, then virtual inclusion via telepresence robots may provide the opportunity for the children to maintain social connectedness and relationships with their peers, teachers, and administrators through computer- and robot-mediated communications. The robots may allow children not only to participate visually and verbally in their classes but also to experience dynamic interactions within the classroom, school, and community. Mobile telerobots have an added physical presence that is missing in other communication devices, which, combined with movement, enhances the perception of a social link for the operator [18].

2.2 Benefits of Telerobot Use

Very little research has been conducted on the use of telepresence robots by homebound children for daily social and academic experiences [3], [6], [7], [19]. Prior research explored the cognitive and socioemotional benefits of this emerging practice [3]. This research identified three themes that emerged from the coding and analysis of the data: (a) anthropomorphism for social acceptance and normalcy, (b) overcoming isolation to meet socio- emotional needs, and (c) new experiences that generated talk of an academic and social future. In addition, this research identified Ryan and Deci's SDT as a key theoretical support for future work (Ryan & Deci, 2000). SDT posits that all humans have universal, innate psychological needs (i.e., competence, autonomy, and relatedness) and that people develop and function optimally only when these needs are met. More specifically, in order for humans to actualize their inherent potential, their social environments must nurture these needs. Being homebound, by its very nature, fails to meet these needs because it socially isolates children from the types of enriched social environments needed both to fulfill children's needs for competence, relatedness, and autonomy and to develop the social skills necessary to meet these needs when they return to school.

Earlier studies also found that using telerobots to interact in their school's social environment allowed students to feel capable of using a robot to interact successfully with classmates, teachers, and other school personnel. This capability reinforced the students' developing feelings of autonomy, relatedness, and competence [3]. In our studies, all participants claimed to feel included in class; classmates referred to the robot by the homebound child's name as opposed to calling it a device or a robot. In addition, parents noted significant increases in their children's interest and happiness at being with their friends.

2.3 Commercially Available Telepresence Robots

For effective child-centered studies, it is critical to understand the uniqueness of the homebound child's experience. The telepresence robot is an innovative technology that can remove the barrier of physical segregation. However, an embodied robot can provide levels of presence that vary from simply being collocated (co-present) to being richly engaged in the organic environment. Telerobots are mobile robot units that can be moved and controlled by a remote person (e.g., homebound child) in a local environment (e.g., real- world classroom). These robots provide real-time audio and video exchange, with the person's face typically shown on the robot's "head" via face screen. The remote user is in control of the movement and behavior of the robot in the local environment. This control provides the remote user a degree of embodiment in the robot and the opportunity to be present and engage in the local environment.

Currently available telerobots (Figure 4) differ from each other in significant ways. They have different mobility features; they may or may not allow pan and tilt of the camera; they have different microphone and speaker placements; they have different net- work security features, and different levels of autonomous or semi-autonomous features.

Figure 4. Four commercially available telerobots: VGo, Double, Beam, BeamPro

3 Overview of Autonomous and Semi-Autonomous Features

3.1 Function in Existing Systems and What is Needed in Future Systems

In our work, telerobots include telepresence robots that have the following features: **Remote-controlled mobility** to navigate the physical environment from a remote location. **Life-size face screen** that displays the remote user's face, head, and shoulders to effectively communicate facial expressions, body gestures, and hand movements (as needed) to engage with interactants. **Synchronous video and audio** capabilities are also requirements of telerobots. Recently, new additions of "robot" models have been added to the category of "telepresence robots" however, not all are mobile or have a face screen. As participants have placed large value on the ability to move (walk), view (see), hear and speak (talk), we do not use desktop or non-face screened units in our studies [3], [6], [7], [15].

Commercially available telerobots have some autonomous and semi-autonomous features that ease remote-operator cognitive load and facilitate engagement and interaction with peers. Features such as obstacle avoidance, semi-autonomous navigation, and voice recognition are available on some models. Recently, we studied the addition of an arm and hand feature for increased engagement and learning capabilities [20]. However, the robot in this study was a prototype and not commercially available. For telerobots that are commercially available, we identified the importance of the following robot features for functioning in existing school environments:

Connectivity. The function of existing telerobot features is largely dependent on connectivity [6]. The most cited frustration with the mobility of the telepresence robot used in this study was not physical obstacles but the Wi-Fi connectivity. Other researchers studying office and health care uses of telepresence robots have stressed the importance of connectivity **[21]–[24]**. **However,** students are more mobile for longer periods of time than either office workers or health care professionals**. C**onnectivity is a particularly salient need for them.

Router transitions. School buildings are also very different in structure than office or health care settings. Many school buildings are older and constructed with bricks, cinder blocks, and outdoor hallways between classrooms. Routers are needed to bridge the Wi-Fi connectivity between classrooms. For increased autonomy, future robots should allow for seamless transition between routers.

Audio. Participating in class discussions is an essential aspect of being present in the classroom. The ability to hear what the teacher is saying, respond, and interact with peers is central to both academic and social learning. Current telerobots do not have microphone and speaker placements that are ideal for one-on-on communications—the microphones pick up all sounds in the classroom and the speakers direct sound in multiple directions. Future robots may have autonomous features that allow the remote user to "follow" a dominant speaker (e.g., the teacher) or to direct the speaker towards one person (e.g., classmate seated next to the robot).

Height. Relative height influences ease of communication and conveys relative power [25]–[27]. Prior research has found adjustable height on a robot to be important [21], [28], [29]. The VGo's static height is 4 feet, which is about the height of younger elementary school children. The height is not adjustable; therefore, the robot cannot "stand" or "sit" to maintain eye contact with peers who choose to stand or sit while talking. The Double robot has remote-controlled adjustable height, suitable for sitting and standing. Participants reported that when "sitting," the height might be helpful in adjusting the sight line around something blocking the view to the teacher, as mentioned by one of our teachers. Future robots may have adjustable height features that match the eye-level of the interactant (i.e., classmate) with the camera on the robot. This would allow the remote-student to focus on communication while the telerobot "stands" and "sits" alongside classmates.

3.2 Trust in Autonomous Features

In our studies, we found that participants valued the autonomous and semi-autonomous features on telerobots. Specifically, obstacle avoidance and navigation were two features that were highly valued for use of the robots in schools. As children became more proficient in operating their robots, they expressed a desire for an arm and a hand to access elevators and manipulate objects in the classroom. During our research with a robot prototype, children appreciated a mapping and navigation feature that allowed them to click on a map and the robot would self-drive to that location [20]. Children expressed that this would be particularly helpful when walking down the hallways as it would allow them to focus on talking to peers or observing activities instead of being focused on "driving" the robot where it needed to go. Obstacle avoidance was also an important autonomous feature as children did not want to bump into people and possibly "fall down" and break the robot [7].

4 Need For Interdisciplinary Approaches to Meet Human Needs.

Understanding the social contexts and developmental needs of homebound children and how they can be achieved via robotic avatars will aid in developing more effective support and technological systems. As autonomous and semiautonomous features are improved and added to robotic systems, interdisciplinary expertise and research methods will continue to aid future research in evaluating the synergy between technological features and social practices that contributes to optimal robot-mediated learning and development.

Additionally, as robots and autonomous systems evolve into public spaces, the need for interdisciplinary approaches that include deep understanding of the human needs and development are critical. Specifically, when exploring the use of emerging technologies for use by children, designers must understand the social contexts of the use cases. Deploying, evaluating, and designing robots on their own does meet the needs of the target users. Interdisciplinary studies that are centered on the needs of the child using the robot are urgently needed.

4.1 Presence and Social Connectedness (PASC) Framework

Our Presence and Social Connectedness (PASC) framework is a first step toward a consistent measure for evaluating the robot-mediated presence and engagement of children and adolescents in schools as well as evaluating the quality of robot- mediated social experiences. The PASC framework provides foundational design implications for both social scientists and robot designers. Synthesis of relevant theories and findings from empirical data informed three descriptive levels of presence in robot-mediated classroom experiences (Figure 6). These levels are on a scale (from copresent to collaborating) and, in this study, fluctuated according to tasks and settings. It is understood that all students may display varying levels of engagement based on tasks, content, classmates, and technical aspects of the robots. In this study, some participants displayed a high level of presence (i.e., collaborating) when participating in certain classes (e.g., science, second language), but displayed a low level of presence (i.e., copresent) when attending other classes (e.g., social studies, math). These fluctuations in robot-mediated presence are expected if they mimic the interests and behaviors of the child as if she or he were present in person. Social and technical design implications are integral to any work seeking to explore this practice beyond basic use and collocation of robots in real-world settings. The integration of semi-autonomous and autonomous

Figure 5. PASC framework; Levels of robot-mediated presence.

features in telerobots should seek to facilitate meaningful transitions from copresent to cooperating and, ideally, collaborating in learning activities.

5 Conclusion

Telerobots are a promising technology for virtual inclusion. However, existing robots are not a perfect fit for child populations. Future autonomous and semi-autonomous robot features may have a significant impact on their use for social and academic learning. Our future studies will continue to explore the use of telerobots in real-world settings that increase access to learning opportunities and facilitate remaining connected to one's physical communities. Our studies will continue to assess the success of robot design relative to the social contexts of the settings.

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