**Literature Review on Teleoperated Driving**

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**Introduction to Teleoperated Driving**

Teleoperated driving (ToD) is the application of teleoperation in the area of automated driving. It is a concept that involves the remote control of vehicles by human operators, allowing them to operate a vehicle from a distant location. It allows a remote operator to control a vehicle using cellular networks, especially in situations that are beyond the vehicle's operational design domain. The use of teleoperation in autonomous vehicles introduces various challenges, which researchers are currently studying. To facilitate this research, an open source ToD software stack has been developed, which can be deployed with minimal overheads to control different vehicle systems remotely. This technology has the potential to enhance the safety and capabilities of autonomous vehicles.

**Existing Teleoperated Driving Systems**

Several types of teleoperated driving systems have been developed and applied in various domains. These include telemedicine, exploration, entertainment, tele-manufacturing, and many more. These systems typically consist of a local site where a human operator controls the vehicle using a hand-controller device, a remote site where the vehicle interacts with the physical environment, and a communication channel that links the two sites (Slawiñski & Mut, 2008). Furthermore, teleoperated systems are mostly associated with manipulation tasks such as remote surgery, space exploration, defense applications, handling of dangerous materials, and search and rescue missions. The challenges in teleoperated driving are transparency, ensuring the safety of both the operator and the environment, proving the boundedness of closed-loop signals, and accurately tracking a desired trajectory (Nath et al., 2008).

**The Relevance of Communications in Teleoperated Driving**

Communication plays a critical role in teleoperated driving. It enables the exchange of information between the remote operator and the vehicle, allowing for real-time control and feedback. Effective communication between the remote operator and the vehicle is essential for successful teleoperated driving. It ensures that commands and instructions are accurately transmitted and executed, and that the operator receives timely feedback about the vehicle's status and environment. Additionally, communication is necessary for transmitting sensor data from the vehicle to the remote operator, allowing them to have a comprehensive understanding of the vehicle's surroundings. Problems in existing teleoperated driving systyems lays on the challenges of reduced situational awareness and the additional mental effort required by the teleoperator to compensate for distortions and recreate missing information from sensor data (Schimpe & Diermeyer, 2020). Besides, teleoperated driving relies on reliable and low-latency communication to ensure the vehicle's responsiveness and safety.

**Human-Machine Interface for Teleoperated Driving**

In order to maintain traffic safety and efficiency, a novel user-centered human-machine interface needs to be designed for teleoperated driving (Kettwich et al., 2021).

This interface should take into account the unique challenges and requirements of teleoperated driving, such as reduced situational awareness and the need for precise control. One study conducted a teleoperated driving study using the direct control concept to address these challenges (Schimpe & Diermeyer, 2020).

The study found that the direct control concept, which involves providing the teleoperator with direct control over the vehicle's movements, can help mitigate the challenges of reduced situational awareness and enable more effective teleoperated driving. Furthermore, the user interface of teleoperated driving systems is crucial for an operator's task performance and situation awareness (Seo et al., 2020). Improving interface usability is an important ongoing challenge for researchers in order to reduce human operator error, utilize human resources efficiently, and minimize operator cognitive load.

**Network Infrastructure and Teleoperated Driving**

In order for teleoperated driving to be effective, a reliable and low-latency network infrastructure is crucial. This is because communication latency significantly impacts human cognitive processes and performance, making even simple driving tasks demanding and stressful for operators in a time-delayed environment (Luz et al., 2023). To mitigate the negative effects of latency on operator performance and robot safety, adequate interaction methods should be integrated into teleoperation systems .

**Literature Review on Teleoperated Driving**

**Communication Protocols in Teleoperated Driving**

**Analysis of Existing Literature on Teleoperated Driving**

**Key Insights from the Literature Review**

**Challenges and Opportunities in Teleoperated Driving**

**Future Prospects of Teleoperated Driving**

**Conclusion: Teleoperated Driving, Communications, and Networks**

**Reference**

1. Schimpe, A. and Diermeyer, F. (2020). Steer with me: a predictive, potential field-based control approach for semi-autonomous, teleoperated road vehicles.. https://doi.org/10.48550/arxiv.2006.15718
2. Kettwich, C., Schrank, A., Avsar, H., & Oehl, M. (2021). What if the automation fails? – a classification of scenarios in teleoperated driving. 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. https://doi.org/10.1145/3473682.3480271
3. Schimpe, A. and Diermeyer, F. (2020). Steer with me: a predictive, potential field-based control approach for semi-autonomous, teleoperated road vehicles.. https://doi.org/10.48550/arxiv.2006.15718
4. Seo, S. H., Young, J. E., & Irani, P. (2020). How are your robot friends doing? a design exploration of graphical techniques supporting awareness of robot team members in teleoperation. International Journal of Social Robotics, 13(4), 725-749. https://doi.org/10.1007/s12369-020-00670-9
5. Luz, R., Silva, J. L., & Ventura, R. (2023). Enhanced teleoperation interfaces for multi-second latency conditions: system design and evaluation. IEEE Access, 11, 10935-10953. https://doi.org/10.1109/access.2023.3240307
6. Slawiñski, E. and Mut, V. (2008). Transparency in time for teleoperation systems. 2008 IEEE International Conference on Robotics and Automation. https://doi.org/10.1109/robot.2008.4543209
7. Nath, N. G., Tatlıcıoğlu, E., & Dawson, D. (2008). Teleoperation with kinematically redundant robot manipulators with sub-task objectives. 2008 47th IEEE Conference on Decision and Control. https://doi.org/10.1109/cdc.2008.4739142

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