Robot Controlling Robots - A New Perspective to Bilateral Teleoperation in Mobile Robots

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***Abstract*—Adaptation to increasing levels of autonomy - from manual teleoperation to complete automation is of particular interest to Field Robotics and Human-Robot Interaction community. Towards that line of research, we introduce and investigate a novel bilaterally teleoperation control strategy for a robot to the robot system. A bilateral teleoperation scheme is typically applied to human control of robots. In this abstract, we look at a different perspective of using a bilateral teleoperation system between robots, where one robot (slave) is teleoperated by an autonomous robot (Master). To realize such a strategy, our proposed robot-system is divided into a master-slave networked scheme where the master robot is located at a remote site operable by a human user or an autonomous agent and a slave robot; the follower robot is located on operation site. The slave-robot is capable of reflecting the odometry commands of the master robot meanwhile also navigating its environment by obstacle detection and avoidance mechanism. An autonomous algorithm such as a typical SLAM-based path planner is controlling the master robot, which is provided with a suitable force feedback informative of the slave response by its interaction with the environment. We perform preliminary experiments to verify the system feasibility and analyze the motion scaling and reflectively in different scenarios. The results show promise to investigate this research further and develop this work towards human multi-robot teleoperation.**

***Index Terms*—Bilateral control, teleoperation, mobile robots, networked robots, adaptive autonomy.**

I. Introduction

The field of Robotics has a long history with key role played by bilateral teleoperation of manipulators in the early 1950s. The research in bilateral control has progressed ever since, along with significant developments in industrial robots and recently in space and surgical applications [1], [2]. Teleoperation allows human control of a robot system remotely in a safe way avoiding challenging or harmful environments that could be far away or out-of-reach for humans [3]. Specifically, we consider the teleoperation of mobile robots, which can be useful in various applications such as exploration of underwater, underground, space or radioactive sites, urban search, and rescue mission, and cooperative transportation [4]–[6].

The complete autonomy of robots is still far from being realized due to which remote teleoperation of the robots can be applied interchangeably with the autonomous capabilities of mobile robots to completely navigate a sophisticated environment. Typical teleoperation requires a human-machine interface using which a human can apply his/her cognitive and intellectual skills to perform a remote robot task [7], [8]. However, we provide a different perspective, where we argue that the teleoperator can as well be another robot with autonomous/AI capabilities.

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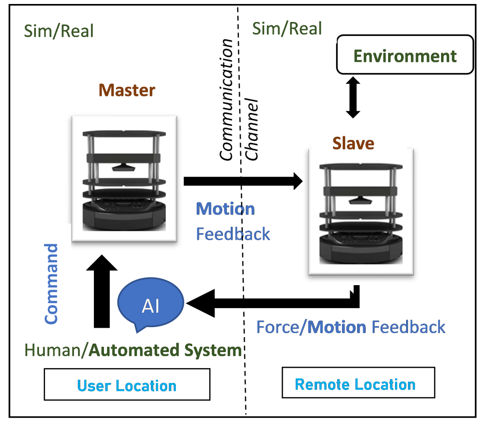

Fig. 1. An overview of the robot-robot bilateral teleoperation system.

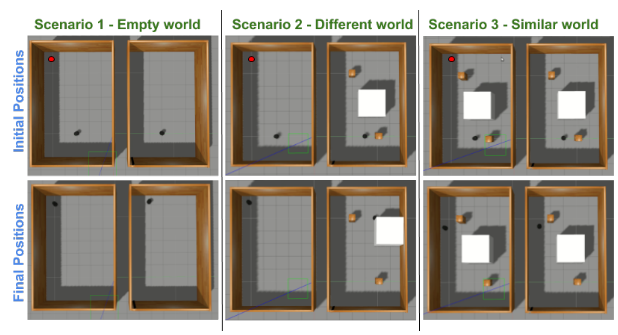

Fig. 2. Experiment setup of various scenarios simulated in ROS Gazebo. The red dot indicates the goal location set in the master side, which is running AMCL and a typical path planner. The slave reacts to the master's motion.

Here, we envision a bilateral robot-robot teleoperation system presented in Fig. 1, where the *Master* robot is an autonomous system that sends task commands over to the *Slave* robot through the wireless communication channel. The task command is carried out by the slave, which is also expected to navigate and perceive the environment through its sensors. Bilateral teleoperation usually involves tight coupling between the Master and the slave using force feedback, which continuously provides a bidirectional flow of information regarding the environment traversed by the robot in either station.

In this paper, we investigate force feedback teleoperation between two robots, one with advanced computation skills at the *Master* side and another with basic navigation skills at the *Slave* side. Through this study, we aim to contribute to reacting to the contacts with the remote environment through intelligent control. The reactions of one robot are sent to the other robot through the bilateral force feedback loop to get corrective actions and supportive navigation commands.

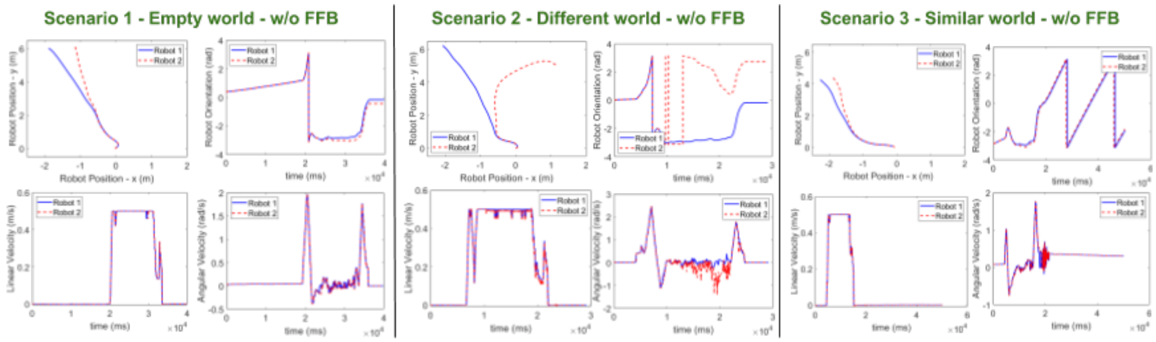

Fig. 3. Trajectories and velocity tracking of the bilateral teleoperation system without force feedback.

II. Proposed Robot-Robot Teleoperation

In our system, the *Master* robot and *Slave* robots are coupled through four control bilateral teleoperation architecture [9], which provides both force and velocities between both the sides. This architecture is well known to provide transparency and stability with manageable time delays. Arguably, the communication channel plays an important role, which needs to provide fast round trip data. However, there are several recent works that address this challenge - both from a networking perspective [10], [11] and from the control architecture perspective [12], [13] to manage the time delays in the feedback loop caused by the communication channel. There can be several situations where our system is applicable.

- Cloud Robotics [14] - The *Master* robot here is a simulated robot in the cloud server, which can be used to offload most of the computation abilities such as high dimensional mapping and path planning. In contrast, the *Slave* robot could only react to the contacts (or close proximity for safety issues) to the environment.
- Human-Robot Interaction - The *Master* robot could be controlled by human to either to ultimately operate the remote task at the *Slave* side or to test the performance of new navigation strategies or algorithms acting at the *Slave* robot. Both sides could have a simulated or a real robot depending on the nature of the interaction.
- Autonomy Algorithms - The proposed system can be used to verify and validate supervised teleoperation or completely autonomous algorithms by testing them in different scenarios and observing dynamic changes or adaptability to the control modes.

III. Preliminary Experiments and Discussion

We consider a scenario where bilateral teleoperation is applied at a remote robot to ensure position tracking of the end-effector while carrying out sub-task control such as obstacle avoidance [15]. We implement this in ROS Gazebo, where we simulate two Turlebot 2e robots in two identically similar experiment rooms of size 5m x 5m. The robots are simulated in two machines connected through a Wi-Fi network with an average of 8ms delay. We achieve overriding of velocity commands through a cmd_vel_mux multiplexer. The master robot can run advanced navigation planner, while the salve can only detect nearby obstacles within 0.5m to 1m range and reacts to it by stopping and making a turn. This reaction force is fed back to the Master.

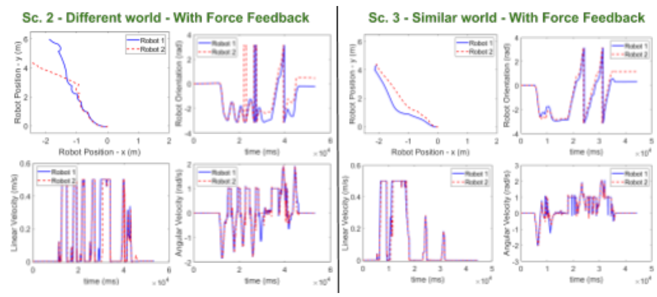

Fig. 4. Trajectories and velocity tracking with force feedback.

Fig. 2 provides an overview of different scenarios (with or without obstacles in the environment) experimented in our initial study. We are interested in how well the slave robot reacts to changes in the Master and how well the force feedback from the slave root been utilized by the master robot. We first test the system without force feedback, meaning that the slave reacts to master, but the Master does not react to the slave. In the second test, we activate the force feedback and observe the tracking performance at the slave and reactivity at the Master. The results of this test are reported in Fig. 3, and the results of the second test is presented in Fig. 4.

From the graphs, we can see that without force feedback, the system was able to track only the linear velocities, but any error in the angular velocities (hence the orientation) is accumulated, and therefore, the system diverged from achieving same trajectory outcomes or tracking performance. However, when the force feedback was activated, the system was able to make better tracking performance at the slave.

We believe the outcome of this approach will help design a control interface for mobile robots such that they can adapt between different control modes from manual teleoperation to full autonomy at the slave side, depending on the performance and computational limitations. This is ongoing research, and we plan to further experiment with variations in network delay, changes to the bilateral architecture, etc.

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