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6 authors, including:

Stephanie Arévalo Arboleda
Technische Universität Ilmenau

Söhnke Benedikt Fischedick
Technische Universität Ilmenau

Chenyao Diao

Horst-Michael Gross
Technische Universität Ilmenau

An exploratory study on the impact of varying levels of robot control on presence in robot-mediated communication

Stephanie Arévalo Arboleda[1], Söhnke Fischedick[2], Chenayo Diao[1], Kay Richter[2], Horst-Michael Gross[2], Alexander Raake[1]

Abstract— **Telepresence robots can enhance communication experiences by providing a sense of physical presence, embodiment and may evoke co-presence. In spite of that, telepresence robots have not made it fully to consumer markets. In this paper, we investigate how different levels of controlling a telepresence robot (teleoperation, shared control, and no control) influence presence. To this aim, we conducted a study (N=45) where participants were evenly distributed to one of the robot control conditions. The task involved navigating an unknown room and listening to stories told by a person co-located with the robot. We collected subjective impressions of presence using the temple presence inventory and performed a thematic content analysis on a post-experiment interview. Our results suggest nuances in perceived presence under different levels of robot control after performing a thematic content analysis. Co-presence can be experienced during teleoperation and shared control, and teleoperation may evoke negative sentiments if it does not provide enough spatial information during navigation. However, our results did not point to significant differences in spatial or social presence. We consider that these findings encourage further discussions on how presence is perceived in robot-mediated communication.**

I. INTRODUCTION

The widespread use of videoconferencing tools during COVID-19 allowed people to stay connected despite geographical distances. However, they do not yet provide a similar in-person interaction. Robot-Mediated Communication (RMC), i.e., human-human communication where at least one person is telepresent audiovisually and can move in the remote physical space in real-time using a telepresence robot [1], [2]. provides opportunities for enhancing communication. It can create a sense of spatial presence and embodiment for communication despite having interlocutors remotely located [3]. In addition, depending on the type of robot used, the person who is located remotely could teleoperate the robot and interact with the remote environment, increasing the sense of social presence [4]. In spite of that, the effect of different levels of robot control on presence when using telepresence robots has been explored scarcely.

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[1]Stephanie Arévalo Arboleda, Chenyao Diao, and Alexander Raake are with the Audiovisual Technology Group, Technische Universität Ilmenau, Germany. {stephanie.arevalo, chenyao.diao, alexander.raake}@tu-ilmenau.de

[2]Söhnke Fischedick, Kay Richter, and Horst-Michael Gross are with the Neuroinformatics and Cognitive Robotics Group, Technische Universität Ilmenau, Germany. {soehnke.fischedick, kay.richter, horst-michael.gross}@tu-ilmenau.de

Robot control could enhance social presence and co-presence in the communication experience for the remote operator. However, to the best of our knowledge, only Rae et al. [5] investigated the effect of control (local or remote) in RMC. Their results point to an effect of robot control on the level of trust, i.e., participants lost trust when the robot was remotely controlled.

In this paper, we focus on the perception of the remote interlocutor with three degrees of involvement when controlling the navigation of the telepresence robot: (i) teleoperation, where the remote interlocutor controls the robot's navigation; (ii) local control, with no control over the robot's navigation, as it is defined by the local operators' movements (the robot adopts a person-following behavior), and (iii) shared control, where both interlocutors can control the robot movements. We aimed to explore whether the level of involvement of the remote interlocutor in robot control may have an effect on presence. Our main contribution highlights that (1) a sense of co-presence can be experienced during teleoperation and shared control in RMC, and (2) remote operators can have a negative sentiment towards teleoperation if they perceive that there is not enough information during navigation. However, we did not find significant differences in spatial or social presence, which may be rooted in the number of participants or the tool used. However, these findings encourage further exploration to determine how different levels of robot control affect specific dimensions of presence, i.e., mental immersion, co-presence, spatial and social presence, or whether telepresence robots provide their own affordances of presence.

II. RELATED WORK

Presence is a vast term defined broadly as the "sense of being there" [6] that involves different components. Minsky [7] introduced the term *telepresence* to define the sense of being physically transported to a remote workspace using a teleoperating system. Closely related, *spatial presence*, i.e., the illusion of being located in an environment that is conveyed by some media technology [8], *social presence*, i.e., the "sense of being with another," and *co-presence* being "in the company of others" [9] are crucial in mediated communication scenarios.

In RMC, the perceived presence of remote users has raised discussion. Telepresence robots can evoke different types of presence during communication as they allow remote operators to have full control over the movements, increasing spatial presence of remote operators [4]. Also, telepresence robots have shown to have a positive effect in terms of connecting interlocutors and evoking social presence [10]. Yang et al. [11] found that using telepresence robots provides a sense of autonomy and fosters similar in-person interactions when communicating with a significant other. However, Boudouraki et al. [12] mentioned that telepresence robots define their own interaction possibilities rooted in the need for intimacy or ”being together” when communicating with loved ones and propose a refocus from presence as being there to being ”present enough” to take part in the interaction [13]. It has also been observed that telepresence robots may increase psychological distance, i.e, how close a person feels to another during interaction [14]. In the aforementioned studies, factors such as familiarity and type of communication task influenced the feeling of presence, leaving space to investigate other factors that could affect presence such as the level of robot control.

Telepresence robots provide a sense of agency to the remote interlocutor while operating a robot within the space of the person who is co-located with the robot. Takayama [15] mentions the term ”apparent agency” to refer to the amount of agency that someone or something may have during the interaction. In the case of telepresence robots, they inherit the agency from their operator. Here, Takayama et al. [16] found that personality traits such as locus of control (belief of having control over events) influence how telepresence robots are used, i.e., navigation performance. However, teleoperation increases the workload of the remote interlocutor which can in turn affect communication. Desai et al. [17] proposed reducing the operators’ involvement and having adjustable autonomy as an essential feature of telepresence robots. Here, a person-following behavior can enhance the experience of the remote operator by lowering the workload that involves teleoperation (high human intervention in planning robot movements). For instance, person-following could allow the person who is remotely located to pay more attention to the conversation [18]. Also, Almeida et al. [19] reviewed a set of studies to dissect presence and identify robot design guidelines to achieve co-presence for the person who is remotely located. One of their guidelines mentioned managing robot autonomy in telepresence systems. However, in the studies reviewed it is not mentioned if and how these different levels of robot control may impact presence.

III. Robot Control for Navigation

Inspired by the taxonomy of levels of robot autonomy for HRI [20], we considered the level of intervention of the remote operator to navigate an unknown remote room. We chose three levels of involvement of the remote operator ranging from high to low as follows.

1) Teleoperation (high intervention of the remote operator): The remote operator has full control over the navigation actions of the robot, namely, manual control. To implement teleoperation, participants were able to see the view of the robot’s front camera on a computer’s screen. To control the robot’s movements, we provided two modes: *Image click*, where participants point and click to a target location (floor) on the screen; and *keyboard’s arrows*, participants use the keyboard arrows to move the robot forward or backward and to rotate the robot to the left or right.

Fig. 1. Experimental set-up. Right: Remote operator/participant. Left: Robot located in front of participant while telling stories.

2) Shared Control (medium intervention of the remote operator): The remote operator and the local operator have control over the navigation actions. The robot initiates navigation by following a person and the remote operator can intervene at any given point. To implement shared control, we used Wizard-of-Oz (WoZ) for the robot initiating navigation to target goals. We pre-defined navigation goals where an invisible (to the remote operator/participant) human operator selects the navigation goal once the local confederate starts walking. This created the illusion of the person-following robot behavior. Participants could intervene at any given point using the same robot controls explained for teleoperation.

3) No control (no intervention of the remote operator): The robot initiates navigation by following a person. To implement local control, we also used WoZ, pre-defined navigation goals, and an experimenter (invisible to the participant) co-located with the robot monitored the experiment and controlled the robot to correct navigation if needed. Participants observed the camera view of the robot and we mentioned that the robot executes a person-following behavior, i.e., if the person starts walking the robot would move behind the person and would stop when the person stops walking.

IV. User Study

A. Research Question

The research question that drives this exploratory study is: *how different levels of robot control affect the remote interlocutors’ perceived presence?*

We carried out an experiment where we evaluated the relationship between the amount of human involvement when controlling a telepresence robot (level of robot control) and presence. All the analysis and considerations are presented from the perspective of the user who is remotely located (remote confederate/operator). The local confederate (co-located with the robot) was one of the experimenters. Figure 1 shows the experimental set-up.

B. Task

The experimental task consisted of navigation and story listening. Participants navigate an unknown room using a

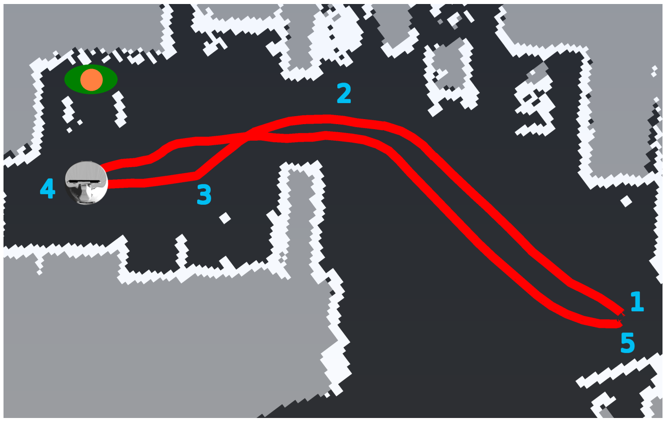

Fig. 2. Map of the room where the local confederate was co-located with the robot. The numbers mark the points where the robot and local confederate stopped. Number 4 shows the robot in front of the local confederate.

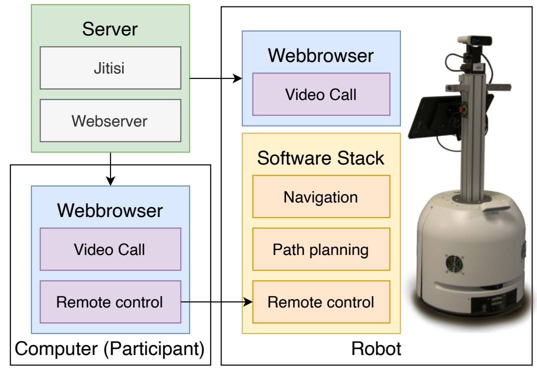

Fig. 3. High-level representation of the system.

telepresence robot. The navigation path did not present any obstacle and is shown in Figure 2. To get familiar with controlling the robot, participants performed a training task. The training task consisted of using all the controls (image click and keyboard's arrows) to move the robot toward a specific area of the remote room. First, participants see the view of the front camera of the robot on a screen. Second, they were instructed to use the mouse to click on a specific area on the floor where they would like the robot to move (image click). Third, they needed to use the arrow keys to move the robot to a specific target and were instructed to do it in a systematic way by rotating to the left, moving forward, rotating to the right, and moving backward. Once participants confirmed they understood how to control the robot, they executed the main task.

Participants could either control the robot to navigate the room by trying to follow the local confederate (teleoperation, shared control) who was moving to certain areas of the room, or they would watch the robot (no control) follow the local confederate. The level of robot control depended on the experimental condition.

C. Experimental Design and Measures

We conducted a 3x1 between-participants experiment with the level of robot control (teleoperation, shared control, and no control) as the independent variable and collected subjective impressions of presence through questionnaires.

We used the following questionnaires to measure the subjective impression of participants. To measure presence, we used the Temple Presence Inventory (TPI) [21] considering spatial presence, social presence, and mental immersion (7-point Likert Scale). The TPI has been previously suggested as an adequate tool to measure presence in robot-mediated environments [22]. During the final interview, we asked questions about (1) what was the most difficult part of the experience? (2) what did they like the most during the experience? and (3) what would they have liked to have when navigating in the room? Additionally, we used a Tobii Pro glasses 2[1] to collect eye-tracking data to measure attention, however, we could not analyze the data as more than half of the files were corrupted.

D. Participants

We recruited a total of 45 participants (31 males, 13 females, and one non-binary), all students or university staff. Participants were assigned to one of the experimental groups (teleoperation, shared control, or no control), yielding 15 participants on each experimental condition. The average age per condition was teleoperation 28.23 (SD = 2.74), shared control 25.8 (SD =6.44) and no control 26.33 (SD = 2.62). The study was conducted in English. The pre-test questionnaire revealed that 16 participants had some experience programming robots and were distributed evenly across conditions. We collected information about their inner locus of control using Clawson & Yemen questionnaire [23]. The questionnaire revealed that 37 participants had an inner locus of control, 2 external, and 6 had both. Hence, we could not distribute them evenly across conditions. Also, 41 participants reported interest in using a telepresence robot for communication purposes.

The study was pre-approved by the ethics committee of the university and participants received 12 euros as compensation.

E. Procedure

The experiment lasted 30-40 minutes and consisted of six phases, with the indicated approximate times used: (1) Participants were given a short introduction about the goal of the experiment and were handed a consent form. (2) They read instructions on how to control the robot and performed a training task. (3) Participants performed the main task. (4) They filled out the presence questionnaires. (5) After that, we carried out a short interview about the whole experience.

F. Devices and Implementation

The system overview is shown in Fig. 3 and presents the robot used, the computer used by the participant and our system architecture. The server was not only used to host the core application as a website, but also contained

[1]https://www.tobii.com/products/discontinued/tobii-pro-glasses-2

a self-hosted Jitsi[2] server to enable the videoconference. Also, it established a direct connection between the two devices, enabling remote control features. The participants used a computer equipped with a Logitech Brio Steam[3] camera to enable them to engage in the videoconference. For carrying the video screen and camera on the local side, a modified MetraLabs TORY[4] platform robot was used. similar to the one described in [24], which offered remote control capabilities. This platform transmitted video images captured by a Microsoft Azure Kinect[5]. To enable remote control, the robot used existing components of its navigation and path planning stack, benefiting from the pre-existing collision avoidance capability enabled through a Sick S300[6] 2D laser range scanner. Key presses from the participant were directly transmitted to the robot and were further used as input to the navigation stack, allowing for precise control, e.g., pressing the up arrow key causes the robot to move forward as long as the key remains pressed. As mentioned in III, we enabled image clicking to navigate to a desired position. To enable that, the coordinates of the clicked pixel were transmitted and then converted through ray tracing to a global position in the robot's local map. The resulting global coordinate was then used as input for path planning, allowing the robot to automatically navigate to its goal. To ensure that participants can listen clearly to the local confederate, we used a Rode Wireless GO[7] microphone.

V. Results

The subjective questionnaire data (mental immersion, social and spatial presence) were analyzed using the Kruskal-Wallis test. Table I shows a summary of the questionnaire data. We did not find a significant effect of the type of robot control after performing the Kruskal-Wallis test. Additionally, we performed a Thematic Content Analysis (TCA) to the final short interview following Anderson's approach [25] and performed a sentiment analysis using MAXQDA [8] to the second question of the interview (what is the most difficult part of the experience?). For the TCA, we transcribed the text using Whisper [26], then two researchers analyzed the text, coded it, and provided their resulting themes, separately. The resulting themes from each coder were later rated by another researcher to define the final themes. As a criterion for relevancy, we established that at least 15 participants should have mentioned the same aspect.

A. Thematic Content Analysis

We identified five themes: spatial information representation, more control over the robot motions, adjustable camera point of view, positive experiences, and co-presence. In the following paragraphs, we elaborate on each theme.

TABLE I
Summary of collected measures

	Teleoperation		Shared control		No control		Sig. Level
	Mdn	IQR	Mdn	IQR	Mdn	IQR	p
Social Presence	5.14	0.82	5.07	0.93	4.85	1.76	0.87
Spatial Presence	4.14	1.72	4.14	0.93	3.74	1.43	0.25
Mental Immersion	5.0	1.59	5.5	0.67	4.33	2.25	0.44

1) Spatial information representation: This theme consolidates the concerns of 22 participants with respect to the lack of spatial representation of the remote environment, including information such as the robot size and position, objects, surroundings, and distance representation. Participants who mentioned this aspect are mostly from the *teleoperation* (10 participants) and *shared control* (9 participants) conditions. Only three participants from the no control condition mentioned this aspect. We related this theme to human spatial navigation cognition, which relies on cognitive maps built from spatial knowledge and presented spatial information of the environment [27].

For most of the participants, the lack of representation of the surroundings made them concerned about crashing into things (15 times), e.g., S1, *"If I want to go backward I don't want to crash into things, so I have to remember what was behind me like the TV or the table."* Also, some participants related being afraid to crash with a lack of knowledge of the robot's real dimensions, e.g., T2 mentioned, *'I didn't know if I would fit. I was afraid of bumping into things all the time."* For some participants, a map or a distance indicator was mentioned to provide spatial information, T12, *"I would like to have some kind of indicator of how close I am to an object, like the ones from cars."*

2) More control over the robot's movements: This theme summarizes 15 participants' comments on the control over the robot's movements. Here, most participants who expressed the desire for more control were the ones who experienced the teleoperation (9 mentions) and shared control (4 mentions) conditions. Only 2 participants who experienced no control mentioned this aspect.

The controls over the movement should allow for a combination of turning and moving forward, according to 10 participants. Most participants mentioned improvements such as "simultaneously move and turn" and "more control", e.g., S6 mentioned, *"So the difficult part was that like to control it like moving and turning simultaneously."* S8 commented on a similar aspect, *"It will be because sometimes you need to use both simultaneously to get not directly to this direction."*

Seven participants proposed new methods to control the robot movement such as using other types of controllers, or using other modalities, e.g., *"So instead of this, there are controllers for video games. So I feel that with those controllers, you get a lot of degrees of freedom around rather than with a keyboard."* And S6 stated, *"I would like to use head movements, if I move my head then I do not have to see the keyboard, using my head will give me more accuracy."*

[2]https://github.com/jitsi/jitsi-meet
[3]https://www.logitech.com/en-us/products/webcams/4kprowebcam.960-001390.html
[4]http://www.metralabs.com/rfid-roboter-tory/
[5]https://azure.microsoft.com/en-us/products/kinect-dk
[6]www.sick.com/de/sicherheitslaserscanner/sicherheitslaserscanner/s300-standard/c/g187239
[7]https://rode.com/en/microphones/wireless/wirelessgo
[8]https://www.maxqda.com/

3) Adjustable point of view of the camera: This theme integrates the desire to adjust the point of view of the camera. Here, 18 participants mentioned this aspect, distributed in 8 from no control, 6 from shared control, and 4 from teleoperation. We highlight that this theme has mostly aspects mentioned by the participants who experienced no control. We attribute this to the camera on the robot, which has a field of view of 90° horizontally and 74.3° vertically, adding constraints for environment exploration.

Most participants expressed that they would like to see more of the scene (7 times), and some participants also mentioned terms like "360-degree view" (6 times), capture the best view" (4), e.g., W9 mentioned, *"It's about how to sync with the view of the camera"*, or T8 added *"I want to have a 360-degree view of the room."* Some participants considered the lack of control over the camera view to be a disadvantage and suggested being able to "tilt the camera" (5 times), e.g., S2 stated, *"Actually, to think the robot, there's no option for tilting it upwards or downwards and that was the most disadvantage in it."*

4) Positive experiences of robot control: There were 17 participants who provided positive feedback on the experiences of robot control. Here, we note that most of the positive feedback came from participants involved in teleoperation (6 mentions) and shared control (7 mentions). We only had 4 positive mentions with the no control condition.

As most of them were for the first time to control the robot, they found the experience interesting (8 times), fun (4 times), exciting (3 times), and enjoyed the overall experience. For example, S8 mentioned, *"It was very nice because this is my first time to control the robot."* T12 said, *"Controlling the robot was quite an interesting experience, especially to be in the control, not like in a video game. I knew that there was a physical robot in that room. I think that's pretty cool."*

5) Co-presence experienced: A total of 21 participants stated that they experienced co-presence. The mentions came mostly from participants who experienced shared-control (9 mentions), followed by teleoperation (7 mentions) and no control (5 mentions). Most participants used the terms "was there", "next to her", and "face to face". For example, as S4 stated, *"To some degree it truly felt like I was there. The woman was talking to me, not to some robot."* And from W7, *"Because I really felt that I was with her next to her, or just spending time with her in the same place. And also that I could see everything while she was walking or talking to me."* Similarly, T8 expressed, *"You can really move along with the person who is speaking, so you get to feel like you are somewhat present in that room."*

B. Sentiment Analysis

Our results when analyzing the sentiment of the second question about the difficulty of the experience can be seen in Table II. Teleoperation yielded the highest count of slightly negative sentiments. Here, T2 and T3 mentioned, *"I was afraid of bumping into things all the time,"* and, *"I didn't want to bump into anything when controlling the robot."*

TABLE II
SENTIMENT ANALYSIS OF LEVEL OF DIFFICULTY

	Teleoperation	Shared Control	No Control
Slightly Positive	1	2	0
Neutral	3	8	9
Slightly Negative	9	4	4
Negative	2	1	2

Shared control and no control yielded 8 and 9 counts with a neutral sentiment, respectively.

VI. DISCUSSION

A. Presence and the Level of Robot Control

We aimed to understand how different levels of robot control affect presence. Our results did not point to significant statistical differences in mental immersion, social or spatial presence. This can be attributed to our sample size and the type of questionnaire used. However, the TCA (Section V-A.5) revealed that more than half of the participants in teleoperation and almost half of the participants in the shared control conditions reported a feeling of co-presence (colocation and mutual awareness [9]). Also, we found most participants who mentioned having a positive experience (Section V-A.4) were the ones involved in teleoperation and shared control conditions.

The differences between the questionnaire and TCA results led us to consider whether the existing tools to measure presence can be used in the case of telepresence robots. Often questionnaires that address presence, e.g., [9], [21] have been designed to measure presence in mediated environments but have not considered having a physical tangible representation or embodying a telepresence robot. This leads us to wonder whether allowing for physicality, as is the case of telepresence robots, provides different interaction affordances and builds a different mental model compared to other mediums, e.g., computer-mediated communication, and avatar-mediated communication. Moreover, these nuances in presence can be aligned with the findings of Boudouraki et al. [12], [13], which suggest that telepresence robots define their own interaction possibilities and are used to achieve a sense of being together that involves being "present enough" to participate and engage in social interaction.

B. Agency over the Robot and Environmental Information

Our TCA revealed that participants in the teleoperation and shared control conditions, namely, the conditions where they could control the robot movements expressed the desire for additional controls (subsection V-A.2) and a better spatial representation of the remote environment (subsection V-A.1). Additionally, our sentiment analysis showed that teleoperation yielded the highest count of negative sentiments. We consider that both the sentiment analysis and the TCA could be related. If teleoperation does not meet the agency expectations of participants this could in turn affect their experience. Here, Takayama [15] showed how the personality and internal locus of control can affect performance. We consider that this may also extend to emotional valence.

Regarding having additional controls, participants expressed their desire to have additional controls that combine robot movements or use speech commands V-A.2. This hints at the desire for higher levels of agency when embodying a telepresence robot. Telepresence robots provide a sense of embodiment to the person who is remotely located, providing a sense of presence. However, this may only hold true when a person has some control over the robot's actions, e.g., in teleoperation or shared control. This is confirmed by the theme in subsection V-A.5, co-presence, where the participants who mentioned a feeling of co-presence were the ones from the teleoperation and shared control conditions. Further, we consider that this aligns with findings from avatar-mediated communication where agency has been deemed as a crucial aspect for embodiment and presence [28].

VII. Conclusions, Limitations and Future Work

We present a study to evaluate the effect of robot control on presence from the point of view of the person who is remotely located. Here, remote users (the participants of our study) used a telepresence robot to navigate in a remote unknown room and listened to stories about objects located in that room. For navigation in the remote room, participants experienced one of the three robot control conditions: teleoperation, local control, or shared control. Our findings did not point to a significant difference in the reported social or spatial presence under the different experimental conditions using the TPI questionnaire. However, our TCA revealed that most participants under the shared control and teleoperation condition experienced co-presence. Also, our findings suggest that teleoperation can evoke negative sentiments if there is not enough spatial information provided.

A limitation of our work comes in terms of the number of participants, the questionnaire used to measure presence (TPI) and measuring mental immersion instead of user engagement. A follow-up study could consider the perspectives of the local user co-located with the robot and evaluate how they perceive the movements of the robot when it was teleoperated vs. higher levels of autonomy.

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