Technologies for Risk Mitigation and Support of Impaired Drivers

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Editorial: Technologies for risk mitigation and support of impaired drivers

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***Abstract*— This editorial serves as an extended introduction to the special issue on Technologies for risk mitigation and support of impaired drivers. It gives the context to recent advances in assisted and automated driving and the new challenges that arise when modern technology meets human users. The special issue focus on the development of robust sensors and detection algorithms for driver state monitoring of fatigue, stress and inattention, and on the development of personalised multimodal, user oriented and adaptive information, warning, actuation and handover strategies. A summary of more recent developments serves as a motivation to each paper that follows.**

***Index Terms*—Driver state, detection algorithms, HMI, monitoring, personalization.**

I. Introduction

ADVANCED driving assistance functions are continuously being introduced and our vehicles are gradually becoming more capable of both driving and handling risky situations by themselves. Today, anti-lock braking systems help us preserve tire traction when we do emergency steering and braking. Lane keeping assistance systems can gently steer us back if we drift out of lane, adaptive cruise control adapts a set cruise speed to vehicles ahead, automatic emergency braking systems can detect slow or stopped traffic and urgently apply the brakes if needed, traffic jam situations can be handled with fallback-ready drivers, etc. However, fully automated vehicles that can drive from A to B with no human intervention are not ready to be deployed on public roads quite yet. When current assistance functions are active, a responsible driver must always be present and ready to manage any part of the assisted driving task in case of malfunctioning or if the driving situation is not within the assistance functions operational design domain. This implies high requirements on the human machine interface (HMI) in automated vehicles, such as maintaining mode awareness and vigilance of the driver, preparing drivers to take back control, especially when inattentive, and support incapacitated drivers by transparent system behaviour.

This interplay between the vehicle and the driver gives rise to new challenges in automotive research [1-3]:

1. New human-machine interfaces (HMI) are needed to ensure that the human driver is aware of his/her responsibilities, as well as of changes of these responsibilities due to activation of different assistance functions and automation modes.
2. Robust sensors capable of monitoring the driver at all times, even when out of the loop or out of position.
3. Reliable detection and prediction algorithms for driver state monitoring (e.g. sleepiness, physical fatigue, stress, distraction, impairing emotions) that work for all drivers and in all situations.
4. Effective countermeasures that alert fatigued drivers and reengage inattentive drivers to ensure that a driver is ready to take over the control of the vehicle when needed.

For this purpose, algorithms that can estimate the current driver state have to be developed. The input for these algorithms can be environmental, behaviouristic, personal, and physiological data. Such data should be gathered in a robust and unobtrusive way which does not interfere with either driving or non-driving related activities. Furthermore, tools and concepts for supporting impaired drivers are needed, with multimodal, user oriented and adaptive warning, actuation and handover strategies.

This special issue invited manuscripts addressing technologies that can mitigate risks related to impaired drivers by detection of critical driver states and/or that can provide support to impaired drivers. The submitted contributions responded to this challenge in various ways, including the use of state-of-the-art physiological measures to assess the driver's state, and investigations of theoretical and empirical methodological approaches to advance the present knowledge in vehicle automation.

II. Safe transfers of control

A key challenge when introducing highly automated vehicles is safe transfers of control between the human driver and the automated vehicle. Hwang, et al. [4] present a hidden semi-Markov model for predicting a driver's response time once an

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alert has been issued. The proposed model was able to predict a driver's response within about 0.5 seconds, which indicates how quickly drivers can transition to driving from another task. Obviously, this time may increase if the driver is in an impaired state, thus necessitating robust driver monitoring, or if the driving task is more complex.

Pipkorn, et al. [5] conducted an experiment to learn more about the effects of automation and automation duration on driver behaviour after a transfer of control. The results from their Wizard-of-Oz test-track experiment showed smaller automation aftereffects compared to previous driving simulator studies. The extent to which these results are a consequence of a more realistic test environment, or due to the duration between the timings of the take-over request and the conflict appearance, is still unknown.

On a longer time-scale, Ahlström, et al. [6] investigated if biomathematical models can be used to estimate the take-over times after being asleep in a highly automated vehicle. They also discussed if drivers could obtain successful rest during automated driving, and thereby be able to drive for longer periods of time. The conclusion is that real-time assessment of driver fitness is complicated, especially when it comes to the recuperative value of in-cab sleep and rest, as it depends on sleep quality, time of day, homeostatic sleep pressure and on the activities that are carried out while resting. The monotony invoked by long-duration driving is clearly interrupted during automated driving, but further research is required to fully understand the long-term consequences.

III. Advances in driver monitoring

Several papers in this special issue emphasize that practically useful driver monitoring systems must take both the driver and the driving context into account.

Leicht, et al. [7] compared unobtrusive methods for physiological monitoring (magnetic induction, photoplethysmography, capacitive electrocardiography and thermal imaging) in urban and highway scenarios. The work conclude that the evaluated unobtrusive measurement systems worked well in long-time driving on highways. However, performance suffered in urban driving where the drivers were more active, showing that motion artifacts need to be overcome before such sensors can be used for everyday driving.

Not just the sensors, but also the algorithms should take context into account. Ahlström, et al. [8] exemplifies this with a new context-dependent driver distraction algorithm based on eye movements. Former distraction detection algorithms typically trigger a warning when the driver's gaze is directed away from forward, but this approach is problematic since it gives rise to false warnings, for example when the driver looks sideways when going through an intersection. The proposed algorithm allows drivers to look in predefined directions that reflects the surrounding environment. It even requires drivers to look away from forward when there is relevant information in other directions.

Taking context into account is but one way to reduce variability when modelling driver behaviour. Another large source of variability comes from individual differences. To tackle this challenge, Bakker, et al. [9] introduce a personalized real-time driver sleepiness detection system. Binary classification of 'alert' versus 'sleepy' showed an accuracy of 92%, but without personalisation, the accuracy dropped with 20 percentage points. The authors conclude that personalized algorithms and multi-dimensional features are important for high-level sleepiness detection performance. Lu, et al. [10] reached the same conclusion when evaluating a wearable heart rate sensor in a driver sleepiness experiment comparing manual driving with partially automated driving. Classification of alert versus sleepy drivers improved considerably when using a personalized algorithm compared to a generic algorithm, and even more so when taking the contextual factors driving time and time of day into account. Also Perello-March, et al. [11] come to a similar conclusion, suggesting that future driver state monitoring systems should exploit multiple measures to reach more robust performance across several time scales.

Mathissen, et al. [12] investigated how impaired driver states can be induced, with the aim to design test protocols suitable for evaluation of driver monitoring systems. When comparing three different ways to induce acute stress (n-back task, sing-a-song stress test and noise exposure), they concluded that subjective stress ratings and physiological responses rarely correlated. This underlines that it is important to realise that many driver states are multidimensional constructs that consist of many mental responses to added task demand. A state change does not occur in isolation but is part of a complex response to task demands in a specific context. Physiological and behavioural measures typically correlate with more than one mental state, thus limiting the inferences that can be made from any individual state.

In higher automation, drivers are allowed to look away from forward, which might induce driver states that may impair driving performance after taking over. Bohrmann, et al. [13] investigated the effects of dynamic visual stimuli on the development of carsickness in real driving, and found tendencies for reduced carsickness when providing enhanced visual information on longitudinal driving dynamics in the peripheral field of view.

IV. Countermeasures and adaptive HMI

Automated driving capabilities of vehicles may vary, depending on the context. It is hence important to support driver's mode awareness constantly and during transitions between different automation modes. Diederichs, et al. [14] investigated the effect of visual cues in the steering wheel on mode awareness and take over performance. They found evidence for stable mode awareness when driving in different levels of automation, supported by the visual feedback, and faster take over reactions when visual cues in the steering wheel were used as countermeasures against distracted drivers.

The issue of safe transition of control to the driver was also addressed by Feierle, et al. [15]. They investigated the effect of an augmented reality head up display (ARHUD) on take over time and performance. ARHUD improved reaction time while the take-over quality remained the same. The authors attribute this to the position and content of the ARHUD and its effect that drivers keep the eyes in the primary field of view for driving, even in automated driving conditions.

Rittger, et al. [16] address the possibilities of adaptive HMI to improve safety and user experience. They focus on the role of transparency for the perception of intelligence and intuitive HMI design. Advancements in driver state detection and artificial intelligence allow for more and more user-centred and individual experiences that can be described with their LASR model of adaptive user interfaces.

Ulahannan, et al. [17] investigated how eye movements toward an adaptive HMI change over time, suggesting that single exposure HMI evaluations may be limited in their assessment. This highlights the importance of longitudinal studies in HMI design to avoid first encounter effects.

V. Conclusion

The works collected by this special issue describe a variety of risk mitigation and support tools. They also identify a wide range of challenges that must be addressed as we improve on our knowledge of the interplay between modern vehicles and the driver. In view of the strong interest in academia and industry, we hope that the present special issue will increase progress, rigor, and reproducibility in driving research.

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References

[1] F. Diederichs *et al.*, "Adaptive transitions for automation in cars, trucks, buses and motorcycles," *IET Intelligent Transport Systems,* vol. 14, no. 8, pp. 889-899, 2020.

[2] A. Halin, J. G. Verly, and M. Van Droogenbroeck, "Survey and synthesis of state of the art in driver monitoring," *Sensors,* vol. 21, no. 16, p. 5558, 2021.

[3] S. Leonhardt, L. Leicht, and D. Teichmann, "Unobtrusive Vital Sign Monitoring in Automotive Environments—A Review," *Sensors,* vol. 18, no. 9, p. 3080, 2018.

[4] S. Hwang, A. G. Banerjee, and L. N. Boyle, "Predicting Driver's Transition Time to a Secondary Task Given an in-Vehicle Alert," *IEEE Transactions on Intelligent Transportation Systems,* 2020.

[5] L. Pipkorn, T. Victor, M. Dozza, and E. Tivesten, "Automation Aftereffects: The Influence of Automation Duration, Test Track and Timings," *IEEE Transactions on Intelligent Transportation Systems,* 2021.

[6] C. Ahlström *et al.*, "Real-Time Adaptation of Driving Time and Rest Periods in Automated Long-Haul Trucking: Development of a System Based on Biomathematical Modelling, Fatigue and Relaxation Monitoring," *IEEE Transactions on Intelligent Transportation Systems,* 2021.

[7] L. Leicht, M. Walter, M. Mathissen, C. H. Antink, D. Teichmann, and S. Leonhardt, "Unobtrusive Measurement of Physiological Features Under Simulated and Real Driving Conditions," *IEEE Transactions on Intelligent Transportation Systems,* 2022.

[8] C. Ahlström, G. Georgoulas, and K. Kircher, "Towards a Context-Dependent Multi-Buffer Driver Distraction Detection Algorithm," *IEEE Transactions on Intelligent Transportation Systems,* 2021.

[9] B. Bakker *et al.*, "A multi-stage, multi-feature machine learning approach to detect driver sleepiness in naturalistic road driving conditions," *IEEE Transactions on Intelligent Transportation Systems,* 2021.

[10] K. Lu, J. Karlsson, A. S. Dahlman, B. A. Sjöqvist, and S. Candefjord, "Detecting Driver Sleepiness Using Consumer Wearable Devices in Manual and Partial

Automated Real-Road Driving," *IEEE Transactions on Intelligent Transportation Systems,* 2021.

[11] J. R. Perello-March, C. G. Burns, S. Birrell, R. Woodman, and M. T. Elliott, "Physiological Measures of Risk Perception in Highly Automated Driving," *IEEE Transactions on Intelligent Transportation Systems,* 2022.

[12] M. Mathissen, N. Hennes, F. Faller, S. Leonhardt, and D. Teichmann, "Investigation of Three Potential Stress Inducement Tasks During On-Road Driving," *IEEE Transactions on Intelligent Transportation Systems,* 2021.

[13] D. Bohrmann, A. Bruder, and K. Bengler, "Effects of Dynamic Visual Stimuli on the Development of Carsickness in Real Driving," *IEEE Transactions on Intelligent Transportation Systems,* 2022.

[14] F. Diederichs *et al.*, "Improving driver performance and experience in assisted and automated driving with visual cues in the steering wheel," *IEEE Transactions on Intelligent Transportation Systems,* 2022.

[15] A. Feierle, F. Schlichtherle, and K. Bengler, "Augmented Reality Head-Up Display: A Visual Support During Malfunctions in Partially Automated Driving?," *IEEE Transactions on Intelligent Transportation Systems,* 2021.

[16] L. Rittger, D. Engelhardt, and R. Schwartz, "Adaptive User Experience in the Car-Levels of Adaptivity and Adaptive HMI Design," *IEEE Transactions on Intelligent Transportation Systems,* 2022.

[17] A. Ulahannan, S. Thompson, P. Jennings, and S. Birrell, "Using glance behaviour to inform the design of adaptive HMI for partially automated vehicles," *IEEE Transactions on Intelligent Transportation Systems,* 2021.