Challenges of Explainability, Cooperation, and External Communication of Automated Vehicles

Mark Colley[1], Enrico Rukzio[1]

[1]*Institute of Media Informatics, Ulm University, James-Franck-Ring 8, 89081 Ulm, Germany*

Abstract

In this position paper, we describe current research questions in the area of interaction with automated vehicles from the viewpoint of users within the vehicle (i.e., passengers) and from the viewpoint of parties outside the vehicle (e.g., other manual drivers or pedestrians). First, we briefly introduce the topics of *Cooperation with Automated Vehicles*, *External Communication of Automated Vehicles*, and *Explainability of Automated Vehicles* before posing, in total, nine research questions guiding these three areas.

Keywords

Automation, vehicles, eHMI, explainability, cooperation, HMI

1. Introduction

Automated vehicles (AVs) are expected to change journeys and, in general, traffic fundamentally [1]. Despite the numerous anticipated advantages (fewer accidents, more time for non-driving-related activities [2], reduced fuel usage), currently, there are two major research areas targeted towards the successful integration of AVs in the life of non-expert users (i.e., the passengers) and also the bystanders of AVs, that is other (vulnerable) road users that have no say in whether they want to interact with them such as pedestrians or bicyclists [3].

Regarding the passengers, current work can be (among other areas) broadly distinguished into take-overs [4, 5], cooperation to overcome system boundaries [6, 7, 8, 9], explainability of the AV's actions [10, 11, 12, 13, 14], and simulators to enable valid experiments [15, 16, 17].

Regarding bystanders, especially the (potential) need to replace current driver-road user communication via external Human-Machine Interfaces (eHMI) is investigated [18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32].

In this position paper and based on our work in these areas, we describe what we see as current challenges of AVs as highly automated systems that permanently interact with other road users and their primary intended users (i.e., the passengers).

---

2. Cooperation with Automated Vehicles

Figure 1: The user interface of the ORIAS system for cooperation in AVs; taken from [8].

.

Besides the classical take-over process [33, 5], cooperation has been suggested as a way to overcome both the shortcomings of today's technology, for example, in object recognition [6] or when integrated knowledge is necessary (e.g., legal requirements to parking somewhere). Such an approach will leverage the capabilities of automation and the integrated understanding of the user to enable safer and more pleasurable journeys. Here, the main question is:

1. *When is cooperation between an AV and a user possible, and which level of engagement has to be maintained during the monotonous part of the journey?*

While we presented first supportive work on this [8, 6, 34, 35] (see Figure 1), this area of research is still under-explored.

## 3. External Communication of Automated Vehicles

Recently, eHMIs have become a popular topic in the automotive domain [27]. External communication of AVs is researched to enable communication between AVs and other road users. This includes other manual drivers [36, 37] and vulnerable road users such as bicyclists or pedestrians. Numerous aspects have been investigated, including anthropomorphism [38], challenges of overtrust [39], various target groups such as children [40] or people with vision impairments [23]. However, in our opinion, several key questions remain:

2. *How can the aspect of scalability, that is, the communication of multiple AVs with multiple vulnerable road users, be solved?* [22]
3. *How can we as researchers include and aid people with disabilities, a group which is even more in danger in the heavy traffic of today's cities?* [20]

4. *What are the long-term effects of eHMIs?*
5. *How can eHMIs be visually pleasing and effectively integrated into the general concepts of automobile manufacturers?*
6. *Can eHMIs be useful for more than communication regarding the crossing decision?* (e.g., see [24, 41, 31, 32])
7. *Are eHMIs necessary or when are they necessary?* [42]

This field is especially interesting as people that are not instructed nor did they actively consent to using AVs in any way are involved in interacting with the AV. Therefore, this topic is one of the first to fully incorporate true novice users of automation.

4. Explainability of Automated Vehicles
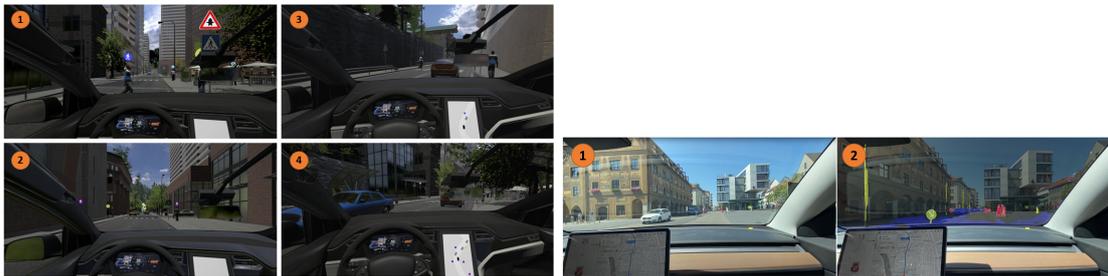
(a) Derived pedestrian intentions; taken from [10]. (b) Displayed semantic segmentation result; taken from [11].

Figure 2: Examples from previous publications regarding the visualization of detected objects and intentions.

Schoettle and Sivak [43] found that 75% of respondents were at least slightly concerned about a possible system failure in unexpected situations. Additionally, the reliability of AVs is a worry of users [44]. Therefore, numerous works have investigated potential visualization concepts to communicate with the user of an AV [45, 12, 14].

One primary rationale regarding the explainability of AVs is to enhance and calibrate trust. Hoff and Bashier defined trust as "a variable that often determines the willingness of human operators to rely on automation" [46, p. 407]. They proposed a three-layered trust model, including dispositional, situational, and learned trust. *Dispositional trust* refers to the trustor's personal background (e.g., culture, age, and personality traits). *Situational trust* is categorized into internal and external variability. External variability refers to alterations occurring with changed automation complexity. Internal variability describes the trustor's mental capacity and psychological state. *Learned trust* was modeled in two layers: initially learned trust, that is trust based on known information about the automation) and dynamically learned trust (which is altered via interaction with the automation).

Hereby, the approaches target either *initially learned trust* (see Körber et al. [47]) or *dynamically learned trust* (e.g., [10, 11, 14, 12]; see Figure 2). Nonetheless, some significant questions remain unanswered:

8. *What are the long-term effects of using AVs, and how will interaction change?*
9. *How can include and aid people with disabilities, for example, people with vision impairments?*

With our approaches, we especially target to enhance calibrated trust by including uncertainty information into the communication (e.g., see [11]).

5. Conclusion

In this work, we briefly outline the two major research areas on automotive automation interaction: with drivers and users or with other road users such as pedestrians. For the three areas *Cooperation with Automated Vehicles*, *External Communication of Automated Vehicles*, and *Explainability of Automated Vehicles*, we briefly describe the previous work and define, in our view, currently relevant research questions.

Acknowledgments

References

[1] D. J. Fagnant, K. Kockelman, Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations, Transportation Research Part A: Policy and Practice 77 (2015) 167–181.

[2] B. Pfleging, M. Rang, N. Broy, Investigating user needs for non-driving-related activities during automated driving, in: Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia, MUM '16, Association for Computing Machinery, New York, NY, USA, 2016, p. 91–99. URL: https://doi.org/10.1145/3012709.3012735. doi:10.1145/3012709.3012735.

[3] K. Holländer, M. Colley, E. Rukzio, A. Butz, A taxonomy of vulnerable road users for hci based on a systematic literature review, in: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA, 2021, pp. 1–13. URL: https://doi.org/10.1145/3411764.3445480.

[4] A. Eriksson, N. A. Stanton, Takeover time in highly automated vehicles: Noncritical transitions to and from manual control, Human Factors 59 (2017) 689–705. URL: https://doi.org/10.1177/0018720816685832. doi:10.1177/0018720816685832.

[5] M. Colley, L. Gruler, M. Woide, E. Rukzio, Investigating the design of information presentation in take-over requests in automated vehicles, in: Proceedings of the 23rd International

Conference on Mobile Human-Computer Interaction, Association for Computing Machinery, New York, NY, USA, 2021, pp. 1–15. URL: https://doi.org/10.1145/3447526.3472025.

[6] M. Walch, M. Colley, M. Weber, Cooperationcaptcha: On-the-fly object labeling for highly automated vehicles, in: Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems, CHI EA '19, Association for Computing Machinery, New York, NY, USA, 2019, p. 1–6. URL: https://doi.org/10.1145/3290607.3313022. doi:10.1145/3290607.3313022.

[7] M. Walch, D. Lehr, M. Colley, M. Weber, Don't you see them? towards gaze-based interaction adaptation for driver-vehicle cooperation, in: Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings, AutomotiveUI '19, Association for Computing Machinery, New York, NY, USA, 2019, p. 232–237. URL: https://doi.org/10.1145/3349263.3351338. doi:10.1145/3349263.3351338.

[8] M. Colley, A. Askari, M. Walch, M. Woide, E. Rukzio, Orias: On-the-fly object identification and action selection for highly automated vehicles, in: 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Association for Computing Machinery, New York, NY, USA, 2021, p. 79–89. URL: https://doi.org/10.1145/3409118.3475134.

[9] M. Walch, S. Li, I. Mandel, D. Goedicke, N. Friedman, W. Ju, Crosswalk cooperation: A phone-integrated driver-vehicle cooperation approach to predict the crossing intentions of pedestrians in automated driving, in: 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Association for Computing Machinery, New York, NY, USA, 2020, pp. 74–77.

[10] M. Colley, C. Bräuner, M. Lanzer, W. Marcel, M. Baumann, R. Rukzio, Effect of visualization of pedestrian intention recognition on trust and cognitive load, in: Proceedings of the 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '20, ACM, Association for Computing Machinery, New York, NY, USA, 2020, pp. 181–191. doi:10.1145/3409120.3410648.

[11] M. Colley, B. Eder, J. O. Rixen, E. Rukzio, Effects of semantic segmentation visualization on trust, situation awareness, and cognitive load in highly automated vehicles, in: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA, 2021, pp. 1–11. URL: https://doi.org/10.1145/3411764.3445351.

[12] M. Colley, S. Krauß, M. Lanzer, E. Rukzio, How should automated vehicles communicate critical situations? a comparative analysis of visualization concepts, Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 5 (2021). URL: https://doi.org/10.1145/3478111. doi:10.1145/3478111.

[13] M. Lanzer, T. Stoll, M. Colley, M. Baumann, Intelligent mobility in the city: the influence of system and context factors on drivers' takeover willingness and trust in automated vehicles, Frontiers in Human Dynamics (2021) 42.

[14] T. Schneider, J. Hois, A. Rosenstein, S. Ghellal, D. Theofanou-Fülbier, A. R. Gerlicher, Explain yourself! transparency for positive ux in autonomous driving, in: Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, CHI '21, Association for Computing Machinery, New York, NY, USA, 2021, pp. 1–12. URL: https://doi.org/10.

1145/3411764.3446647. doi:10.1145/3411764.3446647.

[15] M. Colley, P. Jansen, E. Rukzio, J. Gugenheimer, Swivr-car-seat: Exploring vehicle motion effects on interaction quality in virtual reality automated driving using a motorized swivel seat, Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 5 (2022). URL: https://doi.org/10.1145/3494968. doi:10.1145/3494968.

[16] D. Goedicke, J. Li, V. Evers, W. Ju, Vr-oom: Virtual reality on-road driving simulation, in: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA, 2018, p. 1–11. URL: https://doi.org/10.1145/3173574.3173739.

[17] D. Goedicke, A. W. Bremers, H. Yasuda, W. Ju, Xr-oom: Mixing virtual driving simulation with real cars and environments safely, in: 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Association for Computing Machinery, New York, NY, USA, 2021, p. 67–70. URL: https://doi.org/10.1145/3473682.3480266.

[18] M. Colley, R. Rukzio, A design space for external communication of autonomous vehicles, in: Proceedings of the 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '20, ACM, Association for Computing Machinery, New York, NY, USA, 2020, pp. 212–222. doi:10.1145/3409120.3410646.

[19] A. Colley, J. Häkkilä, M.-T. Forsman, B. Pfleging, F. Alt, Car exterior surface displays: Exploration in a real-world context, in: Proceedings of the 7th ACM International Symposium on Pervasive Displays, PerDis '18, Association for Computing Machinery, New York, NY, USA, 2018, pp. 1–8. URL: https://doi.org/10.1145/3205873.3205880. doi:10.1145/3205873.3205880.

[20] M. Colley, M. Walch, J. Gugenheimer, E. Rukzio, Including people with impairments from the start: External communication of autonomous vehicles, in: Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings, AutomotiveUI '19, Association for Computing Machinery, New York, NY, USA, 2019, p. 307–314. URL: https://doi.org/10.1145/3349263.3351521. doi:10.1145/3349263.3351521.

[21] M. Colley, S. C. Mytilineos, M. Walch, J. Gugenheimer, E. Rukzio, Evaluating highly automated trucks as signaling lights, in: Proceedings of the 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '20, ACM, Association for Computing Machinery, New York, NY, USA, 2020, p. 111–121. doi:10.1145/3409120.3410647.

[22] M. Colley, M. Walch, R. Rukzio, Unveiling the lack of scalability in research on external communication of autonomous vehicles, in: Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, CHI '20, ACM, Association for Computing Machinery, New York, NY, USA, 2020, p. 1–9. URL: http://dx.doi.org/10.1145/3334480.3382865. doi:10.1145/3334480.3382865.

[23] M. Colley, M. Walch, J. Gugenheimer, A. Askari, E. Rukzio, Towards inclusive external communication of autonomous vehicles for pedestrians with vision impairments, in: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, CHI '20, Association for Computing Machinery, New York, NY, USA, 2020, p. 1–14. URL: https://doi.org/10.1145/3313831.3376472. doi:10.1145/3313831.3376472.

[24] M. Colley, J. H. Belz, E. Rukzio, Investigating the effects of feedback communication of

autonomous vehicles, in: 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Association for Computing Machinery, New York, NY, USA, 2021, p. 263–273. URL: https://doi.org/10.1145/3409118.3475133.

[25] M. Colley, R. Rukzio, Towards a design space for external communication of autonomous vehicles, in: Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, CHI '20, ACM, Association for Computing Machinery, New York, NY, USA, 2020, pp. 1–8. URL: http://dx.doi.org/10.1145/3334480.3382844. doi:10.1145/3334480.3382844.

[26] M. Colley, M. Walch, E. Rukzio, For a better (simulated) world: Considerations for vr in external communication research, in: Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings, AutomotiveUI '19, Association for Computing Machinery, New York, NY, USA, 2019, p. 442–449. URL: https://doi.org/10.1145/3349263.3351523. doi:10.1145/3349263.3351523.

[27] D. Dey, A. Habibovic, A. Löcken, P. Wintersberger, B. Pfleging, A. Riener, M. Martens, J. Terken, Taming the ehmi jungle: A classification taxonomy to guide, compare, and assess the design principles of automated vehicles' external human-machine interfaces, Transportation Research Interdisciplinary Perspectives 7 (2020) 100174.

[28] M. Colley, E. Bajrovic, R. Rukzio, Effects of pedestrian behavior, time pressure, and repeated exposure on crossing decisions in front of automated vehicles equipped with external communication, in: Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, CHI '22, Association for Computing Machinery, New York, NY, USA, 2022. URL: https://doi.org/10.1145/3491102.3517571. doi:10.1145/3491102.3517571.

[29] M. Lanzer, F. Babel, F. Yan, B. Zhang, F. You, J. Wang, M. Baumann, Designing communication strategies of autonomous vehicles with pedestrians: An intercultural study, in: 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '20, Association for Computing Machinery, New York, NY, USA, 2020, p. 122–131. URL: https://doi.org/10.1145/3409120.3410653. doi:10.1145/3409120.3410653.

[30] M. Colley, M. Lanzer, J. H. Belz, M. Walch, E. Rukzio, Evaluating the impact of decals on driver stereotype perception and exploration of personalization of automated vehicles via digital decals, in: 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Association for Computing Machinery, New York, NY, USA, 2021, p. 296–306. URL: https://doi.org/10.1145/3409118.3475132.

[31] M. Colley, S. Li, E. Rukzio, Increasing pedestrian safety using external communication of autonomous vehicles for signalling hazards, in: Proceedings of the 23rd International Conference on Mobile Human-Computer Interaction, Association for Computing Machinery, New York, NY, USA, 2021, pp. 1–10. URL: https://doi.org/10.1145/3447526.3472024.

[32] M. Colley, S. Mytilineos, M. Walch, J. Gugenheimer, E. Rukzio, Requirements for the interaction with highly automated construction site delivery trucks, Frontiers in Human Dynamics 4 (2022). URL: https://www.frontiersin.org/article/10.3389/fhumd.2022.794890. doi:10.3389/fhumd.2022.794890.

[33] M. Walch, K. Lange, M. Baumann, M. Weber, Autonomous driving: Investigating the feasibility of car-driver handover assistance, in: Proceedings of the 7th International

Conference on Automotive User Interfaces and Interactive Vehicular Applications, Automotive UI '15, Association for Computing Machinery, New York, NY, USA, 2015, p. 11–18. URL: https://doi.org/10.1145/2799250.2799268. doi:10.1145/2799250.2799268.

[34] M. Woide, D. Stiegemeier, S. Pfattheicher, M. Baumann, Measuring driver-vehicle cooperation: development and validation of the human-machine-interaction-interdependence questionnaire (hmii), Transportation research part F: traffic psychology and behaviour 83 (2021) 424–439.

[35] M. Walch, M. Colley, M. Weber, Driving-task-related human-machine interaction in automated driving: Towards a bigger picture, in: Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings, AutomotiveUI '19, Association for Computing Machinery, New York, NY, USA, 2019, p. 427–433. URL: https://doi.org/10.1145/3349263.3351527. doi:10.1145/3349263.3351527.

[36] M. Rettenmaier, M. Pietsch, J. Schmidtler, K. Bengler, Passing through the bottleneck-the potential of external human-machine interfaces, in: 2019 IEEE Intelligent Vehicles Symposium (IV), IEEE, IEEE, New York, NY, USA, 2019, pp. 1687–1692.

[37] M. Rettenmaier, J. Schulze, K. Bengler, How much space is required? effect of distance, content, and color on external human–machine interface size, Information 11 (2020) 346.

[38] C.-M. Chang, K. Toda, D. Sakamoto, T. Igarashi, Eyes on a car: An interface design for communication between an autonomous car and a pedestrian, in: Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '17, Association for Computing Machinery, New York, NY, USA, 2017, p. 65–73. URL: https://doi.org/10.1145/3122986.3122989. doi:10.1145/3122986.3122989.

[39] K. Holländer, P. Wintersberger, A. Butz, Overtrust in external cues of automated vehicles: An experimental investigation, in: Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '19, Association for Computing Machinery, New York, NY, USA, 2019, p. 211–221. URL: https://doi.org/10.1145/3342197.3344528. doi:10.1145/3342197.3344528.

[40] V. Charisi, A. Habibovic, J. Andersson, J. Li, V. Evers, Children's views on identification and intention communication of self-driving vehicles, in: Proceedings of the 2017 Conference on Interaction Design and Children, IDC '17, Association for Computing Machinery, New York, NY, USA, 2017, p. 399–404. URL: https://doi.org/10.1145/3078072.3084300. doi:10.1145/3078072.3084300.

[41] M. Colley, M. Walch, E. Rukzio, Towards reducing energy waste through usage of external communication of autonomous vehicles, 2020.

[42] D. Moore, R. Currano, G. E. Strack, D. Sirkin, The case for implicit external human-machine interfaces for autonomous vehicles, in: Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI '19, Association for Computing Machinery, New York, NY, USA, 2019, p. 295–307. URL: https://doi.org/10.1145/3342197.3345320. doi:10.1145/3342197.3345320.

[43] B. Schoettle, M. Sivak, A survey of public opinion about autonomous and self-driving vehicles in the US, the UK, and Australia, Technical Report, University of Michigan, Ann Arbor, Transportation Research Institute, 2014.

[44] M. Kyriakidis, R. Happee, J. C. de Winter, Public opinion on automated driving: Results of

an international questionnaire among 5000 respondents, Transportation research part F: traffic psychology and behaviour 32 (2015) 127–140.

[45] S. R. Winter, S. Rice, N. K. Ragbir, B. S. Baugh, M. N. Milner, B.-L. Lim, J. Capps, E. Anania, Assessing pedestrians' perceptions and willingness to interact with autonomous vehicles, Technical Report, US Department of Transportation. Center for Advanced Transportation Mobility . . . , 2019.

[46] K. A. Hoff, M. Bashir, Trust in automation: Integrating empirical evidence on factors that influence trust, Human factors 57 (2015) 407–434.

[47] M. Körber, E. Baseler, K. Bengler, Introduction matters: Manipulating trust in automation and reliance in automated driving, Applied ergonomics 66 (2018) 18–31.