ROStopbox: A Human-Centered Vehicle Environment Data Acquisition System

Daniel Schneider[1,2], Jonas Nesensohn[1], Bernhard Schick[1] and Daniel Watzenig[2]
Kempten University of Applied Sciences[1], Graz University of Technology[2]

INTRODUCTION

Advanced driver assistance systems (ADAS) are one of the most important trends in the automotive industry with the aim of increasing road safety, supporting drivers in their driving tasks and reducing workload. The data-driven development process is used to develop future ADAS, whereas the scenario-driven validation process makes it possible to validate the ADAS within critical scenarios. Current ADAS follow predefined control strategies and do not adapt to real driving situations, which limits their predictability and the driver's confidence in the system. Neither subjective information nor objective physiological data are considered in these processes. Hence, the driver's subjective perception and physiological reactions are excluded from the development and validation process.

With the system presented, we are demonstrating a human-centered data acquisition system that combines both environmental and physiological data.

METHODS

As the UN/ECE R157 [1] defines the first real-world scenarios for the type approval of ALKS, this regulation was chosen to derive the design objectives for the ROStopbox (RTB).

LiDAR and Image-Based Perception

LiDAR sensors with a minimum lateral coverage of ±9 meters and longitudinal range of ±150 meters were used, along with 360° image-based sensors.

Inertial and Localization Sensors

The RTB was designed for velocities up to 130 kph, measured precisely with an ISO 13674-compliant IMU [2], and localized with centimeter accuracy using RTK-GNSS.

Vehicle Fieldbus Communication

The vehicle's internal Fieldbus messages were recorded to consider the system status and onboard sensor signals.

Car2X Communication

Car2X communication was integrated to evaluate the perception in the real driving test using the relative position information of the hunter and target vehicle.

Physiological Sensors

ECG, EDA, EMG, EEG, and eye tracking sensors were integrated to capture the physiological responses of the driver and passenger related to cognitive workload and stress [3,4].

Subjective Perception Data

A questionnaire application was integrated to record the subjective scenario perception.

Sensor Synchronization

All sensors and modules were synchronized with a common clock using the generalized Precision Time Protocol (gPTP) [5] and GPS time.

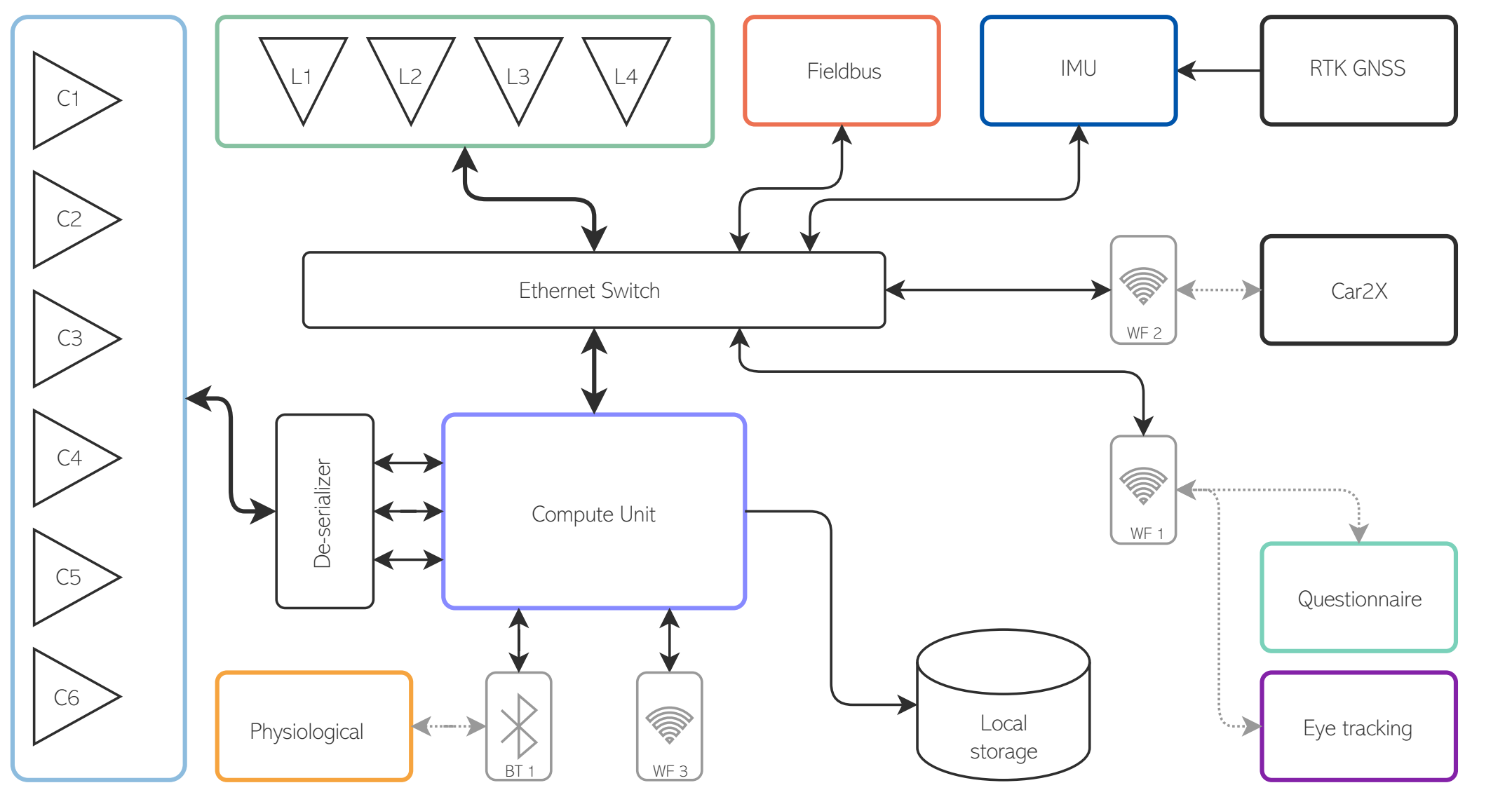
Non-Intrusive Design

The system was designed to avoid affecting the surrounding vehicles and at the same time be flexible enough to be mounted to different vehicles under test (VUT).

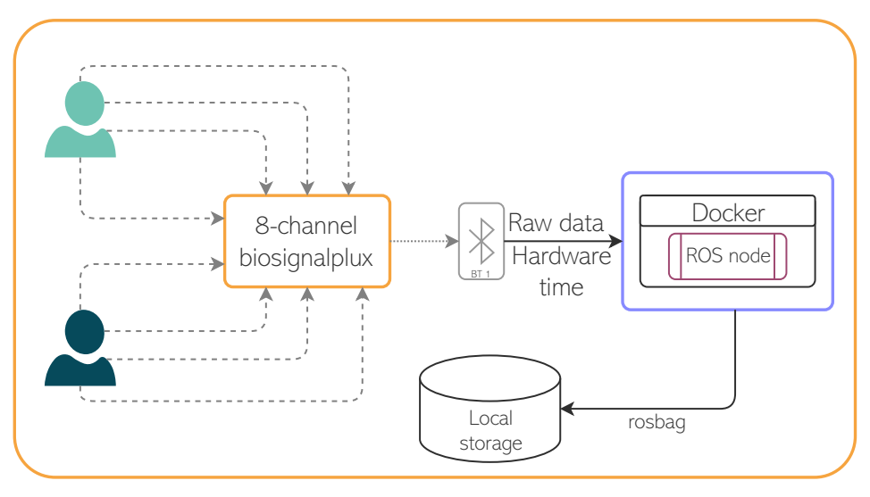
SYSTEM SETUP

Centralized Hardware Architecture

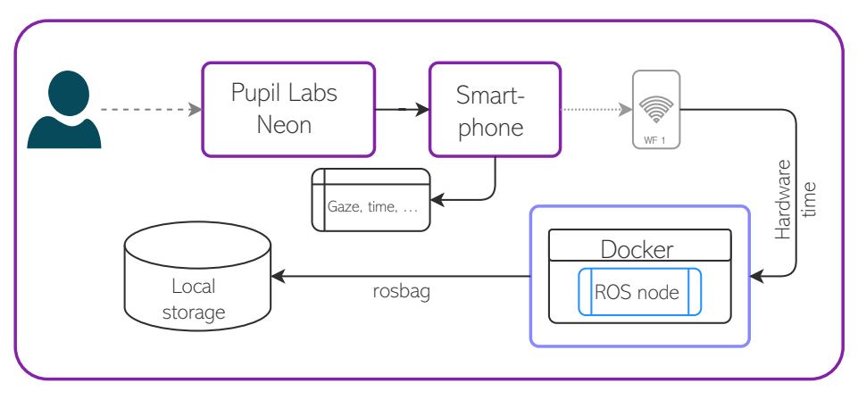
The hardware was mounted in a roof box, providing weather protection and minimal impact on surrounding traffic participants. Four LiDAR sensors aligned perpendicular to each other generated a 360° point cloud, while six cameras created a panoramic image, using a hardware de-serializer for maximum hardware acceleration. An IMU enabled centimeter-precise localization using RTK-GNSS, with all sensors mounted on a damped aluminum frame. The Fieldbus data from the VUT was forwarded to the compute unit (CU) via dedicated hardware. Physiological sensors transmitted the data to the CU by Bluetooth. A local Wi-Fi network ensured the integration and synchronization of subsystems such as eye tracking and questionnaires.



a) Schematic overview of the entire RTB setup.



b) Detailed overview of the physiological sensor integration.



c) Detailed overview of the eye tracking integration.

Fig. 1: Schematic representation of the entire RTB setup (a) and detailed information on the integration of the physiological sensors (b) and eye tracking (c).

ROS-Based Software Architecture

The software setup was based on the Robot Operating System (ROS) for sensor integration in a Dockerized environment. All LiDAR sensors were synchronized via gPTP. Due to the large amount of camera data, a C/C++ module was developed to process and encode all video streams simultaneously outside of ROS using GStreamer. To synchronize the camera data to other sensors, additional timestamp files were created that stored both the ROS and the prevailing decoding time for each frame. Eye tracking and subjective data followed the same synchronization principle. Physiological data was recorded in the ROS-framework, and subjective evaluations from a digital questionnaire were linked to sensor data during post-processing. For this purpose, the ROS time was distributed in the sensor network via TCP/UDP.

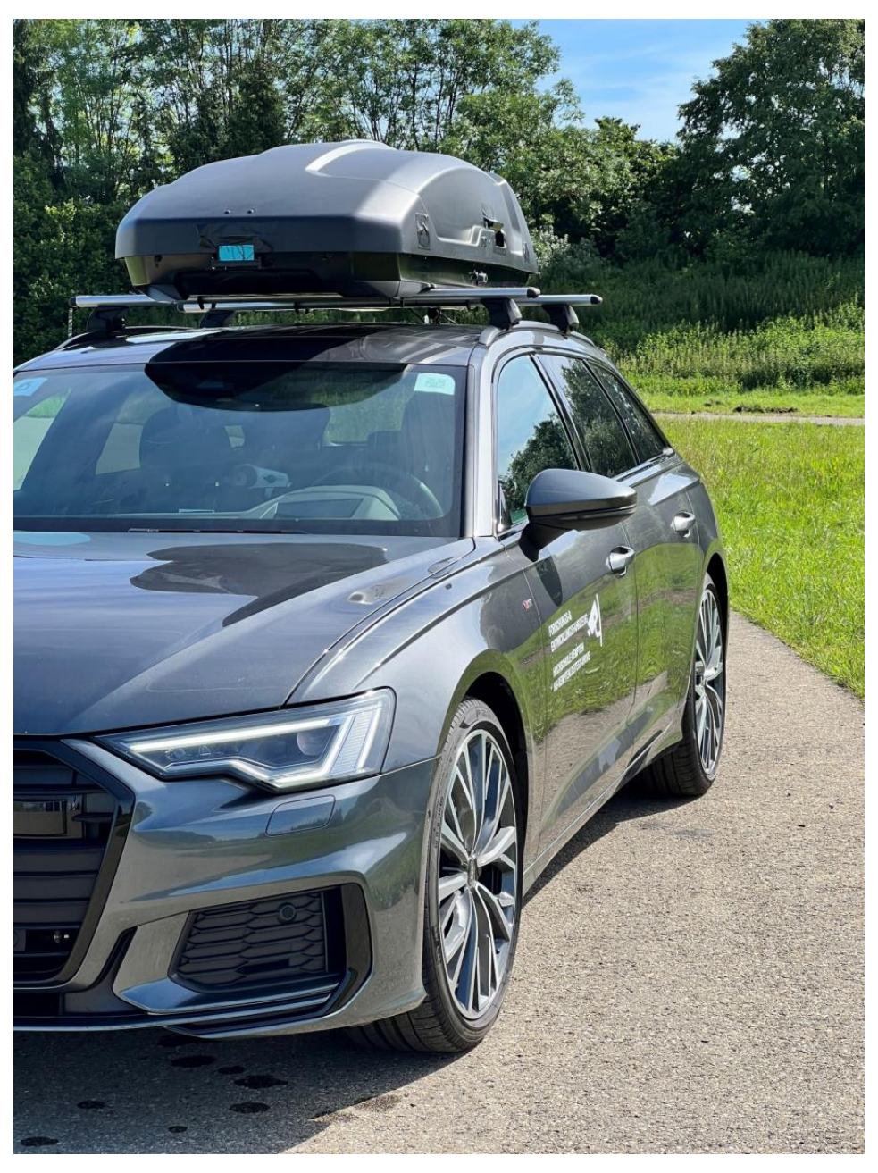
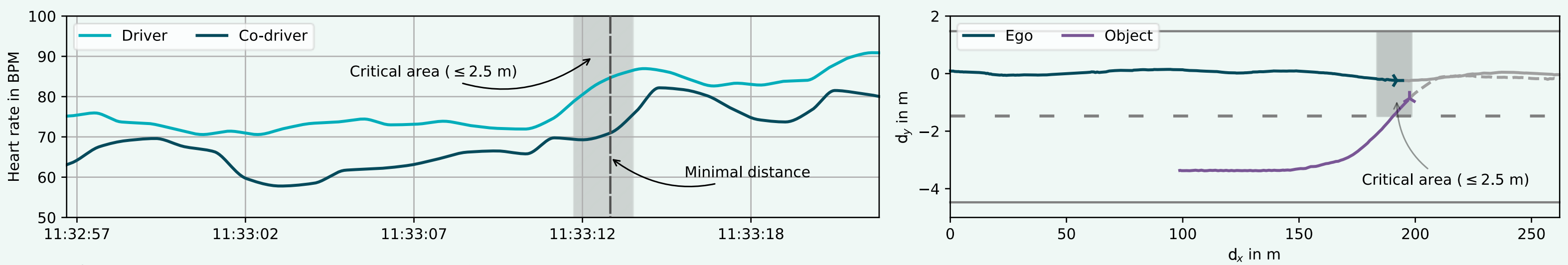


Fig. 2: Photograph of the RTB.

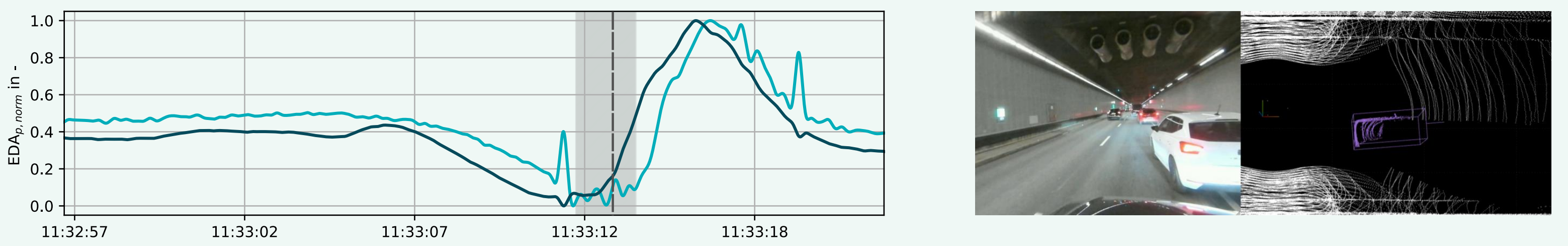
RESULTS

We conducted a measurement campaign on a federal highway and selected a 38-minute subset for further evaluation. The collected data were processed semi-automatically to assess the workload and stress level under the prevailing driving situation. Relevant scenarios (RS) were identified by linking subjective questionnaire feedback with physiological signals. Within the RS, a cut-in maneuver caused a significant increase in heart rate (HR) and electrodermal activity (EDA). The increase in HR and EDA indicates increased stress for drivers and passengers.



a) Physiological response heart rate of the driver and co-driver.

c) Trajectories of the ego and the object vehicle.



b) Normalized phasic EDA signal of the driver and co-driver.

d) Visualization of the scenario by the front left camera and LiDAR.

Fig. 3: Illustration of the physiological data for the preselected scenario. The heart rate (a) and the phasic EDA signal (b) of the driver and co-driver with highlighted critical area. The trajectory (c) and the visualization (d) show the scenario in the 2D plane.

The object approaching from the right triggered a physiological response in the EDA and HR channels in both persons in the VUT. The gray marked area described a critical interval in which the relative distance between the object and the ego-vehicle was less than half the length of the VUT.

DISCUSSION

The results showed that the combination of physiological and perceptual data was effective in identifying stress-inducing scenarios. A cut-in maneuver triggered an increase in HR and EDA in both the driver and the co-driver. Questionnaires helped to isolate relevant scenarios. The filtered physiological signals showed a phase shift which had to be considered during localization. Signal noise caused by movement artifacts made the analysis more difficult. The EMG and EEG data were insignificant, and the eye tracking delivered poor results in dark situations. Nevertheless, the sensor housing was inconspicuous in road traffic and caused no noticeable interference.

CONCLUSION

This research evaluates the integration of human factors in the development of ADAS by combining physiological, perceptual, and subjective data. We presented a system that combines LiDAR, camera, IMU, GNSS, and questionnaire along with physiological sensors to capture the reactions of drivers and passengers to real driving scenarios. During a measurement campaign, we identified relevant scenarios by correlating subjective questionnaires, EDA, and HR with sensor signals from the perception sensor stack.

This approach enables precise identification of scenarios triggering physiological reactions and offers the possibility of deriving development guidelines for future systems to increase passengers' sense of safety while reducing workload. The system also enables the validation of near-series software and sensor modules, making it a versatile tool. The re-simulation of scenarios accelerates the entire development and validation process.

REFERENCES

[1] UN Economic Commission for Europe, "UN Regulation No. 157 - Automated Lane Keeping Systems (ALKS), Revision 3", 2023.

[2] International Organization for Standardization, "Road vehicles - Test method for the quantification of on-centre handling - Part 1: Weave test", Edition 3, Geneva, CH, 2023.

[3] M. Beggiato, F. Hartwich, and J. Krems, "Physiological correlates of discomfort in automated driving", Transportation Research Part F: Traffic Psychology and Behaviour, vol. 66, pp. 445 - 458, 2019.

[4] Q. Meteier, M. Capallera, S. Ruffieux, L. Angelini, O. Abou Khaled, E. Mugellini, M. Widmer, and A. Sonderegger, "Classification of Drivers' Workload Using Physiological Signals in Conditional Automation" Frontiers in Psychology, vol. 12, 2021.

[5] Institute of Electrical and Electronics Engineers, "IEEE Standard for Local and Metropolitan Area Networks - Timing and Synchronization for Time-Sensitive Applications", Std. IEEE 802.1AS-2020, 2020.

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www.hs-kempten.de/ifm
daniel.schneider@hs-kempten.de
www.github.com/adrivelivinglab