Evaluation of control factors affecting the operator's immersion and performance in robotic teleoperation

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Abstract— **This paper presents the results of an experimental study in which users teleoperating a mobile robot evaluated three controllers: a keyboard, a game controller, and a touchpad interface. It is motivated by the need to engage a broader, non-expert user audience in teleoperation as robots become more prevalent in everyday applications. Analysis focuses on how specific control elements and the user's comfort with a device improve the operator's sense of immersion in the task and how this alters performance. Our results show that perceived controllability of the controller, users' level of technological anxiety, and the physical nature of feedback from the controller had an effect on user feelings of immersion and presence. Our findings have implications for the development of controllers that can be used for teleoperating robots by a broad user audience.**

I. Introduction

As robotics applications are extended to various open-ended environments outside of assembly lines and laboratories, teleoperation has become a popular solution that is more immediately viable than full automation. Contemporary uses of teleoperation are wide ranging, including remote-controlled unmanned vehicles [4], bomb detonation robots [14], urban search and rescue robots [13], as well as experimental applications for guiding people in malls [5] and enabling the public to explore museum and art exhibits [5],[6].

Typically, the operators of telerobotic systems are trained individuals, such as scientists and engineers who control NASA's rovers, unmanned aerial vehicle (UAV) pilots, or urban search and rescue robot (USAR) operators. The complex control devices that they use can be unwieldy even for such experienced operators [11]. With the entry of robotic applications into various domains of everyday life, such as caretaking and education, it will be important to make teleoperation easier to perform and accessible to a wider range of users. Designers of health-oriented and assistive applications envision that potential users may include nurses and doctors as well as family members, patients of various ages and cognitive capabilities, and other untrained operators [3],[9]. Applications in museums, shopping centers, and other everyday venues could also benefit from making teleoperation accessible to a broad range of untrained users to whom robotic operation could be crowd-sourced. These non-expert operators need controllers and interfaces that are intuitive and familiar to them, and can give them the necessary sense of presence and immersion in the remote environment to allow them to complete their task.

With untrained users of telerobotics in mind, in this paper we present a within-subjects experiment evaluating three widely available control systems for teleoperating mobile robots in a remote environment—a keyboard, a game controller, and a touchpad interface—in respect to their effect on user performance and feelings of immersion and overall satisfaction with teleoperation. Our aim is to explore the design factors of the controllers that make some devices easier for untrained users to work with, as well as the personal attributes of users that might predispose them to certain controllers. We focus on the perspective of the operator controlling the robot to understand how control elements such as controllability, realism, and naturalness can affect the robot operator's sense of immersion and general satisfaction with the controller, as well as their performance in terms of time to task completion and accuracy of movement in the remote environment.

II. Background

Previous research on telepresence and teleconferencing has mostly focused on static systems (web cameras and screens), only recently including robots as communication media. Researchers studying telecommunication robots have explored new social norms arising in the use of robots teleoperated by humans [13], appropriate cues for telepresent interaction [1], as well as novel means for controlling a robot, such as sketching a path for the robot to follow [14]. Our research extends these perspectives by focusing on understanding the experience of navigating a remote environment from the perspective of the robot operator. It is informed by previous work on controller design for and immersion in robot teleoperation and other contexts, such as gaming.

A. Controller design for robot teleoperation

To design an effective teleoperation interface for a broad range of operators that extends beyond engineers and technical experts, we have to consider the impact of different control factors in the design of intuitive and immersive

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controllers. Complicated controls, such as those for the PackBot, require training, intense focus by the user, and may detract from overall performance [9]. To appeal to a larger user base, researchers developing robotic controllers have turned to popular electronics, such as the iPhone. Designs implemented using the iPhone have taken advantage of the accelerometer and tilt controls, onscreen control buttons, onscreen sliders, and the device's ability to handle streaming media [9]. The researchers additionally found that users prefer gestures to onscreen buttons or sliders; this mode of operation also left more open screen space on the small iPhone device. Some control methods have utilized a laser point-and-click interface to enable users to engage both physically and socially with an environment. Part of the appeal of these accessible control systems is their wide availability and familiarity to a broad range of users.

B. Operator presence and immersion in remote environments

In working with teleoperated robots, the user's feelings of immersion and presence in the remote environment are important because they enable the user's actions and reactions to be more tightly coupled with the remote space. Research on remote presence in telerobotics has focused on the perceptions of social agents in the environment and those using the remote device in applications such as teleconferencing. Tsui [19] describes a study in which a teleoperated robot used for social interaction in an office conveyed a feeling of presence to the operator, although the mere operation of the device required a great deal of the remote team member's attention, causing a perceived drop in productivity.

While many studies investigate how individuals in the remote environment feel the social presence of the operator through the robotic device, little work has been done to investigate the sense the operator has of being more physically located, or immersed, in the remote rather than their own local environment. Research on the development of virtual worlds suggests some guidelines for studying and designing immersive telerobot controllers that would support the operator's sense of "being there." Hendrix [10] emphasizes the importance of a task or activity that the user can focus on to add to their sensation of presence. While presence is a psychological state of being, the sense of immersion is attributed more to what the system provides to the user [20], suggesting the importance of studying different design characteristics of the robotic technology, including the controllers being used.

Keeping in mind the availability of different types of controllers and the importance of a sense of immersion in the remote environment for tele-operation, we study the effects of both prior user attributes and perceived control factors on the operator's immersion and performance in controlling telerobotic devices. We also expect that an individual's increased level of immersion will positively affect their task performance.

III. Methods

A. Participants

Participants for our study were recruited by posting paper flyers across the university campus, as well as emailing flyers to a variety of departments at the university. Subjects were chosen based on availability. We recruited 14 participants among graduate and undergraduate university students, ages 20-46. Seven (50%) participants were male and seven (50%) were female. As we expected the participants' familiarity with technology to affect their performance with and evaluation of the controllers, we included a range of majors: five participants from the humanities (Business, History, Cultural Studies), three from technology-related fields (Computer Science, Informatics), two in the sciences (Biology, Psychology), and four undeclared. One of the participants had an associates degree, five had bachelor's and three had masters degrees, one had a doctorate, and four had high school diplomas. We feel this population was appropriate for our study, as we were trying to develop a general understanding of the experiences of non-expert users teleoperating robots using a variety of controllers. Future studies would benefit from more targeted user populations related to particular telerobotic applications, including caretakers and the elderly, foreign language teachers, and others.

Of the 14 participants 12 completed the entire experimental procedure (initial interview, tasks, and exit interview). One was unable to complete the tasks due to technical failure and their exit interview was omitted. Another had performance times well outside the range of other participants so that data was not included in performance evaluations; however this participant's final interview observations were considered.

B. Materials

1) Robot & controllers

The platform for our teleoperated mobile robot was an iRobot Create. The controllers were a standard USB keyboard, USB game controller, and a Samsung Galaxy Tab Android tablet. Player/Stage software and java applications were used for communicating the inputs to the robot. Visual information for the users was streamed from a USB web camera over Skype.

Figure 1 The touchscreen controller display used by participants (top) and the iRobot Create (bottom).

2) Surveys and Interviews

Participants were asked to fill out a preliminary survey before being introduced to the controllers. The preliminary survey measured participants' attitudes toward technology using a scale combining the Computer Attitude Measure (CAM) [12] and the Attitudes-Towards-Computer-Usage Scale (ATCUS) [2], perceptions of robots using the Negative Attitudes Towards Robots Scale (NARS) [16], and immersive tendencies using Witmer and Singer's Immersive Tendency Questionnaire [20].

During the study, users performed three different tasks using each controller, and after each task they filled out a questionnaire to gauge their satisfaction with the device, sense of immersion, and overall performance. While we used the ITQ as a trait test before the task, in this post-task questionnaire we used Witmer and Singer's [20]Presence Questionnaire (PQ) to measure the degree to which individuals experienced presence in the remote environment and the influence of possible contributing factors on that experience. For the ITQ, participants were asked questions such as whether they feel as if they were a member of the team when they watch sports matches, if they have played video games and felt they were inside the game, and how often they became emotionally involved in news stories they have read or watched. Questions asked on the PQ included asking participants how able they were to control events, how natural their interactions with the environment were, and how aware they were of the display and control devices. We modified the original PQ by excluding questions relating to sound, since our setup did not include audio feedback.

After all tasks were completed, researchers conducted a semi-structured interview with users to understand their general reactions to the teleoperation experience and controllers. This final interview asked participants to describe their experience controlling the robot, comment on the comparative ease of use, entertainment, and other factors relating to the controllers, and discuss their awareness of the remote environment prior to and after actually seeing it.

C. Design

Our study used a within-subjects design. Each participant was exposed to all three controllers described in section 3.2 and performed all three experimental tasks giving a total of over 100 observations. We wanted to explore whether particular user traits (e.g. technological anxiety, field of study) and characteristics of the controllers (e.g. controllability, naturalness, realism) had an effect on user performance and their evaluation of immersion and presence during teleoperation. We also sought to test the following hypotheses related to ease of use of the controllers:

H1: Controllers users evaluate as easier to use promote a greater sense of immersion in the task and remote environment than controllers rated lower on ease of use.

H2: Controllers the user evaluates as easier to use enable them to complete tasks more quickly and accurately than less easy-to-use controllers.

D. Procedure

Upon arrival in our lab, participants filled out the preliminary questionnaire and were shown the robot they would be controlling remotely and allowed to test drive it using the first controller. The robot was then placed in a different room, previously unseen by the participants. Each participant was asked to use the three different control interfaces to control the robot in a series of tasks: (a) pushing an object to a specified location, (b) negotiating an obstacle, (c) driving the robot in a square pattern. The order in which the control methods and tasks were presented to participants was randomized. Additionally, the robot's starting position and orientation were randomized for each task.

While the participants operated the robot, we noted the time they took to perform each task. We also videotaped the robot's actions so we could evaluate the accuracy of their performance, which was calculated based on the observation of certain events for each experimental task (bumping into walls, hitting obstacles, driving in straight lines, etc.). After completing all three tasks using each control method, participants filled out an evaluation questionnaire. In the course of the experiment, participants completed nine tasks and three evaluation surveys. After using all three controllers, participants took part in a semi-structured interview in which they discussed the different control methods in regards to their ease of use and feelings of immersion in the remote space.

Figure 2 The user in one location would control the robot using a control device (right), while the robot is in a remote location (left).

IV. RESULTS

A. Task and controller completion time

		Mean	SE
Task	Push	2.025	0.045
	Obstacle	1.757	0.045
	Pattern	1.869	0.045
Controller	Keyboard	1.874	0.045
	Gamepad	1.853	0.045
	Touch	1.923	0.045

Table 1 Mean completion time (min) and SE for the tasks and controllers across all participants (n=12)

There are significant differences in completion time across tasks ($F(2, 96)$=23.11, p<.001), controlling for other factors. Completion time does not statistically differ across controllers ($F(2, 96)$=1.66, p=.196), but a significant interaction exists between controller and task ($F(4, 96)$=4.175, p=.004). The pairwise comparisons between each level of task suggest that the time for push task is the highest among all tasks (M=2.03, SE=0.05), followed by pattern (M=1.87, SE=0.05) and obstacle (M=1.76, SE=0.05). The differences between any two tasks are statistically significant (push vs. obstacle p<.001, push vs. pattern p<.001, and obstacle vs. pattern p=.017). Participants commented that pushing the box provided immediate visual feedback regarding their performance, while driving in a pattern and obstacle avoidance were not as clear, which may have encouraged them to take their time with the push task.

In studying whether particular participant attributes have an effect on performance, significant differences were found between the areas of research and time to task completion (H(3) = 17.373, P = 0.001) with mean rank scores of 78.08 for Science, 76.49 for Humanities, 52.10 for those that were undeclared, and 47.33 for Technology. Participants in the humanities and sciences took longer to complete the tasks than those that were undeclared or in technical fields. The individuals that remained undeclared were some of our younger participants and may have a higher degree of comfort with the controllers. This complements our findings that those with a higher technological anxiety score (being less likely to learn a programming language, or not enjoying computerized toys) typically took longer to complete tasks (H(3) = 8.688, P = 0.034, with mean rank scores 32.39 for Slightly Negative, 61.69 for Neutral, 70.57 for Slightly Positive, and 62.13 for Strongly Positive), (see Figure 2).

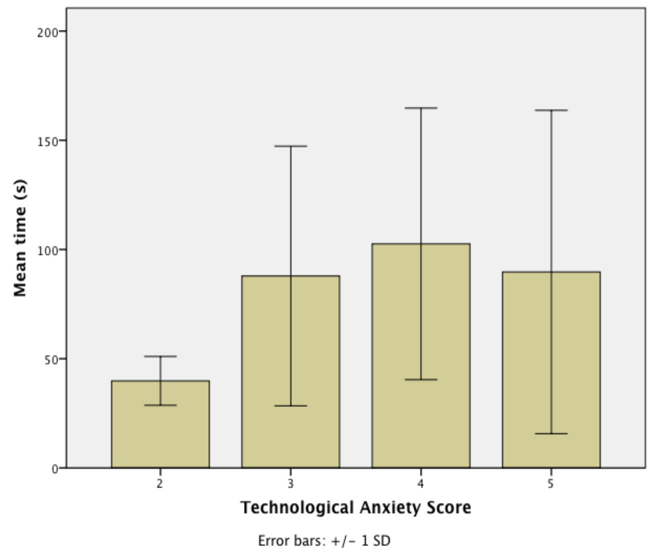

Figure 2 Mean completion times by technology anxiety scores, 2=Somewhat Anxious, 5=Very Anxious (n = 12)

B. Task accuracy and completion

We also assessed user performance based on our observations of the robot's behavior in the remote room, including driving the robot in straight lines, completing tasks without collisions (aside from the box being pushed), and generally completing the task. The tasks were given a percentage of completion based on points achieved; the push task received a 75%, the obstacle 87%, and the pattern 83% overall. These scores are congruent with user attitudes. Many reported in the final interview the difficulty of the push task. We also observed the score for accurate task completion with relation to the controllers. The keyboard and game pad scored similarly at 75% and 78%, respectively. The touch controller scored at 67%. There are no significant differences in accuracy scores across controllers ($F(2, 96)$=.97, p=.383), controlling for other factors. The interaction between controller and task was also not significant ($F(4,96)$=1.599, p=.181). We therefore observe that one controller does not seem to facilitate accuracy over any other, and accuracy is not affected by the interaction of controller and task.

C. Controller assessment

Survey

We did not see any marked preferences across the three control methods in terms of the control factors we were measuring: controllability (Did the controller respond as commanded?), sensory information (Was the environment represented accurately or intelligibly for the user?), distracting elements (Did an element of the system detract from the users ability to focus?), how involving the experience was (Was the user particularly focused on what they were doing, or enrolled in task completion), how natural it felt, and realism. This indicates that the devices did not have any major comparative inherent flaws or strengths. Participants' prior experiences with technology—their ability to do various tasks online, self-teaching with technology, and overall anxiety—and their pre-existing immersive tendencies also showed no correlation with evaluations of the controllers ($R^2 = 0.00$).

Most noteworthy were correlations between user evaluations of the controllability factor and the involvement factor, in which we found a weak correlation for all the controllers (keyboard: R^2 = 0.859, gamepad: R^2 = 0.603, Touch: R^2 = 0.811). This suggests that, the higher the user rates the controllability of a device, the better they feel they can manipulate the robot and immerse themselves on the tasks they are performing.

D. Final Interviews

The final semi-structured interviews showed that participants were generally satisfied with the controllers. Participants were asked to describe their experience with the robots in three words and came up with 39 responses. After categorizing these responses into positively and negatively valenced terms (e.g. "exciting, engaging" and "primitive, limited", respectively), we found that a majority (27 out of 39) evaluated their experience positively. Participants also ranked the controllers in relation to four categories—intuitiveness, ease of use, comfort, and confidence of use—and reported being the most satisfied with the gamepad and keyboard, and least satisfied with the touch pad (see Figure 3). 9 of the 14 participants had mentioned they played video games or had done so in the past, so the gamepad was as familiar to them as the generally ubiquitous keyboard. Users stated the touchpad was the most difficult to use, occasionally due to the responsiveness of the system and the robot's response, but more specifically the lack of tactile feedback (P02, P03, P13, P22, P29) as opposed to the immediate physicality of moving the gamepad's joystick or the button press of the keyboard.

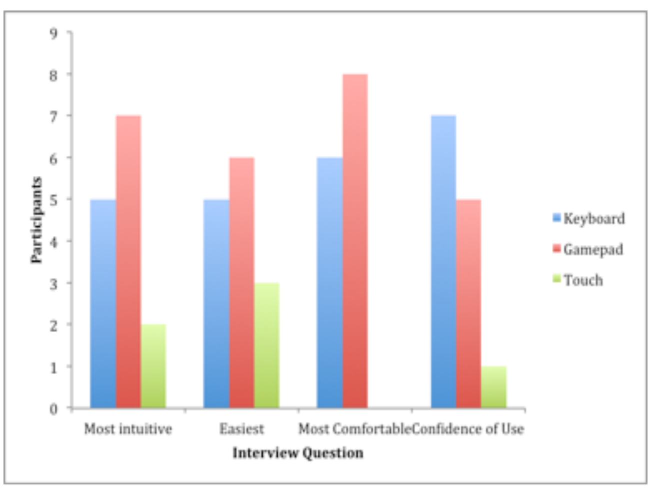

Figure 3 Participant evaluations of "Most Intuitive, Easiest, Most Comfortable, and Most Confident to Use" after operation (n=13)

When asked where they would use such a robot, users named search and rescue situations, or monitoring their homes or a loved one. Three participants mentioned the robot could be used for entertainment, while two others said that, if it included arms, tools, or other actuators, it could be used to for various household tasks.

V. Discussion

Our study suggests that a technical background allowed participants to perform better overall. Users with higher levels of anxiety regarding technology had lower performance, while younger users (undeclared majors) showed better performance. While these results suggest that it may be useful to screen out people with certain pre-existing characteristics when selecting telerobot operators, they also point to the need to generally increase the level of public education about how technology operates in order to give a broader audience the skills and confidence to operate telerobots.

While we did not see that ease of use alone (H1) impacts immersion, the user's overall evaluation of the device's control factors did have a significant effect. This included assessments such as whether the device operated the way they expected it to, ease of travel in the remote environment, and a feeling of control of remote events. We found that users who reported having confidence in their ability to control the device also felt they could immerse themselves in the tasks. In interviews, participants mentioned preferring the gamepad because of the physical sense of feedback that gave most users a sense of comfort that they were operating the device properly; however, there was no significant difference in performance times. A lack of clear results prevents us from rejecting or failing to reject H2, however the anecdotal evidence of the users confidence in the controller because of their perceptions of accurate operation does suggest further investigation is merited to explore this hypothesis.

Furthermore, the significant interaction found in the interaction of controllers and tasks suggests that particular controller designs facilitate the completion of certain tasks in a remote space. A more appropriate question may be not whether users' prior experience can inform a better controller and effect performance and immersion, but rather what is an appropriate controller designed for a specific task. Our results suggest that, to create immersive experiences for telerobot operators, designers should focus on increasing the users' feeling of control. In order for a robotic system to become an extension of the user and improve performance, it is also important to provide more haptic and visual feedback to users to reaffirm their confidence in the device and its controllability. In our study, the touchpad, though novel and possibly more intuitive than other controllers, was least preferred by users and used with the lowest accuracy, possibly due to the lack of the correct type of feedback.

In our current study, the level of similarity between the control method and the user's desired movements in the remote space seemed to have an effect on their sense of immersion and satisfaction with the controller; users reported liking to be able to swipe up or tilt the joystick forward and those actions mapping to the events correlating to the performance of the robot. In future work, we will study how additional visual and tactile feedback can be used to improve performance, user satisfaction and immersion.

We will also evaluate more atypical controllers, such as the Microsoft Kinect, which rely on embodied control by the users. We would also investigate what problem domains different controlling devices may be most applicable to. Additionally we would want to include a larger sample size to represent a more diverse population, rather than that limited to a university campus.

VI. CONCLUSIONS

From our study we concluded that users do indeed perceive certain control methods as more pleasurable and easier to use and that these positive evaluations facilitate a sense of immersion and greater accuracy (though not shorter time) in task completion. We propose that the design of controllers for use by non-experts should focus on physical feedback and confirming controllability, as well as on matching controllers to particular types of tasks to be performed.

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