Sensory Feedback and Perception in Tele-operation of Remote Robotic Systems

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Abstract

In the realm of tele-operation for remote robotic systems, this paper investigates the critical roles played by sensory feedback and perception in shaping the effectiveness and safety of control interfaces. Visual perception is heightened through the integration of high-resolution cameras and stereo vision systems, enabling operators to gain an accurate and immersive understanding of the remote environment. Concurrently, audio sensors contribute auditory feedback, fostering a more comprehensive situational awareness. The study places a particular emphasis on haptic feedback, exploring the incorporation of advanced force feedback mechanisms in control interfaces. This tactile interaction allows operators to sense and respond to the remote environment, significantly improving precision and control. However, the integration of these sensory modalities poses challenges related to latency, bandwidth, and the seamless fusion of diverse feedback sources. The paper delves into current technological advancements addressing these challenges, emphasizing the need for robust communication protocols and signal processing algorithms. By unraveling the intricate interplay between sensory feedback and tele-operation, this research aims to advance the development of user-friendly and efficient interfaces, fostering safer and more intuitive control of remote robotic systems across various domains.

I INTRODUCTION

In the ever-evolving landscape of robotics, the tele-operation of remote robotic systems stands as a transformative paradigm, enabling human operators to control machines from a distance. This shift has profound implications for various domains, from hazardous environment exploration and intervention to space missions and healthcare applications. At the core of this transformative evolution lie the intricate dynamics of sensory feedback and perception, where the fusion of advanced technologies seeks to bridge the physical gap between the operator and the remote environment. The first page of this exploration delves into the visual perception aspects of tele-operation, emphasizing the integration of high-resolution cameras and stereo vision systems. The strive for an accurate representation of the remote surroundings, complemented by the inclusion of audio sensors providing ambient sounds, shapes the foundation of operator situational awareness. As we navigate through this visual and auditory landscape, the challenges and opportunities associated with these sensory modalities will unfold, laying the groundwork for a comprehensive understanding of the technological advancements driving this field forward.

The second page delves into the realm of haptic feedback, a cornerstone in replicating the sense of touch for operators. Here, we explore the incorporation of force feedback mechanisms in

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haptic interfaces, allowing operators to feel and interact with the remote environment. The synthesis of visual, auditory, and haptic feedback becomes a focal point, promising to elevate tele-operation experiences to new heights. However, as we embark on this technological journey, we confront challenges related to latency, bandwidth, and the harmonious integration of multiple feedback sources. Unraveling these complexities not only opens avenues for innovation but also underscores the critical importance of user-centric design in shaping the future of tele-operated robotic systems. Through this exploration, we aim to chart a course toward a more immersive, responsive, and safer tele-operation landscape across diverse applications.

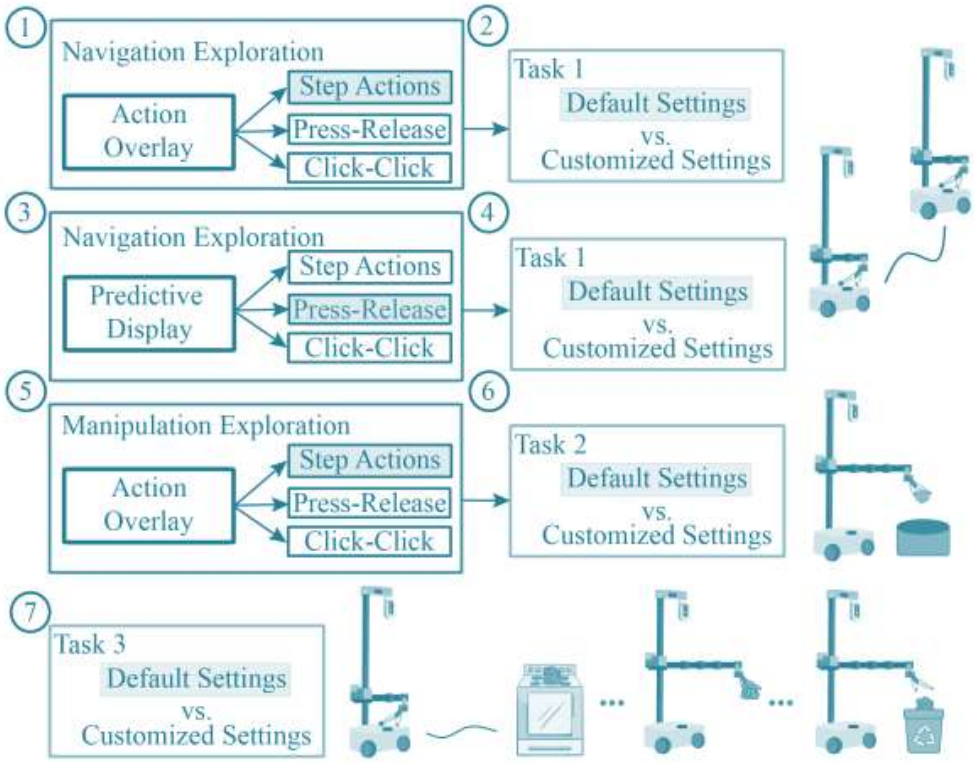

Fig. 1: An overview of the study design

II Related Work

The potential for assistive robots to help persons who have motor disabilities has been investigated in previous research [2, 3]. It has been shown that tele-operation of these robots is a plausible approach that may allow persons who have motor restrictions to independently accomplish activities of daily living (ADL) [4, 5], [6]. Tele-operation also meets the customers' demand to have control over their robots, which makes it possible for robots to be useful without the need for complete autonomy. Semi-autonomous tele-operation systems have been the subject of much research since they are designed to alleviate the strain placed on the user while yet allowing them to maintain control. The inference of user purpose during teleoperation and the provision of autonomous assistance in accordance with that intent is a large portion of this body of work [7], [8], [9], [10], [11], (12). These tele-operation interfaces, on the other hand, provide a single control configuration that may not be accessible to users with varying skills or meet the preferences of users

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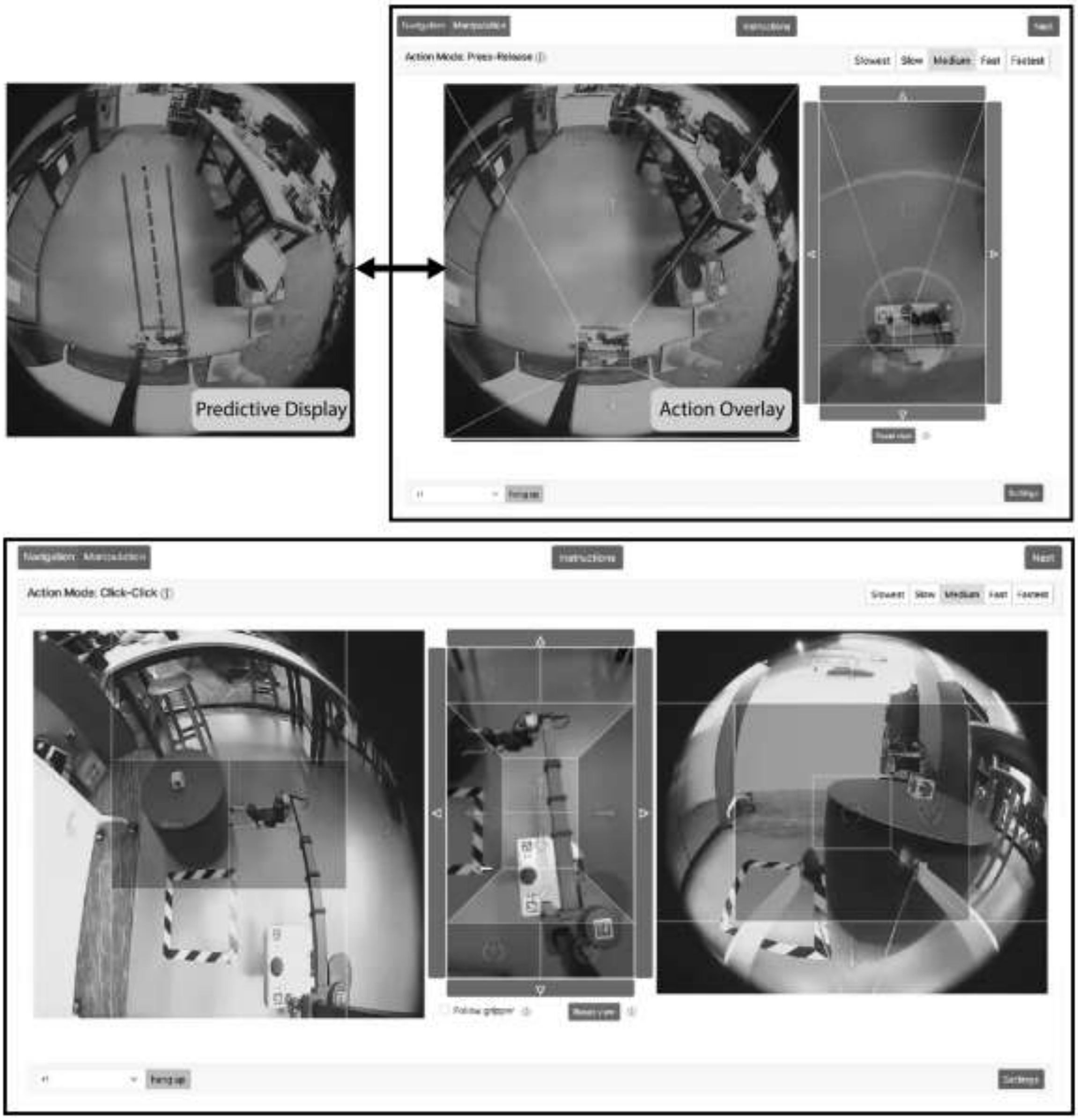
in every circumstance. Accessibility to users with unique physical abilities and compatibility with user preferences will be achieved via the customization of control interfaces. During a user research that was conducted in the past, a participant who had motor impairments explicitly underlined the necessity for adaptable interfaces that are designed to accommodate persons who have them [1]. Furthermore, previous research has shown that having the ability to personalize tele-operation interfaces has an effect on the amount of time it takes for individuals to do tasks as well as their subjective preferences [13]. GUIs have been the focus of a significant portion of the work that has been done on interface customisation [14], [15], [16]. The control interface itself has not been investigated by Jain et al. [17], but they have investigated the possibility of customizing the degree of support that the robot offers. In this work, we investigate the possibility of customizing a web interface that is based on a cursor for the purpose of having a mobile manipulator be operated remotely. For the purpose of remotely tele-operating a Stretch RE1, we expand on the work that was done by Cabrera et al. [1], who established a web interface. In order to assess subjective preferences, task performance, and success, we added extra control elements for the tele-operating Stretch that we designed.



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III ROBOT SYSTEM

The mobile manipulator known as the Stretch RE1 is what Hello Robot is working on. The telescoping arm of Stretch is coupled to a prismatic lift that expands to a height of 110 centimeters vertically and extends horizontally to a distance of 50 centimeters. A rotating joint is coupled to the gripper that has one degree of freedom on the arm. To put it another way, the movement of the differential drive base is orthogonal to the movement of the arm. Stretch also features two fixed fish-eye cameras, one of which has an overhead view of the base and arm, and the other of which has a view of the gripper. Additionally, Stretch has a Realsense camera that is coupled to a pan-tilt head. Stretch is a product that may be used in the homes of inexperienced users for an extended period of time because of its affordability, safety, and physical capabilities. ROUS1 serves as the foundation for Stretch's open-source software. Our effort concentrates on remote tele-operation of the robot using a web interface, despite the fact that it has a suite of autonomous characteristics. As shown in Figure 2, the remote tele-operation interface for Stretch has two unique modes that may be toggled by switching tabs located in the upper left corner of the interface. The controls for commanding a separate subset of the robot's actuators are available for each mode. The Manipulation mode is responsible for controlling the arm height, extension, and gripper, while the Navigation mode dictates how the movable base is situated. A fixed overhead fish-eye camera view and an overhead camera view with pan and tilt adjustments are also available in the Navigation mode. also of these camera views are fixed. Additionally, the Manipulation mode includes a fish-eye camera view from the gripper's point of view, in addition to the two camera views that are available in the Navigation mode. Every mode has its own group of control displays and action modes that are exclusive to it. 1) The Action Overlay Control Display refers to a control display that superimposes buttons on each camera view. Individual actuators on the robot are controlled by the buttons. During navigation, there are two translation actions and two rotation actions available. Two buttons are used to control each of the following degrees of freedom in the Manipulation mode: the height of the arm, the extension of the arm, the rotation of the gripper in and out, the opening and closing of the gripper, and the translation of the mobile base. This brings the total number of buttons to three.

A tooltip text that provides an explanation displays when the cursor is hovered over a button, and an icon that shows the action is superimposed on top of it. Furthermore, when the robot's arm or gripper is in contact with an item, the icon changes to red in the Manipulation mode. Additionally, a red stop sign appears over the icon when the arm and gripper have reached their respective joint limitations. A red stop sign is shown over the icon. Each of the five predetermined speeds may be selected by the operator in order to regulate the speed of the robot. During the time when the robot is carrying out the required activity, the outline of the button will become red. 2) Displaying Future Events This control display is only usable in the Navigation mode, and it superimposes a trajectory over the fixed overhead fish-eye view of the robot's base. It is shown in the control display. In terms of speed and heading over the robot, the length of the trajectory and the curvature of the trajectory both have an impact. To put it another way, the robot will travel more quickly if the trajectory is longer, and it will move more slowly if the trajectory is shorter. There is a predetermined pace at which the robot will go rearward if the operator pushes anyplace behind the base. If the user pushes on the left side of the base, the robot will rotate to the left. On the other hand, if the user taps on the right side of the base, the robot may revolve to the right. When the robot is moving, the trajectory shows a red pattern.

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IV. USER STUDY DESIGN

This research was carried out in a kitchen environment, which included a working space that was about 2.15 meters by 4 meters. To complete the objectives, you will need to drive the robot to a certain location and orientation, pick up a cube, and recycle rubbish. The tasks need a mix of viewing the surrounding environment, navigating, manipulating, and avoiding collisions. First, the user is responsible for guiding the robot from its starting point into a square that is located in front of the refrigerator. In order to face the refrigerator, they need to position the robot. Task 2 requires the user to take control of the robot and ensure that it picks up a cube off a table. To the right of the table is where you will find the robot. Task 3 requires the user to drive the robot from the refrigerator to the stove, pick up a piece of garbage that is on the stove, drive to the recycling bin, and then dump the trash in the recycling bin (Fig. 3c to complete the task). The procedure, B Participants participate in a video conference call by using Zoom, which has the capability to share their screens as necessary. Following that, they connect onto the online interface that allows them to operate the robot. Despite the fact that they were not physically present, participants were dispersed throughout the United States. The first thing that the user does is watch a video that provides an overview of how the robot and interface function. During the first stage of the research project, the user investigates the many ways in which the action overlay control display may be used in the navigation mode.

Through the use of video lessons, they learn how to operate each of the action modes. Following the completion of each film, students are given the opportunity to get familiar with the controls. After that, they do job 1 using both the default parameters and the options that they have adjusted. They are able to personalize their settings by picking the activity mode that best suits their preferences from the options menu. The initial action mode that was supplied by the interface that was built by Hello Robot is the step actions mode, which is the default option. During the subsequent stage of the research project, the user will investigate the predictive display mode that was modeled after the interface of the Beam tele-presence robot. In the same manner as in the previous phase, the user sees a video instruction that explains how to utilize each of the action modes that are shown on this control window. Following the completion of each film, students are given the opportunity to get familiar with the controls. After that, they do job 1 using both the default settings and the modifications they made. The press-release mode is considered to be the default configuration. When the Beam's interface was first introduced, this was the action mode that was available. If the user is able to successfully drive the robot to the desired location and have it face the refrigerator, then Task 1 is regarded to have been completed successfully.

V FINDINGS

Participants who did not have any motor deficits There were thirteen people from the general public who participated in our research. There were six males, six females, and one other person. Their ages ranged from 20 to 55 years old, with the mean being 26 and the standard deviation being 9. Using a Likert scale of seven points, we asked participants to assess how proficient they were with technology. In terms of ratings, the average was 5.31, while the standard deviation was 1.97. The participants were rewarded with a $50 Amazon gift card and the research lasted for a total of ninety minutes. First, we give our results, which include a summary of user preferences for establishing preferences, task performance (including success and efficiency), and then we discuss how the

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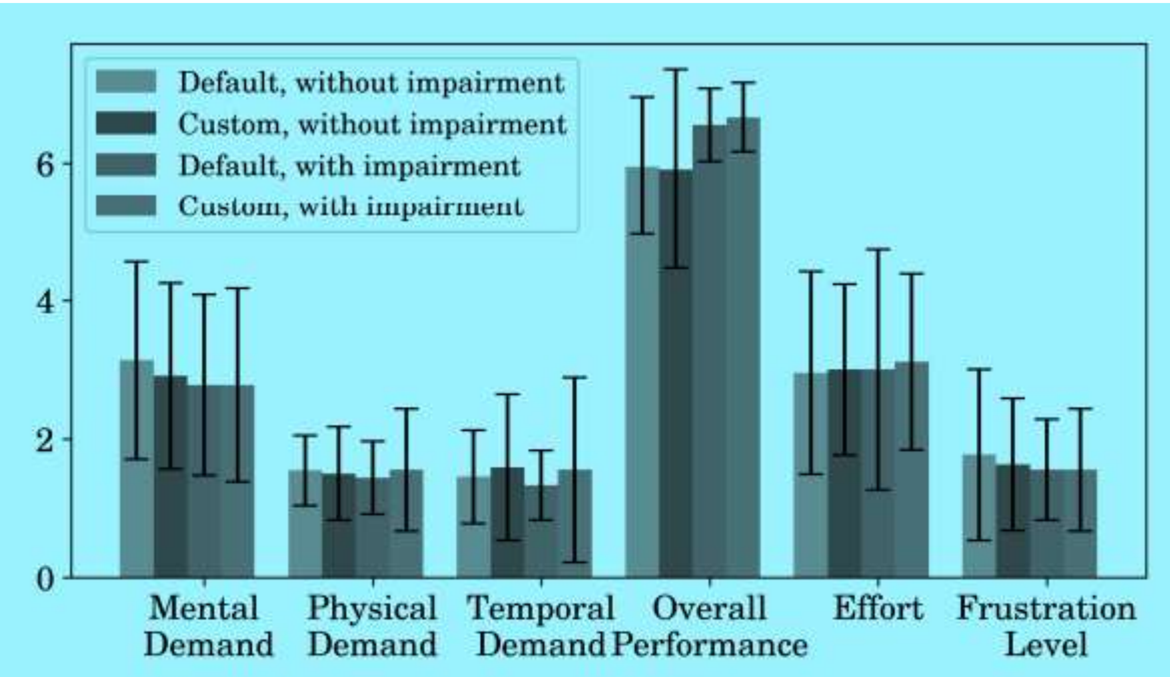
teleoperation interface is used. 1) Specifying Your Preferences: Figure 4 depicts the settings that the participants found to be most suitable for Task 3. During the navigation mode, the action overlay control display was selected by 46% of the participants, while the predictive display control display was selected by 54% of the participants. In compared to the action overlay mode, the simplicity of the predictive display was a major selling point for the participants who opted for it: "Obviously, the predictive display is very nice because it gets rid of buttons" (M, 25). Using a Likert scale of seven points, we asked participants to assess how proficient they were with technology. The vast majority of participants who selected action overlay gave themselves a worse rating (M=3.83, SD=1.86) than those who selected predictive display (M=6.57, SD=0.49).

In general, the press-release action style was favored by the majority of users in both the navigation mode and the manipulation mode: "I prefer the press-release mode more." In the [step-actions] mode, the instructions were to touch, stop, touch, and stop (M, 29). However, there is no one subset of choices that can be considered a "winner" since there is a wide range of preferences about the control display and the action mode. It should be noted that 7.69% of participants, across all of the various options, selected their personalized configuration to be identical to the default setting. 2) Successful Completion of Tasks: All of the participants were able to successfully complete Tasks 1 and 2 using both the default and customized settings. With the default settings, all of the participants were able to successfully complete Task 3, while eleven of the participants were able to successfully complete Task 3 with the modified parameters.



In general, the participants had a quicker time completing the activities when they used customized settings for navigation. However, they had a faster time completing the tasks when they performed the tasks a second time for the manipulation mode. This was true regardless of whether they used modified settings or the default settings initially. As a result of the increased number of buttons and degrees of freedom that are available to control, the manipulation mode is more challenging to operate than the navigation mode. Furthermore, the manipulation mode was deemed to be overwhelming by one of the participants, who said, "Having so many buttons

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makes me nervous." Regardless of the sequence in which the tasks were assigned for the manipulation mode, this may have resulted in a learning curve.

VI. Conclusion

The purpose of this work was to investigate the possibility of personalizing tele-operation interfaces in order to offer assistance to people who have significant motor impairments and possible caregivers. For example, if the robot were to be installed in someone's house for an extended period of time, we feel that we would observe higher advantages from personalization (e.g. [18]). Nevertheless, the results of this study demonstrate that such a robot is useful and that there are advantages to designing tele-operation interfaces that are tailored to the needs of both user groups. 1) A Preferences for the Settings: Variations in user preferences were seen in interface setups. There was not a particular configuration of the interface that was favored more strongly than any other single configuration. Users with motor impairments did not choose the step actions option because they found the repetitive clicking to be very taxing on their bodies. Some of the participants who did not have any motor impairments choose to utilize the step actions mode in the action overlay control display. This was due to their concern that they would cause harm to the robot if they used the continuous control modes initially. In addition, P1 was unable to employ the press release mode with his head array of equipment. The results of this study provide evidence that supports our hypotheses, which state that there is no one interface design that can accommodate the capabilities and preferences of all users (H1) and that there are differences in preferences between individuals who have motor impairments and those who do not have such disability (H2). 2) Task Performance: With the customized settings in the navigation mode, all users were able to complete tasks more quickly and with fewer clicks. However, when they changed to the manipulation mode for the second time, they performed better than they had in the navigation mode. This was true regardless of the interface configuration they began with. This leads one to believe that there was a learning curve, which may have been caused by the intricacy of the interface controls in the manipulation mode. Based on our findings, we feel that if consumers had been given more time to get acquainted with the manipulation mode, they would have done more effectively with the personalized settings. A further limitation was that users did not have access to a practice task that combined the navigation mode with the manipulation mode. When we attempted to perform a task utilizing both modalities, we discovered that there was a learning curve involved. Overall, the number of mistakes was very low; all of the individuals successfully performed tasks 1 and 2, and task 3 was successfully completed by all of the participants, with the exception of two who did not have any motor impairments. When users employ their personalized settings, the amount of time it takes them to complete tasks, the number of mistakes they make, and the number of clicks they make will all be reduced. This data partly confirms our hypothesis (H3).

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