The Teleoperation of Highly Automated Vehicles: A Human-Centered Workplace Design for Remote Assistants

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Abstract: The vision of fully autonomous vehicles remains unfeasible in the foreseeable future. One potential solution is teleoperation, which refers to the intervention by a remote operator in the event of a problem. High-level, remote assistance can solve several problems, such as overcoming construction zones or resolving ambiguous perceptions. Essentially, the vehicle retains responsibility for the journey (e.g., lateral and longitudinal control). The remote assistant can resolve specific issues by applying high-level interpretation skills and problem-solving abilities. A suitable setup is crucial for conducting scientific studies in this field. From the human factors and ergonomics perspective, optimizing the interface design between the remote operator and the vehicle is of significant interest. These factors are quantified through measuring mental strain, stress, the successful resolution of situations, and situational understanding, highlighting the importance of a well-equipped research environment. The majority of existing work in this field concerns remote driving. In this scenario, the remote driver assumes control of the vehicle's lateral and longitudinal movements. Several approaches to implementation exist, including virtual reality, simulator setups, or control with a steering wheel and pedals. While only two publicshed concepts for remote assistance have emerged to date, there is a clear need for further research and development in this field. We are developing an ergonomic workplace used as a controlled test environment, paving the way for future advancements. It is based on the knowledge of the relevant information, interaction concepts, and required context information. We are carrying out usability and performance tests in the iterative development process. The scientific basis and the latest setup, with its evaluation, will be presented and discussed.

Keywords: Teleoperation, remote assistance, workplace design, user-centered HMI

1. Introduction

Academia and industry agree that fully automated vehicles are still far off. The lack of feasibility for all possible scenarios is primarily due to perception problems, unknown situations, problems in decision-making, or ambiguity with contradictory cues (Tener & Lanir 2022). Examples include construction zones with (incomplete) yellow lines, poor weather conditions, traffic lights, customized traffic signs (Kang et al. 2018), and general poor visibility conditions (Tener & Lanir 2022). Kettwich et al. (2022) published a list of problematic situations extended to public transport. Teleoperation is one solution for highly automated vehicles (HAVs) to overcome at least some of the identified obstacles. Teleoperation is an umbrella term for remote driving, remote assistance (RA), and remote monitoring (Majstorovic et al. 2022). Following the Society of Automotive Engineers (2021), level 4 automation means that all driving functions are executed autonomously under defined conditions (e.g., weather conditions or geographical areas) without the intervention of a human driver. If these conditions are no longer met, the control is returned to a human. According to German road traffic regulations, it is possible to give control to a remotely situated human. The HAV can execute a minimal-risk maneuver and ensure the least dangerous position if necessary. RA is an allowed way of operating level 4 vehicles on public roads (BMDV 2021). Here, RA can be defined as the system receiving assistance from an operator, while the responsibility for driving rests with the system (Majstorovic et al. 2022). Unlike in remote driving, the dynamic driving task (e.g., lateral and longitudinal control) is not part of the assignment of remote operators (RO) (Society of Automotive Engineers 2021). According to German law (StVG § 1) and further relevant publications, the process for RA is illustrated in Figure 1 (BMDV 2021; Schrank et al. 2024). Following the StVG, ROs have four different tasks. These are to get in contact with passengers of HAVs in the case of minimal risk maneuvers, deactivate the automated driving function, access the signals of the HAV regarding functionality and initiate safety measures as well as give clearance for alternative driving maneuvers (BMDV 2021).

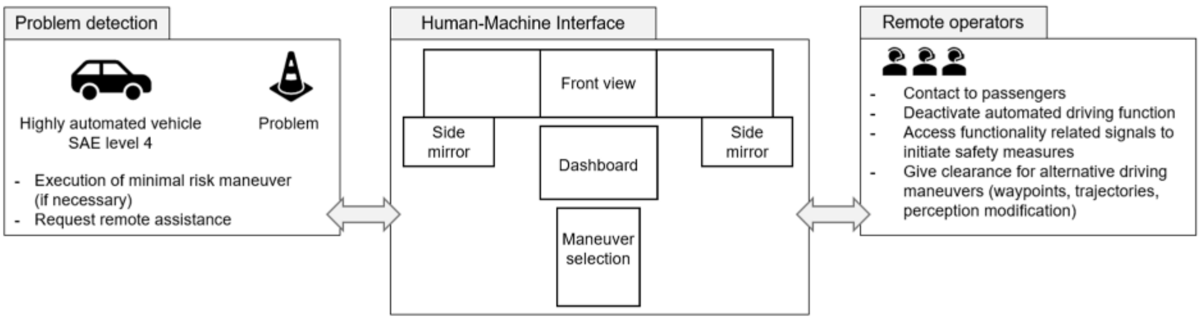

***Figure 1**: Illustration of RA for HAVs according to German road traffic regulations.*

2. Background

Automation in road traffic places new demands on support systems. RA systems are becoming increasingly important as they enable human operators to intervene remotely. Technological and ergonomic aspects are crucial for an effective interaction between operators and vehicles.

In the literature, only a few examples of prototypical systems exist. There are two main types of interfaces for RA HMIs. They have varying degrees of complexity and amount of information, as the examples in Figure 2 illustrate. One approach followed by Schrank et al. (2024) is a multi-monitor setup for RA with various information, including simulated driving situations, map information, and several status indicators. Complex traffic situations like construction zones or urban environments can be analyzed. Tener and Lanir (2023) established a more high-level user interface with a simplified solution. Only the most critical vehicle information is displayed without much situational context. Suggested maneuvers are proposed so that the RO can select one of them or create its own solution.

***Figure 2**: Illustration of different approaches for RA prototypes. Left: multi-monitor workstation with detailed situations and a touch-based interface by Schrank et al. (2024). Right: High-level user interface for a simplified HMI where only the most critical information and suggested maneuvers are displayed by Tener and Lanir (2023).*

A novel field of work and workplaces emerges with the development of RA. The workplaces we focus on are multi-monitor workstations where the RO is seated in the center in front of the screens. To ensure an ergonomic and pleasing setup, the general design requirements from the ASR-A6 are considered (2022). Text and graphics must be sharp, clear, and appropriately sized based on viewing distance and task. Adjustable settings for resolution, contrast, brightness, and viewing angles are crucial to prevent distortion or flickering and to ensure individual adaptation. Software ergonomics guides the development process so that the software enables users to perform tasks effectively, efficiently, and in a user-friendly way. Due to the amount of context information, multiple monitors may be necessary. Their arrangement should minimize strain by aligning resolution, brightness, and display characteristics. The setup must support wide viewing angles to ensure clear visibility from different positions. The positioning of monitors should prioritize frequently used screens centrally and arrange multiple screens closely together to reduce excessive head and eye movements. Uniform viewing distances across all screens are essential for ergonomic efficiency. There has been no scientific research into what information is often needed for RA (Gafert et al. 2023). Building on ergonomic principles (Ries 2021), HMI design guidelines, and prior research, we aim to evaluate whether our workplace design aligns with these recommendations and assess the required types and volumes of information. Additionally, we plan to investigate the cognitive abilities that correlate with performance in RA, particularly across different interaction methods.

3. Method

A laboratory experiment is conducted. The experimental design is a within-design experiment with two study parts on different dates. The independent variable is the type of interaction (waypoints, trajectories, perception modification). The dependent variables are individual cognitive abilities, performance, visual attention, situational awareness, workload, and usability. In addition, ratings for the importance of displayed information and overall usability are collected.

The development of the current setup is based on literature and various expert discussions about design decisions. In Figure 3, the setup for this experiment is illustrated. The driving scenarios are staged on a traffic training ground[1]. All scenarios are challenging to solve for HAVs and are inspired by the literature and databases

[1] https://www.verkehrswacht-karlsruhe.de

about problems in mixed traffic (e.g., Kettwich et al. 2022; Waymo LLC 2025). The videos are recorded with six GoPro cameras mounted on the ego vehicle. One is mounted on each mirror, and four cameras are mounted on the vehicle's roof. Three of them are used to create the front-view data stream. The last camera is mounted on the back to generate the rear-view perspective.

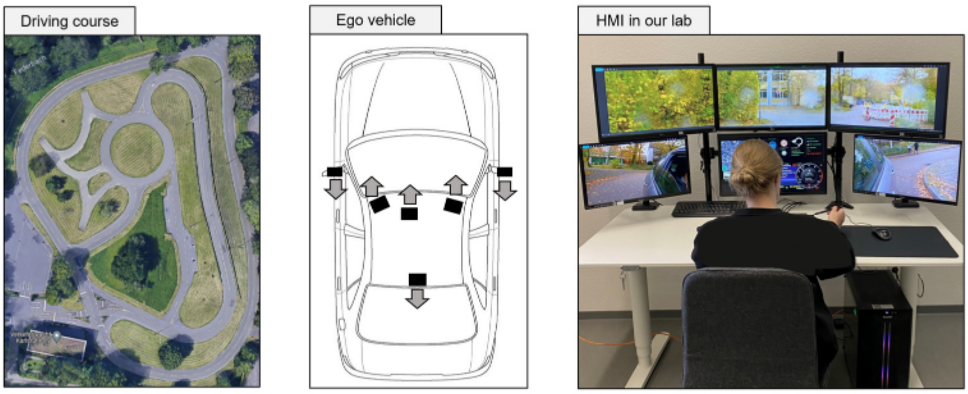

***Figure 3**: Illustration of the experimental setup planned for the study. From left to right: The training course, the ego vehicle, and the physical setup in our lab are displayed. The black boxes on the ego vehicle indicate the positioning of the cameras, with the arrows as an indication of the recording direction.*

Due to its length, the experiment is divided into two study appointments: Study Part I and Study Part II. An overview is provided in Figure 4. A requirement for participation is to hold a German driving license, which is checked during the welcome phase. *Study part I* contains the demographical and cognitive skill assessment. To describe the *sample,* the participants are asked for the gender they identify with, their age, and their highest education level. Further, the Affinity for Technology Interaction Scale (ATI) by Franke et al. (2019) assesses their affinity for technology. The driving experience and simulator gaming experience is measured as control variables. Different cognitive abilities are possible correlates for performance in teleoperation settings (e.g., Tang et al. 2023). To approach the relevance of different skills, we plan to use the Vienna Test system, established in diagnostic and job-related testing. We consider peripheral vision, sustained attention, spatial orientation, rotation abilities, and rapid detection skills for the proposed experiment. We conduct a set of tests to measure these abilities in our lab[2]. Each test is explained and test trails are completed before execution. Short breaks are planned between the tests to avoid fatigue of the participants. After this, the first part of the study is finished.

Study Part II contains the actual interaction and evaluation of the developed work-station. After a short welcome, the research context and the setup are explained. A test trial for each interaction type is conducted. During this familiarization, the partici-pants are encouraged to ask any questions regarding their tasks, functionalities, or problems they encountered. The stationary eye-tracking Smarteye 9.3 is used to evaluate *visual attention* to presented information. Areas of interests (AOIs) are used to identify which of the presented information is attended during the driving scenarios. The eye tracker is calibrated for each participant individually. The data is collected during all driving scenarios. Before the experimental trials start, the participants' mental

[2] WG (Perceptual Speed), WAFV (Perception and Attention Functions: Vigilance & Sustained Attention; Reaction to Changes in Intensity), ZBA (Time and Motion Anticipation), and PP-R (Peripheral Perception) from SCHUHFRIED GmbH, 2025

state is pre-tested with the German version of the Short Stress State Questionnaire (SSSQ-G, Ringgold et al. 2024). In each interaction method (setting waypoints, drawing trajectories, modifying perception) five prerecorded videos are presented. The order of these blocks is randomized. After each block, the interaction method is evaluated regarding *workload* with the NASA Task Load Index subscale mental demand (NASA-TLX, Hart & Staveland 1988). The *usability* is evaluated with the short version of the User Experience Questionnaire (UEQ-S) by Schrepp et al. (2017). The order of the individual videos within each block is randomized as well. After each scenario, the Situational Awareness Rating Technique (SART) by Taylor (1990) measures subjecttive *situational awareness*. The *participant's performance* is measured based on the time and quality of the results needed. The task reaction time, task completion time, and inferred task duration time are used for the time evaluation. The quality of the participant's waypoints and trajectories is compared to defined ideal trajectories. Rule violations like leaving the street or drawing through an obstacle are noted as errors.

After the three blocks, the mental state is measured again. Afterward, the usability of the HMI system is evaluated with the Systems Usability Scale (SUS) by Brooke (1996), the Acceptance Scale (van der Laan et al. 1997), a ranking of the three interaction methods, and open questions for feedback. Finally, the participants rated the relevance of the presented information. This helps to understand the fixations on specific areas during the driving scenarios and guides future setup improvements. In the end, general feedback regarding the study is collected, compensation for participation is paid, and farewell is given.

This experiment aims to provide insights into human information processing in complex systems with frequent context switches, contributing to the user-centered design of emerging workplaces. By considering physiological and cognitive ergonomics, the results will help to optimize HMIs as well as to enhance efficiency and safety for RA and HAVs. To the author's knowledge, no experiment has yet utilized real-life driving videos in this context. The results will address key questions such as the suitability of ROs and the cognitive skills linked to their performance. Findings will also generalize performance evaluation methods to similar assistance settings in other workplaces.

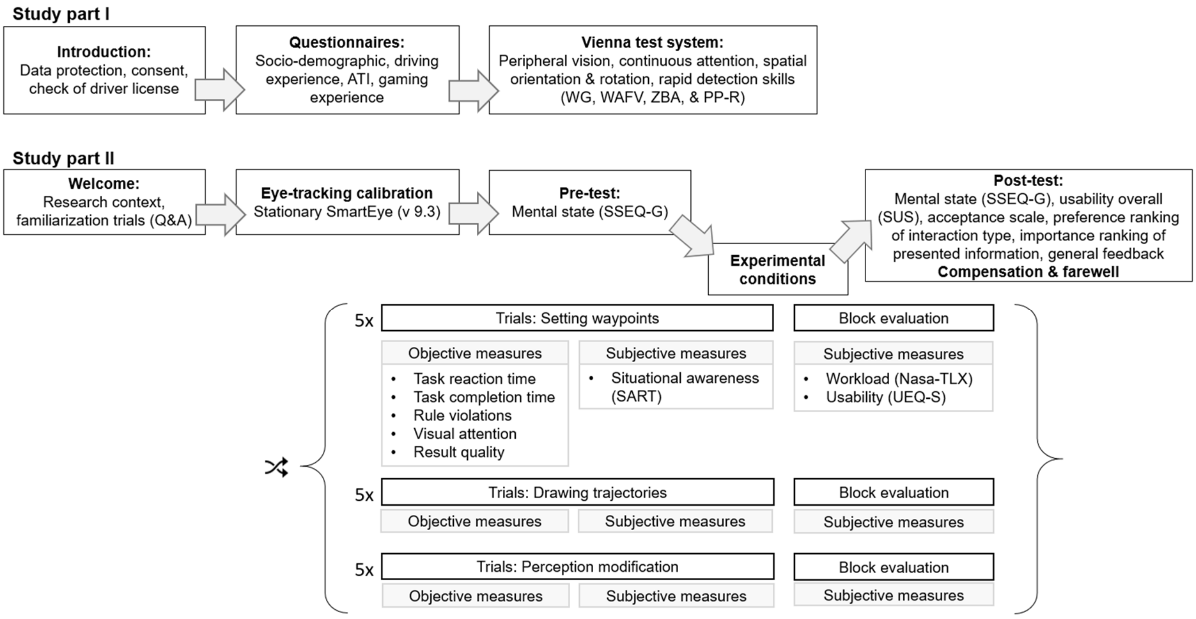

***Figure 4**: Schematic illustration of parts I and II of the study procedure.*

5. Literature

Ausschuss für Arbeitsstätten, 2022. Technische regel für arbeitsstätten: ASR A6 - bildschirmarbeit.

Beckmann, S., Biletska, O., Zadek, H., 2020. Requirements for pilot routes and infrastructure for the introduction of automated shuttle buses in public areas. 10.2195/lj_Proc_beckmann_en_202012_01

Biletska, O., Beckmann, S., Glimm, T., Zadek, H., 2021. Key requirements and concept for the future operations control center of automated shuttle buses, in: 2021 International Scientific Symposium on Logistics: Conference Volume.

Bundesministerium für Digitales und Verkehr (BMDV), 2021. Straßenverkehrsgesetz (StVG),§1e – Betrieb hoch- und vollautomatisierter Fahrzeuge; (12.07.2021 (BGBl. I S. 3108), in Kraft getreten am 28.07.2021).

Franke, T., Attig, C., Wessel, D., 2019. A personal resource for technology interaction: Development and validation of the affinity for technology interaction (ATI) scale. International Journal of Human-Computer Interaction 35, 456–467. 10.1080/10447318.2018.1456150

Gafert, M., Mirnig, A.G., Fröhlich, P., Kraut, V., Anzur, Z., Tscheligi, M., 2023. Effective remote automated vehicle operation: a mixed reality contextual comparison study. Personal and Ubiquitous Computing 27, 2321–2338. 10.1007/s00779-023-01782-5

Hart, S.G., Staveland, L.E., 1988. Development of NASA-TLX (task load index): Results of empirical and theoretical research, in: Hancock, P.A., Meshkati, N. (Eds.), Human Mental Workload, Advances in Psychology. North-Holland, pp. 139–183. 10.1016/S0166-4115(08)62386-9

Kang, L., Zhao, W., Qi, B., Banerjee, S., 2018. Augmenting self-driving with remote control: Challenges and directions, in: Proceedings of the 19th International Workshop on Mobile Computing Systems & Applications, HotMobile ’18. pp. 19–24. 10.1145/3177102.3177104

Kettwich, C., Schrank, A., Avsar, H., Oehl, M., 2022. A helping human hand: Relevant scenarios for the remote operation of highly automated vehicles in public transport. Applied Sciences 12. 10.3390/app12094350

Majstorovic, D., Hoffmann, S., Pfab, F., Schimpe, A., Wolf, M.-M., Diermeyer, F., 2022. Survey on teleoperation concepts for automated vehicles. 10.48550/arXiv.2208.08876

Ries, F. (2021). Visual complexity in human-machine interaction = Visuelle Komplexität in der Mensch-Maschine Interaktion. PhD thesis, Karlsruher Institut für Technologie (KIT). 10.5445/IR/1000130377

Ringgold, V., Shields, G.S., Hauck, F., Kurz, M., Schindler-Gmelch, L., Abel, L., Richer, R., Eskofier, B.M., Rohleder, N., 2024. The Short Stress State Questionnaire in German (SSSQ-G): A Multi-Study Validation. European Journal of Health Psychology 31, 189–200. 10.1027/2512-8442/a000160

Schrank, A., Walocha, F., Brandenburg, S., Oehl, M., 2024. Human-centered design and evaluation of a workplace for the remote assistance of highly automated vehicles. Cognition, Technology & Work 26, 183–206. 10.1007/s10111-024-00753-x

Schrepp, M., Thomaschewski, J., Hinderks, A., 2017. Design and evaluation of a short version of the user experience questionnaire (UEQ-s). International Journal of Interactive Multimedia and Artificial Intelligence 4, 103–108. 10.9781/ijimai.2017.09.001

Society of Automotive Engineers, 2021. Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. (SAE J 3016–202104) (manual). 10.4271/J3016_202104

Tang, W., Tian, Y., Tan, L., Xue, S., Jiang, T., Zhou, S., Wang, C., 2023. Human factors design and evaluation of china’s space manipulator teleoperation system. International Journal of Human–Computer Interaction 40, 1943–1959. 10.1080/10447318.2023.2250055

Taylor, R., 1990. Situation awareness rating technique (SART): the development of a tool for aircrew systems design (AGARDCP-478), in: Situational Awareness in Aerospace Operations. NATO-AGARD, Neuilly Sur Seine, France, p. 3/1-3/17.

Tener, F., Lanir, J., 2023. Design of a high-level guidance user interface for teleoperation of autonomous vehicles, in: Adjunct Proceedings of the 15th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI ’23 Adjunct. pp. 287–290. 10.1145/3581961.3609845

Tener, F., Lanir, J., 2022. Driving from a distance: Challenges and guidelines for autonomous vehicle teleoperation interfaces, in: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, Chi ’22. 10.1145/3491102.3501827

Van Der Laan, J.D., Heino, A., De Waard, D., 1997. A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research Part C: Emerging Technologies 5, 1–10. 10.1016/S0968-090X(96)00025-3

Waymo LLC, 2025. Waymo open dataset: Autonomous driving data for research.