Demo: A Hands-on Teleoperated Driving over 5G

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***Abstract*—Teleoperated driving plays a major role in bridging the gaps of autonomous vehicle in complex scenarios by enabling a human intervention without a safety driver. However, it is highly reliant on network performance and requires ultra-low latency and high-reliability communication. This demonstration presents a 5G-enabled teleoperated driving of an actual remote vehicle, showcasing the potential and current shortcomings of 5G in this context.**

***Index Terms*—5G, Teleoperated Driving, Demonstration**

I. Introduction

Recent developments in autonomous vehicles have revolutionized transportation, promising safer, more efficient, and more accessible mobility solutions. However, fully autonomous vehicles remain limited in complex and unpredictable scenarios, such as construction zones or adverse weather conditions [1]. Teleoperated driving alleviates these limitations by allowing remote human intervention in these challenging scenarios [2] while maintaining the system otherwise fully autonomous. Teleoperated driving is heavily reliant on network performance and requires ultra-low latency and high-reliability communication with sufficient bandwidth. Low glass-to-glass (G2G) latency [3], in particular, is crucial to maintain accurate control and situational awareness at traffic speeds. Wide accessibility to 5G is promising for enhancing teleoperated driving by reducing latency and improving reliability over conventional 4G/LTE networks, however, real-world evaluations are limited and key challenges remain before large-scale deployment [4] [5].

This demonstration offers the possibility of trying a 5G-enabled teleoperation of an actual remote vehicle sitting on our premises in Luxembourg. The ergonomics, perceived latency, and overall feasibility of our system will be assessed.

II. System Description and Specifications

A. Remote Vehicle

The remote test vehicle is a modified KIA Soul EV equipped for autonomous and teleoperated driving [6]. It features a built-in drive-by-wire system for brake, acceleration, and steering connected to a Polysync DriveKit based on the Open Source Car Control (OSCC) project[1]. The DriveKit provides a custom CAN interface for vehicle control while ensuring a reliable takeover mechanism for the safety driver in emergencies. An onboard Sintrones ABOX-5200G4 computer, featuring an Intel Core i7-8700T CPU, an NVIDIA GTX 1060 GPU, and 32GB RAM, hosts the autonomous and teleoperation functions. Localization relies on a Trimble BX992 GNSS-INS, delivering centimeter-level positioning and accurate heading at 20Hz. Teleoperation utilizes an Insta360 X3 camera with a 170-degree field of view in single-lens mode. The test vehicle equipment are shown on Fig. 1. The vehicle runs RoboCar as its Autonomous Driving System (ADS) software, a modular ROS2-based platform for autonomous driving research [6]. A dedicated teleoperation component, operating at 100Hz, uses two ZeroMQ TCP sockets for commands and telemetry transmission with messages serialized in JSON. Video feedback is captured, preprocessed, and streamed in real-time at 30 FPS using H.264 compression via FFmpeg to a local RTSP server [7]. The remote vehicle is connected to a VPN through a 5G cellular network provided by a 5G-enabled smartphone using USB tethering.

B. Teleoperation Interface

The teleoperated driving interface provides an immersive and realistic experience, centered around a 49-inch ultra-wide curved monitor with a 5120×1440 dual QHD resolution for a panoramic field of view. It features a Next Level Racing GT Track Simulator Cockpit equipped with a Thrustmaster direct-drive force feedback racing wheel and a three-pedal set with a load cell brake and adjustable resistance. A Next Level Racing Motion Platform V3 enhances realism by simulating acceleration, braking, and cornering forces, making the setup suitable for professional training and high-fidelity teleoperation. Fig. 1 illustrates the complete cockpit configuration. This hardware platform is coupled with a Python interface that includes a compact dashboard displaying real-time information, such as vehicle speed and steering position, received via JSON-formatted telemetry messages. Steering and pedal inputs are continuously read, normalized, and transmitted as control commands to the remote vehicle. Input calibration ensures responsiveness and ergonomics. Additionally, an FFmpeg RTSP client receives and displays the vehicle camera feed in real-time. The teleoperation interface uses Ethernet and is connected to the remote vehicle using a VPN.

C. System Evaluation

An initial evaluation covering G2G latency, round-trip time (RTT) and steering delay was conducted in Kirchberg, Luxembourg, to assess the capabilities and characteristics of our teleoperated driving system using a commercial 5G network (3.6 GHz band). RTT determines the responsiveness of teleoperation commands. Measured over 1000 samples, the mean RTT was 46.63ms (standard deviation of 10.05ms), with occasional peaks at 120ms and lows near 30ms. The system operates at 100Hz, contributing up to 10ms of delay. Assuming a mean latency of half the RTT, a vehicle at 30km/h covers around 0.2m per 23ms, indicating that teleoperation remains

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[1]https://github.com/PolySync/OSCC/wiki

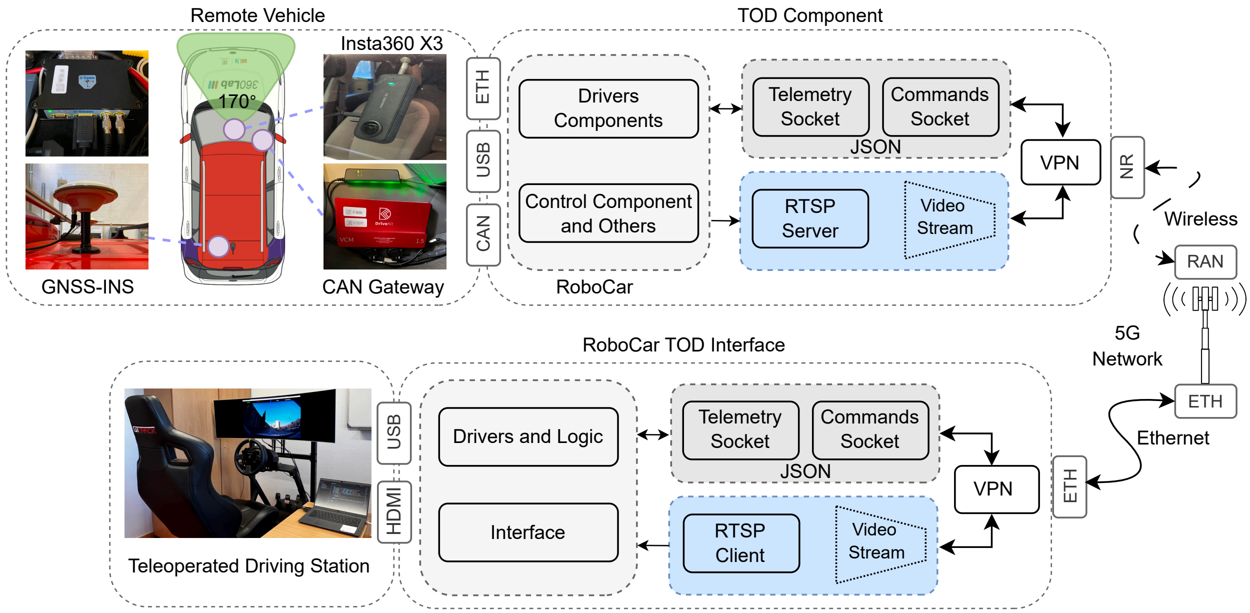

Fig. 1: Overview of the hardware and software architecture of the teleoperated driving demo setup.

TABLE I: Measured RTT and G2G latency.

	Number of samples	Average [ms]	Standard Deviation [ms]
G2G	100	202.41	31.56
RTT	1000	46.63	10.05

safe at moderate speeds. G2G latency directly impacts teleoperation control, safety, and user experience. We measured G2G latency using a video-based method with an estimated accuracy of 50ms. Over 100 measurements (90s of video), the mean G2G latency was 202.41ms with a standard deviation of 31.56ms, as given in Table I. Accounting for measurement uncertainties, safe teleoperation is deemed feasible at speeds below 20km/h. Steering response, distinct from network latency, depends more on the vehicle actuation system. An analysis over 5000 samples spanning 250s revealed a latency reaching up to 750ms, punctually increasing cognitive load on the driver. Future work should refine actuation latency and address compounding video delays. Despite these factors, low-speed operation (<20km/h) remains safe.

III. Demonstration

The demonstration enables remote teleoperation of a test vehicle in Luxembourg using a steering wheel, pedal set, and monitor. The network setup follows Fig. 1. with the remote vehicle using 5G. The user is able to assess the ergonomics, accuracy and practical implications of 5G teleoperation in a realistic setup. Consecutive to the initial evaluation, the demonstration takes place at low speed.

IV. Conclusion and Future Work

Teleoperated driving fills in the gaps of autonomous driving in difficult environments by allowing remote human intervention without a safety driver. However, it requires a highly reliable and low-latency network. This demonstration showcased a 5G-enabled teleoperation of a remote vehicle in a real-world testbed. Following an initial evualution of G2G latency, RTT and steering delay, teleoperation was conducted at low speed. Future work will explore adaptive network optimization, streaming strategies, and predictive control to enhance reliability and scalability of teleoperated driving.

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