Enhanced AR: Integrating Haptic Feedback from Tactile Sensors for Immersive Teleportation

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I. Introduction

In the realm of robotics, teleoperation has emerged as a critical method for enhancing human-robot interaction, enabling users to remotely control robotic systems with increased precision and awareness. This paper introduces a novel framework for teleoperating a robotic arm using the Robot Operating System (ROS) and the Quest 3 headset's augmented reality (AR) function. We incorporate haptic feedback through a sensor attached to the robotic arm, allowing users to experience tactile sensations when interacting with objects. Our methodology leverages the immersive capabilities of AR and the tactile feedback system to provide an intuitive teleoperation experience. This work highlights the integration of emerging technologies to enhance user interaction with robotic systems, offering pathways for future advancements in robotics teleoperation.

Traditional teleoperation interfaces often limit user awareness and precision, hindering the ability to perform delicate tasks. [5] The Quest 3 headset, equipped with AR functionality, alongside the implementation of haptic feedback via sensors on the robotic arm, presents an innovative solution to these challenges. This project explores the synergy between AR's visual immersion and tactile feedback's physical sensation, aiming to enhance the user's control and awareness during teleoperation tasks.

Low-Cost Teleoperation with Vision-based Tactile Sensors: Lippi et al.'s work [7] on teleoperation using vision-based tactile sensors outlines a framework that translates tactile information into haptic feedback, allowing operators to perceive the pressure exerted on grasped objects. This method aligns closely with our project, as both endeavors leverage the advancements in tactile sensor technology to improve human-robot interaction. Our work extends this concept by focusing on the integration of AR through the Quest 3 headset, enriching the user's sensory experience with spatial and visual context to the tactile feedback. The combination of tactile sensing and AR introduces a novel dimension to teleoperation, where operators not only feel but also see their actions in an augmented environment, potentially increasing precision and control in manipulating fragile objects.

Influence of Haptic Feedback on Robotic Manipulation: The integration of haptic feedback in teleoperation systems has been demonstrated to significantly impact task performance, particularly in delicate manipulations. Previous research within human-robot interaction highlights various feedback mechanisms, from vibrotactile signals to force resistance, each contributing uniquely to the user's understanding and control of the robot's actions. [1] [2] [3] [8] Our project contributes to this discourse by implementing a tactile-to-haptic (T2H) translation algorithm, which adapts the intensity of the controller's vibrations based on real-time tactile sensor data. This approach not only provides immediate feedback on the gripping force but also introduces partial autonomy to prevent object slippage. In Cao et al.'s work [4], they gave a solution for rendering haptic feedback via the controller based on visual tactile sensors.

Our project is building on top of Wozniak et al. [6] and Lippi et al. [7] project and situates itself at the intersection of tactile sensing, haptic feedback, and AR in teleoperation. By synthesizing these elements, we aim to enhance the operator's ability to perform complex manipulations, moving toward a more immersive teleoperation framework. The integration of low-cost hardware further emphasizes the accessibility and applicability of our solution, potentially broadening its adoption in diverse teleoperation scenarios.

II. Framework Design

The teleoperation framework designed for robot arm manipulation via the Quest 3 headset is an intricate system that can be divided into three main components: ROS Nodes, ROS-Unity Communication, and Oculus Quest 3 Integration with tactile sensor-based haptic feedback.

- **ROS Nodes for Robot Arm Control**:The framework's core is built on ROS (Robot Operating System), which utilizes a series of nodes to control the robotic arm. These nodes are responsible for various tasks, including motion planning, sensor data processing, and actuator control. They communicate through a publisher/subscriber model that ensures synchronized operations and real-time responsiveness. Each node is a modular unit that can be individually developed, tested, and optimized, providing a flexible and scalable solution for complex robotic operations.

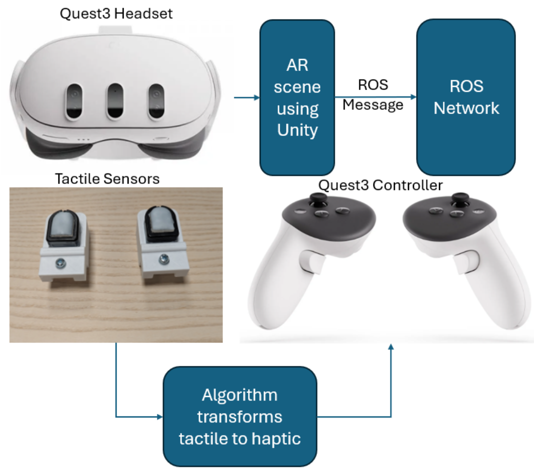

Fig. 1. Framework overview

- **ROS-Unity Communication**:The interface between the robotic control system (ROS) and the graphical simulation environment (Unity) is established via a TCP server endpoint acting as a ROS node. This communication hub is vital as it facilitates serialized message passing between Unity and ROS, maintaining the structure and type safety of the data being exchanged. Serialization and deserialization of the messages are handled by the ROS-Unity plugin, which creates C# classes from .msg files. This setup ensures that the simulation in Unity accurately reflects the real-world state of the robotic system and allows for immersive interaction through the AR interface.
- **Oculus Quest 3 AR Function in Teleoperation:**: The integration of the Oculus Quest 3 headset into the teleoperation framework brings a host of benefits, primarily due to its advanced AR functionality. The Quest 3's AR capability is pivotal in creating a more realistic operating environment for the user. It provides a clear, high-definition overlay of digital information onto the physical world, thus allowing for a seamless blend of virtual and real elements. This augmented visual feedback is essential for tasks that require high precision, as it enables operators to visualize the robot's movements and the surrounding environment with enhanced clarity and context.
  The AR parts also contributes significantly to the user-friendliness of the system. Operators can interact with the robot arm in a way that mimics real-life manipulations. The high-quality passthrough function of the Quest 3 ensures that users can see their hands and the controller within the operational context, reducing the learning curve and cognitive load compared to traditional teleoperation systems that might rely solely on abstracted controls or indirect visual feedback.
  Furthermore, the immersive nature of the Quest 3's AR experience deepens the user's sense of presence within the teleoperated environment, fostering a connection between the operator and the robotic system. This immersive interaction is not only critical for task performance but also has the potential to make teleoperated sessions more intuitive and responsive to the operator's intentions.
- **Tactile sensor-based haptic feedback**: The haptic feedback system is an integral component of the teleoperation framework, designed to provide users with tactile sensations that replicate the experience of direct interaction.With using the component's from Lippi et al.'s [7] work, two vision-based tactile sensors are employed. The system captures detailed information about the contact forces between the robotic gripper and the objects it manipulates. This data is then processed to create a real-time haptic response, delivered through the controller to the user.
- **Haptic Feedback Integration:** The feedback mechanism operates by comparing a pre-recorded background image from the tactile sensor with real-time images when the sensor is triggered. The differences are computed into a mask image, which is transformed into a corresponding vibrational amplitude. This amplitude modulation reflects the intensity of contact and conveys critical information about the interaction, such as the firmness of grip or the texture of the object's surface.
  By integrating this advanced haptic feedback into the teleoperation framework, the system not only augments the visual and spatial information provided by the AR interface but also enriches the user's sensory experience, thereby enhancing the overall precision and control of robotic manipulations. The clear and responsive feedback is crucial for operations that require delicate touch, providing an essential layer of interaction that closely mimics the nuances of natural human tactile perception.

III. Future work

The current iteration of the teleoperation framework sets the stage for extensive user studies aimed at quantitatively and qualitatively evaluating the impact of AR control and haptic feedback on task performance. Future research will concentrate on user-centric metrics to assess the efficacy of the augmented reality interface provided by Oculus Quest, with particular attention to the enhancement of spatial awareness and manipulation precision. Similarly, we intend to investigate the subjective and objective benefits conferred by our vision-based tactile sensor system through comprehensive haptic feedback testing. Different haptic rendering model may be used to enhance the interface. The goal is to refine the haptic feedback parameters and AR visualization techniques to align with user preferences and performance metrics. Ultimately, this future work aims to evolve the framework into a more intuitive and effective tool for complex teleoperation scenarios, potentially extending its application to fields that demand high fidelity and nuanced interaction, such as telemedicine and precision engineering.

REFERENCES

[1] C. E., Stepp, B. T., Dellon and Y. Matsuoka, ”Contextual effects on robotic experiments of sensory feedback for object manipulation,” in *2010 3rd IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics* pp. 58-63.

[2] D., Sieber, S., Musić and S., Hirche,(2015, September). ”Multi-robot manipulation controlled by a human with haptic feedback,” in *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 2440-2446. *IEEE trans. visualization and computer graphics*, vol. 23, no.11, pp. 2372-2377.

[3] F., Danion, J. S., Diamond and J. R., Flanagan, ”The role of haptic feedback when manipulating nonrigid objects,” *Journal of neurophysiology*, vol. 107, no.1, pp. 433-441, 2012

[4] G.,Cao, J., Jiang, N., Mao, D., Bollegala, M., Li, and S. Luo, ”Vis2hap: Vision-based haptic rendering by cross-modal generation,” in *2023 May IEEE International Conf. on Robotics and Automation (ICRA)*, pp. 12443-12449.

[5] M. D., Moniruzzaman, A., Rassau, D., Chai and S. M. S. Islam,(2022). ”Teleoperation methods and enhancement techniques for mobile robots: A comprehensive survey,” *Robotics and Autonomous Systems*, vol. 150, pp. 103973, 2022.

[6] M. K.,Wozniak, R.,Stower, P.,Jensfelt and A., Pereira, ”Happily error after: Framework development and user study for correcting robot perception errors in virtual reality,” in *2023 Aug. 32nd IEEE International Conf. on Robot and Human Interactive Communication (RO-MAN)*,Busan, Korea, pp. 1573-1580.

[7] M., Lippi, M. C., Welle, M. K., Wozniak, A., Gasparri and D., Kragic, ”Low-Cost Teleoperation with Haptic Feedback through Vision-based Tactile Sensors for Rigid and Soft Object Manipulation,” 2024, *arXiv:2403.16764.*

[8] Y., Gaffary, B., Le Gouis, M., Marchal, F., Argelaguet, B., Arnaldi and A., Lécuyer, ”AR feels “softer” than VR: Haptic perception of stiffness in augmented versus virtual reality,”