Haptic Feedback Assistance in Teleoperation Driving Tasks

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***Abstract*—This proposal introduces an enhanced interaction mechanism for teleoperating a mobile robot, focusing on the concept of physical embodiment to improve telepresence. By utilizing this principle, the operator can experience both a visual and physical presence at the remote location, enabling more natural interactions and simplifying the task of controlling the robot remotely. The operator receives immersive visual feedback aligned with their head movements, via a head-mounted display, and through a haptic belt that provides spatial cues about obstacles detected by the robot's sonars. This short paper describes the development of the system designed to map these obstacles.**

***Index Terms*—teleoperation; telepresence; embodiment; immersion; haptic feedback; visual feedback; human robot interaction; task performance evaluation.**

I. Introduction

In recent years, the development of teleoperation and telepresence systems has seen significant advancements driven by improvements in haptic feedback, visual immersion, and physical embodiment. Studies have shown that integrating sensory feedback such as haptic devices and immersive visuals can significantly enhance the user's sense of presence and embodiment, making interactions more fluid and less mentally taxing. In fact, everyday products are increasingly incorporating capacitive touch displays and interfaces. These systems are cheaper to manufacture than traditional control panels equipped with discrete switches, and designers appreciate the creative freedom to develop user interfaces (UIs) in unique shapes. Plus, users miss the mechanical click or tactile sensation of a physical switch being activated. Haptic technology can address this gap by simulating the experience of pressing tactile switches. Moreover, recent work highlights that advancements in haptic feedback, such as spatially mapped signals to indicate obstacles, have helped to refine robotic teleoperation, making it more intuitive and safer for high-stakes operations like disaster recovery and healthcare [1]. The increasing integration of AI and robotics in these systems is also enhancing user cognition and control, allowing for more precise and natural task execution remotely.

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This work introduces an enhanced interaction mechanism for teleoperating a mobile robot, leveraging physical embodiment to boost telepresence. By combining immersive visual feedback with haptic feedback, such as through a belt that signals the proximity of obstacles, sensory inputs will provide the operator with a near-physical sense of presence in the remote environment. This multisensory approach helps bridge the gap between virtual and physical environments, thereby improving both teleoperation precision and user experience.

II. Related works

Analyzing requirements for a strong sense of embodiment during teleoperation is crucial for improving telepresence and achieve a natural interaction with remote mobile robots.

Telepresence and Embodiment in Robotics: The enablement of operators to experience and manipulate remote environments has seen growing support in industries ranging from healthcare to space exploration. Yet, one of the ongoing challenges in teleoperation is the disconnection between the operator's physical actions and the sensory feedback provided by the remote environment. Studies have shown that incorporating more naturalistic feedback mechanisms, such as multimodal sensory inputs (visual, auditory, and haptic), is essential for enhancing embodiment and telepresence. They emphasize the value of synchronization between operator movements and feedback from the remote environment, to achieve a *sense of ownership* and *agency* over the robotic system [2] [3]. Moreover, immersive technologies such as head-mounted displays (HMDs), further enhance the perception of remote environments and provide a sense of embodiment. Through virtual reality (VR) headsets, the operator can receive real-time visual feedback based on head orientation and/or body posture. This is central to achieving *point of view transfer*, as it allows the operator to see what the robot sees, leading to a more intuitive and immersive interaction.

Advances in Haptic Feedback: One promising approach to improving embodiment in teleoperation is through enhanced haptic feedback systems. Researchers have developed wearable devices, such as haptic belts [4] and vests [5], which provide spatial awareness of obstacles in the environment. This enables operators to better comprehend their surroundings without relying solely on visual cues. In addition, these systems enhance both the operator's control over the robot and their sense of presence in the task space by enabling a more tactile interaction, further closing the gap between real and virtual experience [6] [7].

III. System Design

Considering the significant downside of capacitive interfaces related with their lack of haptic feedback indicating that a button has been pressed, in our application we utilize vibration feedback methods that employ Eccentric Rotating Mass (ERM) vibration motors to create realistic touch sensations.

The general architecture is meant to facilitate the testing of different combinations of software modules, developed for both the robot and the control station. As different interaction strategies are to be tested and assessed, the active modules comprising the setups vary from one experiment to another. To streamline development, communication between the modules at both locations is done via wireless TCP/IP connections.

IV. System Description

A system consisting of a mobile robot and a control setup was constructed, both shown in Fig. 1. The robot platform is based on a Monarch base by IDMind, equipped with an array of 12 sonars. A Microsoft LifeCam is already mounted on top of the robot head. The robot is controlled by a module that receives commands from the HMD associated controllers. The selected HMD is Oculus Quest, with video from the robot camera being transmitted via Meta Quest Link, providing high-quality video with minimal bandwidth loss.

The configuration of the control setup varies depending on the intended experiment. This may include additional components such as other controllers, a screen monitor, RGB-D sensor or a head-mounted display with an IMU. Here, we focused on the haptic vibration belt, considering the specific requirements of our experiment.

A. *Obstacles Proximity Module*

Sonar readings are continuously sent to both the Haptic Vibration Feedback Module, which is connected to the vibration belt. Whenever an obstacle is detected within one meter of the robot, the sonar data is processed by the module, triggering the appropriate motor in the haptic belt to match the obstacle's location. As the robot gets closer to the obstacle, the frequency of the vibration increases, providing more intense feedback to the operator.

V. Preliminary Experiments

Sensor calibration was performed to assess the real metric distance of the robot to the obstacle (horizontal axis) versus the sonar readings distance to that obstacle (vertical axis). Here it could be observed that the sonars readings below 30 cm have an inconsistent non-linear behaviour. Hence, we assume that any obstacle in this area is very close to collision. The delay/frequency is calculated considering sonars readings less than one meter to obstacles. Closer the robot is to an obstacle, less delay between vibration and thus more frequent vibrations. This was tested locally, for proof of concept. Further testing of the effect over telepresence will incur a number of participants and appropriate questionnaire taking.

Fig. 1. Mobile Robot (left) and Remote Control Overview (right).

VI. Discussion and Conclusion

This work presents the development of an interaction mechanism for teleoperating a mobile robot, focusing on enhancing physical embodiment to strengthen telepresence. It details the integration of a haptic device in a control system designed to map obstacles in a remote environment. By integrating immersive visual feedback with haptic systems, such as the belt that vibrates to indicate the proximity of obstacles, sensory inputs provide the operator with a near-physical sense of presence in the remote surroundings. This multisensory approach helps bridge the gap between virtual and physical environments, ultimately enhancing teleoperation precision and improving the overall user experience.

Future work will involve testing the system during real robot teleoperation, as well as map the distance sensors to the vibrotactile actuators using machine learning techniques, to prevent desensitization of the operator's reactions.

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