Bilateral Tactile-Based Telerobotics Interface for Blind Objects Reconstruction

Gabriele Giudici[1], Bukeikhan Omarali[1], Augusto Bonzini[1], Kaspar Althoefer[1], Ildar Farkhatdinov[1,2], Lorenzo Jamone [1]

***Abstract*—In this pilot work, we present a leader-follower paradigm-based haptic robotic system. This system is designed by combining two leader devices, which enables the human operator to directly impact the control variables used to simultaneously operate a robotic arm and hand on the follower side. Tactile sensors are mounted on the four fingers of the robotic hand to gather information on the forces exerted during experiments involving the manipulation of objects or surfaces. The measured force information is then rendered to the user in the form of haptic feedback, which improves the performance of the human operator by increasing transparency and decreasing physical and mental fatigue during experiments. The goal of using this robotic system is to demonstrate the ability to examine and recreate real-time scenes by identifying surfaces and objects during blind teleoperation experiments, i.e., without any visual feedback on the workspace. Along with contributing to blind teleoperation studies we also aim to learn further about how individuals manoeuvre hidden spaces and recognise items in order to complete challenging tasks.**

***Index Terms*—Teleoperation, Robotics, Tactile Sensing, Haptic Feedback, Robotics Manipulation**

I. INTRODUCTION

Although the interest and effectiveness of robot teleoperation have been widely acknowledged [1], various technological and cost barriers have hindered research in this field, leaving many aspects unexplored. The vast bulk of research on the topic has focused on the use of artificial or human visual feedback, which has led to advancements in transparency (i.e.the ease with which one can cognitively accept a robotic arm as an extension of their own body) and dexterity in completing increasingly challenging tasks [2]. Additionally, significant progress has been made in the development of tactile sensors capable to gather reliable information while manipulating or exploring objects [3]. As a result, it is no longer rare to find tactile sensors used as the end effector tips of robotic arms, particularly during remote teleoperation experiences [1], [4]. The prospect of combining these two technological systems is driving the development and integration of devices that provide, during teleoperation, the human operator with a sense of physical contact with remotely controlled items through haptic feedback.

Our work introduces a robotic interface that enables a fluent and immersive teleoperation experience utilizing advanced robotic systems capable of replicating a realistic haptic experience. Through this setup, we are able to gather valuable information about the manipulation strategies of the human operator and the corresponding action replicated by the robotic follower. Additionally, information on the manipulated objects can be gathered, to facilitate further studies such as digital reproduction or classification of items, learning from human demonstration protocols for dexterity, and assessing the behaviour of the human operator in performing complex activities in cooperation with a robot.

II. ROBOTIC INTERFACE

The robotic setup depicted in Figure 1 has been meticulously designed to offer a configuration that is as human-centric and realistic as possible for everyday handling scenarios. The leader side of the robotic setup does not necessitate any special arrangements and has been positioned to have an operating height that is consistent with the average human arm posture. The expansive range of motion offered by the Virtuose 6D [5] allows for effective manipulation in this position, regardless of the height of the user. In contrast, the standard configuration of the UR5, when positioned on a table, lacks the desired realism. To mitigate this, the robotic arm has been mounted on a custom-made vertical stand, known as MARIA configuration. Although this has yet to be demonstrated, it is anticipated to result in a more human-like appearance during teleoperation, thereby reducing cognitive load and mitigating errors caused by kinematic configurations extremely dissimilar to the human anatomy.

The following subsections provide a detailed explanation of the devices and control strategies employed. The Robot Operating System (ROS) is utilized as the middle-ware interface for communication and control.

A. Leader Side

On the leader side, a combination of Virtuose 6D and HGlove [6] is used to track the position of the hand of the operator in Cartesian space and the bending of each of the fingers. In particular, Virtuose 6D is able to provide the pose of the wrist and relying on an impedance controller it is possible to generate haptic feedback on the arm of the operator. This can be used to mimic the force sensed on the follower side including the weight of the grasped object,

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[1] ARQ (Advanced Robotics at Queen Mary) Queen Mary University of London

[2] Department of Bioengineering, Imperial College of Science, Technology and Medicine, London, UK.

{g.giudici, b.omarali, a.bonzini}@qmul.ac.uk

{k.althoefer, i.farkhatdinov, l.jamone}@qmul.ac.uk

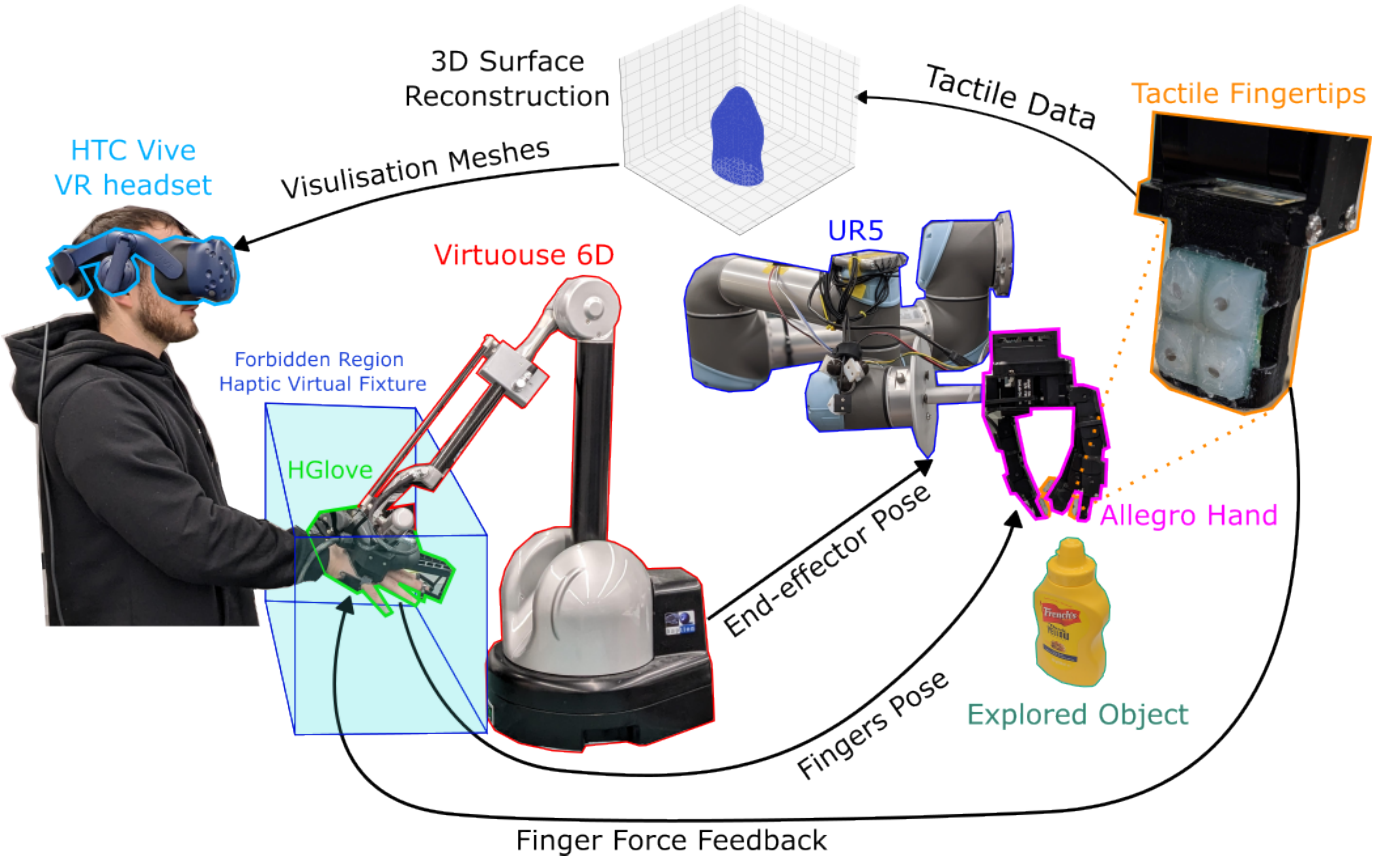

Fig. 1. **C**ontrol Scheme for Bilateral Teleoperation: the end effector pose of the UR5 is controlled by the operator using Virtuose 6D while the finger movement of the Allegro Hand is controlled using HGlove. Beyond the blue box, a forbidden movement region is enforced using a haptic virtual fixture that prevents the operator from teleoperating the robot past it. Information regarding contact forces is gathered from the custom tactile sensors mounted on the fingertips of the robotic hand and used to create haptic feedback using Hglove as well as to digitally reconstruct the shape of the explored object in real-time. Finally, visualization meshes can be streamed to the operator through a display apparatus to improve the transparency of teleoperation.

or simply to compensate for the weight of the exoskeleton. This latter feature is crucial in reducing the muscular effort of the user during prolonged teleoperation. Additionally, it is possible to create a software-implemented constraint known as a forbidden region haptic virtual feature [7] that prevents the operator from teleoperating the follower robot in that area. Figure 1 exhibits a light blue box encompassing the non-forbidden region.

Furthermore, the movement of the fingers of the operator in the joint space can be tracked using HGlove, an exoskeleton glove. It provides a measure of the distal, proximal, and lateral movements of each of the three fingers, namely the thumb, index, and middle. Additionally, HGlove has actuators which produce kinesthetic feedback for each finger on the distal and proximal joints.

B. Follower Side

For the follower side, a combination of UR5, Allegro Hand, consisting of four fingers, and customised tactile sensors [8] is proposed. To match the information received from Virtuose 6D, we found it convenient to proceed to work in Cartesian space. For this reason, we used RelaxedIK [9] as an optimiser to compute the inverse kinematics of UR5. On the other hand, for finger control, we identified a reasonable empirical mapping to transfer information from the finger joint space of the HGlove to the finger joint space of the Allegro Hand. To ensure that this mapping remains consistent, HGlove is software-calibrated for each use to align each user's open/closed hand with the corresponding Allegro Hand configuration. Furthermore, since the number of Allegro Hand fingers is higher than the number of HGlove fingers, two main approaches can be used: the first is to control only three fingers of the Allegro Hand, the second is to couple the control of two fingers, such as the middle finger with the ring finger. However, we believe that this, or other solutions, depend mostly on the task requirements.

In the design of the Allegro Hand fingertips, we made the decision to customize our sensors to provide more flexibility in terms of the forces sensed as well as the shape that would be most convenient for manipulation experiments. We based our model on previous work, specifically the uSkin model [3], while also reducing the number of sensors on each fingertip. In fact, we firmly believe that having four hall magnetic sensors that can measure 3D forces in four contact points during manipulation is sufficient for obtaining enough information for both object classification and 3D virtual object representation, as demonstrated by the research of Bonzini [8], [10]. Using these tactile sensors, it is possible to estimate an averaged normal force on the four contact points from each fingertip, which can be used as force feedback to generate kinesthetic feedback on the hand. While with the shear forces information, it is possible to detect slips and estimate the inertial properties of the grasped object.

III. FUTURE EXPERIMENTS

In this section, we illustrate what the next goals of our research are.

First of all, we want to demonstrate how it is possible, with our robotic setup, to explore and characterise a hidden and unknown environment through the remote control of a robot. After identifying the presence of objects and surfaces in the scene and describing their position, we aim to recreate a real-time 3D representation of the objects on an external monitor (or later integrate a virtual reality viewer). The aim of this feature is to facilitate the cognitive process during teleoperation-oriented manipulation in unknown spaces. Consequently, we want to perform increasingly complex manipulation experiments, for example, pick-and-place, dexterous hand manipulation activities or more complex tasks such as unscrewing and removing a lid or shuffling a card deck etc. Other properties, such as hidden shapes and object weights, can be evaluated during this phase.

Finally, a further objective of the experiments is to collect informative data on the intrinsic ability and strategies of the human operator to perform blind exploration and manipulation, as well as information on the contact force exerted during manipulation. The aim is to generalise a control policy that makes the robot autonomous and able to explore hidden environments in order to identify objects within it and, if required, be able to disassemble and manipulate objects while a graphic representation is rendered to an external observer.

IV. DISCUSSION

This robotic interface makes it possible for non-experienced personnel, after a short training session, to teleoperate a robot in real-time with a highly transparent experience.

Tasks such as pick-and-place activities, dexterous manipulation, and even more complex tasks like unscrewing a lid or selecting a card from a deck can all be performed with minimal customization. Additionally, customizable haptic sensors and feedback systems enable space exploration tasks to be performed without the need for a vision system. The challenge of limited camera installation options or low data transmission capacities is a significant obstacle to the optimal performance and consistency of teleoperation systems. Moreover, cameras are often unable to capture images effectively under varying lighting conditions, which underscores the importance of developing effective solutions to overcome these challenges and enhance the reliability and effectiveness of teleoperation systems.

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