Demo: Untethered Haptic Teleoperation for Nuclear Decommissioning using a Low-Power Wireless Control Technology

Joseph Bolarinwa*, Alex Smith*, Adnan Aijaz†, Aleksandar Stanoev†, Manuel Giuliani*
*Bristol Robotics Laboratory, University of the West of England, Bristol, United Kingdom
†Bristol Research and Innovation Laboratory, Toshiba Europe Ltd., Bristol, United Kingdom
firstname.lastname@brl.ac.uk; firstname.lastname@toshiba-bril.com

***Abstract*—Haptic teleoperation is typically realized through wired networking technologies (e.g., Ethernet) which guarantee performance of control loops closed over the communication medium, particularly in terms of latency, jitter, and reliability. This demonstration shows the capability of conducting haptic teleoperation over a novel low-power wireless control technology, called GALLOP, in a nuclear decommissioning use-case. It shows the viability of GALLOP for meeting latency, timeliness, and safety requirements of haptic teleoperation. Evaluation conducted as part of the demonstration reveals that GALLOP, which has been implemented over an off-the-shelf Bluetooth 5.0 chipset, can be a replacement for conventional wired TCP/IP connection, and outperforms WiFi-based wireless solution in same use-case.**

***Index Terms*—Bluetooth, haptic, control, low-power, nuclear decommissioning, tactile, teleoperation, wireless.**

I. Introduction

Nuclear decommissioning is a prominent application of haptic teleoperation where robotic platforms are used due to the risk of harmful radiation exposure. Teleoperation systems employed for handling nuclear waste are typically tethered, i.e., based on a wired connection. However, the complexity of nuclear facilities, the risk of cable disconnection due to wear and tear, and the emerging requirement of using mobile robotic platforms necessitates exploration of wireless technologies for haptic teleoperation.

GALLOP [1].

II. Demonstration Overview

We examined key differences in performance (measured in terms of position and velocity errors, as well as responsiveness scores from Heuristic testing) between selected wired and wireless communication protocols. TCP/IP communication protocol was implemented for wired and wireless robot teleoperation for performance comparisons with wireless robot teleoperation using the GALLOP low-power wireless technology. Our setup and implementation demonstrates that low-power wireless control technology can be used to implement real-time haptic tele-operation.

III. Design and Implementation

A. Teleoperation Setup

Fig. 1 shows the different setups employed in our demonstration. Franka Emika robot arms [2] were used at the leader and follower ends of the setup. Computations and communication between the leader and follower robots were carried using Nvidia Jetson Xavier boards [3] connected to the controllers of the leader and follower robots. Ubuntu operating system was installed on the boards with real-time kernel to meet the 1KHz frequency control loop requirement of the robots.

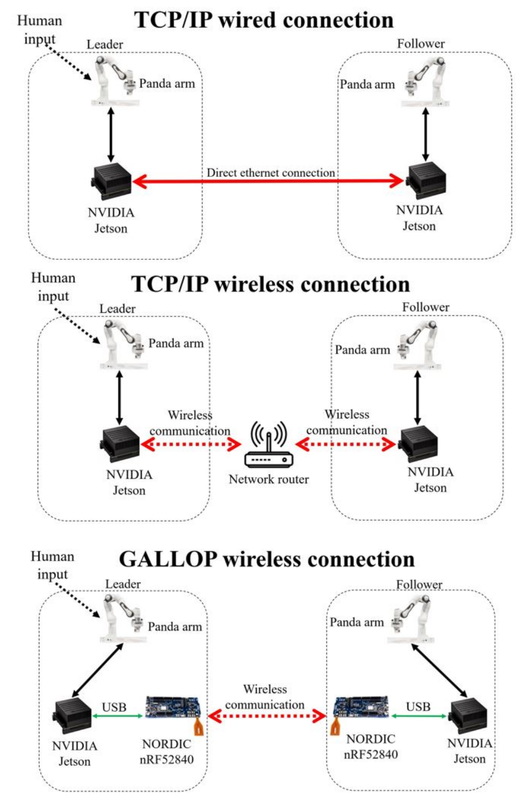

Fig. 1. "Teleoperation setups for wired and wireless robot teleoperation implementation.

The task for the experiment consisted of using the teleoperation system to sort a random pile of six objects into three categorised boxes, with an obstacle placed between the pile and the boxes. Three expert participants - familiar with the system - ran each condition (wired, wireless (Wi-Fi), GALLOP communication) three times in a randomised order.

After each experimental run they were asked to feedback on three heuristics (responsiveness, smoothness and perceived safety) based on a 5-point Likert scale.

B. *Wireless Control Technology*

Toshiba

C. *Performance Aspects*

Position and velocity errors were calculated as the difference between leader and follower arm feedback at every time step, i.e. $e(t) = q_l(t) - q_f(t)$ and $\dot{e}(t) = \dot{q}_l(t) - \dot{q}_f(t)$ where e and $\dot{e}$ are joint position and velocity errors respectively, and the subscripts $\cdot_l$ and $\cdot_f$ denote feedback from the leader and follower manipulators respectively. The RMS for each joint is calculated and then summed together to get the metric ϵ for position error and $\dot{\epsilon}$ for velocity. $N = 13$.

TABLE I
SUMMARY OF RESULTS FOR POSITION ERROR ϵ

	Wireless (Wi-Fi)	Wired	GALLOP
Mean	3.00	3.15	**2.38**
σ	0.390	0.585	0.393
Range	1.12	2.18	1.34
IQR	0.614	0.423	0.628

TABLE II
SUMMARY OF RESULTS FOR VELOCITY ERROR $\dot{\epsilon}$

	Wireless (Wi-Fi)	Wired	GALLOP
Mean	**1.60**	1.76	1.70
σ	0.363	0.411	0.403
Range	1.34	1.39	1.32
IQR	0.363	0.496	0.541

To determine if statistically significant differences appear between wireless (Wi-Fi), wired and GALLOP conditions, the Wilcoxon Sign-Rank Tests with a Bonferroni correction was used.

For position errors ϵ analysis shows no significant difference between the wired and wireless (Wi-Fi) conditions ($Z = -0.454$, $p = 0.65$), however there was a statistically significant reduction in ϵ between GALLOP and wired ($Z = -3.18$, $p = 0.001$) and GALLOP and wireless (Wi-Fi) ($Z = -2.76$, $p = 0.006$). Examining the velocity errors $\dot{\epsilon}$ shown in Table II no significant difference was found.

Examining Examining the results of the heuristics, for all criteria (safety, smoothness and responsiveness) there was no significant result between wired and GALLOP connections, but significance was found between wired/Wireless (Wi-Fi) and GALLOP/wireless (Wi-Fi) connections. This can be seen reflected in Fig. 2 results for responsiveness.

IV. REMARKS

This demonstration ... A video is available here...

TABLE III
SUMMARY OF RESULTS FOR HEURISTIC QUESTIONNAIRES

	Safety		
	Wireless (Wi-Fi)	Wired	GALLOP
Mean	3.53	**4.93**	4.67
σ	0.834	0.258	0.617
Range	2	1	2
IQR	1	0	0.750
	Smoothness		
	Wireless (Wi-Fi)	Wired	GALLOP
Mean	3.33	**4.53**	4.33
σ	0.817	0.743	0.617
Range	3	2	2
IQR	0.75	1	1
	Responsiveness		
	Wireless (Wi-Fi)	Wired	GALLOP
Mean	3.53	4.73	**4.87**
σ	0.990	0.458	0.352
Range	3	1	1
IQR	1	0.750	0

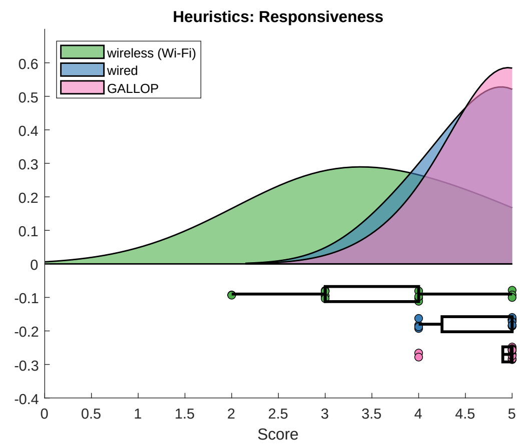

Fig. 2. "Responsiveness" scores from Heuristic testing.

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