Designing the Interaction of Highly Automated Vehicles with Cyclists in Urban Longitudinal Traffic

Relevant Use Cases and Methodical Considerations

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ABSTRACT

In future urban traffic, highly automated vehicles (HAVs) will have to successfully interact with vulnerable road users, such as pedestrians and cyclists. While the interaction of HAVs with crossing pedestrians is already well studied, HAV interaction concepts for the encounters with cyclists are yet to be explored. We present a project that focuses on the user-centered design of HAV driving maneuvers for interactions with cyclists travelling upfront and in the same direction in urban longitudinal traffic. This work introduces the use cases and the methodical approach to explore current cyclist-vehicle interactions in a real life setting. With this approach, we aim to derive implications for the design of future HAV interaction behavior.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); HCI design and evaluation methods; User studies; Interaction design; Empirical studies in interaction design.

KEYWORDS

highly automated vehicle, cyclist, vehicle-cyclist-interaction, external communication, user-centered design

ACM Reference Format:

Nicole Fritz, Fanny Kobiela, Dietrich Manstetten, Andreas Korthauer, and Klaus Bengler. 2020. Designing the Interaction of Highly Automated Vehicles with Cyclists in Urban Longitudinal Traffic: Relevant Use Cases and Methodical Considerations. In *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '20 Adjunct), September 21, 22, 2020, Virtual Event, DC, USA.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3409251.3411710

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AutomotiveUI '20 Adjunct, September 21, 22, 2020, Virtual Event, DC, USA

ACM ISBN 978-1-4503-8066-9/20/09.
https://doi.org/10.1145/3409251.3411710

1 INTRODUCTION

In urban areas, different types of road users share the same infrastructure for their daily trips. As a natural consequence 'space-sharing conflicts' [1, p.9] occur, when several road users are about to simultaneously occupy the same road section in the future [1]. Human road users dissolve such conflicts by adapting their behavior to each other – they interact [1]. Unfortunately, not all traffic interactions proceed smoothly. In particular, collisions of motorized vehicles with vulnerable road users (VRUs), such as pedestrians and cyclists, can have fatal consequences [2]. Highly automated vehicles (HAVs; i.e. SAE level 4 [3]) have the potential to increase traffic safety and efficiency by reducing human error [4] and have recently been discussed to be introduced into urban traffic. However, to successfully master mixed traffic encounters, HAVs will have to understand and apply the relevant – and sometimes subtle – communication cues of human-human traffic interaction [5]. Different types of human machine interfaces could be added to the HAV to design a successful strategy for the interaction with other road users. Their selection should be based on the capabilities of the automation system as well as on the static and dynamic infrastructure of a given scene, including the type of road user that is addressed [6]. Previous studies in the field of HAV-VRU interaction explored different HAV communication means, ranging from implicit signaling via the vehicle dynamics (e.g., [7, 8]) to explicit communication via additional external interfaces (e.g., [9, 10]). However, they focused almost exclusively on pedestrian crossing scenarios.

Only few studies investigated HAV-VRU interaction focusing on cyclists as the target group [11, 12]. A recent simulation study [12] explored the benefits of different types of interfaces in HAV-cyclist lane merging scenarios. The authors noted that similar interfaces had different efficacies for cyclists comparing their results to findings from a previous study focusing on pedestrian crossing scenarios [12]. Therefore, the proposed design solutions from pedestrian crossing scenarios may not be applicable for HAV-cyclist interactions other than crossing paths. Further research is necessary to

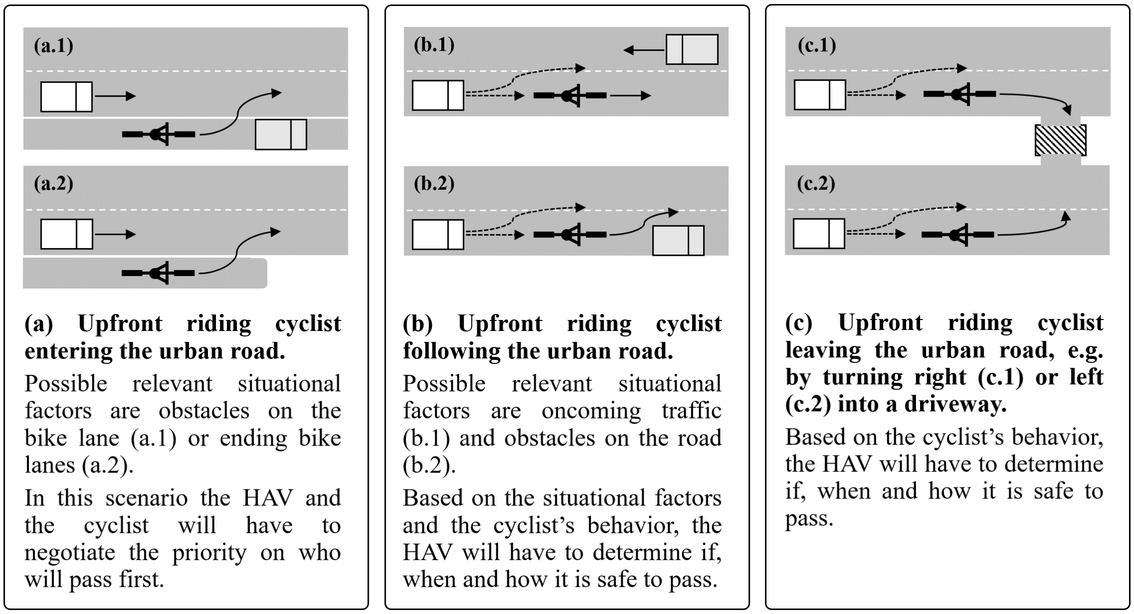

Figure 1: Examples of relevant use cases and situational factors for the interaction between an HAV and an upfront riding cyclist in longitudinal traffic.

determine how HAVs should behave in dynamic situations around cyclists.

2 USE CASES

In the city of the future, HAVs on urban roads will have to interact with cyclists travelling in the same direction in various situations. Designing such interactions is challenging. Due to the relatively high velocities in longitudinal traffic as compared to cross traffic at intersections, interactions play out in a short time frame, requiring fast decision-making and reactions by human road users (see also [12]). Furthermore, the cyclist's behavior in a given situation is expected to vary widely across the heterogeneous group. Cyclists differ on multiple dimensions, such as frequency of bicycle use or road rule violations among other factors (e.g., [13]). Therefore, the HAV will encounter cyclists with different experiences and skill levels on a variety of bicycle types. It can be expected that such factors will have a considerable effect on the cyclist's decision-making behavior in a given situation. Hence, the HAV will have to interpret a variety of cyclist behavior and to adjust its interaction strategy based on that.

We argue that the design of interactions with a cyclist riding upfront the HAV is especially challenging for additional reasons: (1) The cyclist's ability to check whether a conventional car or an HAV approaches from behind is very limited. Cyclists can retrieve such information only via short shoulder glances. External interfaces communicating the HAV's automation status or intent, which are currently discussed for crossing scenarios, are of limited value in this case. Consequently, we believe that it is vital to design the HAV's driving behavior such that it meets the cyclist's expectations of how such situations are resolved. At the same time, the HAV should avoid frequent mistakes made by human drivers, such as not adjusting their speed accordingly during an overtaking maneuver [14]. (2) The cyclist's behavior can change quickly based on dynamic situational changes in urban traffic, such as obstacles appearing on the road section ahead. The HAV will have to continuously adapt its interaction behavior accordingly. Hereto, the HAV will have to interpret the cyclist's behavioral cues to show suitable behavior regarding if, when and how to pass.

We propose a number of relevant use cases to be considered during the process of designing HAV-upfront riding cyclist interactions. They can be categorized into interactions while the cyclist is (a) entering the urban road, (b) following the urban road, or (c) leaving the urban road. Examples for the use cases and potential situational factors influencing the HAV-cyclist interactions are displayed in Figure 1.

3 METHODICAL CONSIDERATIONS AND NEXT STEPS

As a first step in the project, an exploratory study will be conducted to investigate the cyclist's perspective on the development of HAV driving maneuvers. In the study, we aim to assess natural cyclist interaction and communication behavior during encounters with a vehicle approaching from behind. We argue that this should be explored in a real life setting rather than in a simulated environment to achieve higher ecological validity, especially on the degree of the observed kinematic behavior [15].

Another major decision, aside from the study environment, is the appropriate amount of experimental control when aiming to investigate natural behavior. Several methods could be applied to investigate cyclist interaction behavior in a real life setting with different advantages and disadvantages regarding the validity of the observed behavior, the study complexity and the data quality. Traffic observation via video cameras is a frequently used method to investigate human interaction behavior in a natural setting (e.g., [16, 17]). It allows recording interactive behavior while creating minimal artifacts due to (lack of) experimental interventions. However, the observed interactions may vary tremendously due to situational differences such as the presence of other road users. Therefore, it can be difficult to collect an adequate sample of similar situations that can be compared to identify relevant behavioral cues. Additionally, behavioral data from the observed VRUs can only be inferred from the video data without the access to kinematic data. Further, no personal information of the observed road users other than their appearance can be obtained.

Quasi-naturalistic cycling studies are an alternative method to observe a sample of cyclists riding along a predefined route in real traffic. Such studies allow experimental intervention in a natural setting to a certain extent. At the same time, kinematic data can be recorded via instruments mounted to the bicycle in addition to video recordings of the scene. The method further allows for the collection of personal information of the participants and was already successfully applied to investigate cyclist behavior during overtaking maneuvers [18]. However, due to the lack of experimental control in the natural setting there may still be situational variance complicating the identification of relevant behavioral cues. Additionally, it may be difficult to observe all relevant details of vehicle-cyclist interactions without the extensive measurement equipment available on a test-track. Last but not least, scripting interactions in real traffic could be a safety hazard for participants or other road users.

That is why the exploratory study in this project will be realized as a test-track experiment. Applying this method, we will be able to produce similar and reproducible interactions and to control situational variability to a high extent while ensuring that the cyclist's safety is guaranteed at any time. Further, we will be able to measure the cyclist's behavior very precisely using a variety of different instruments and to record additional personal information. Since the situations will be simple and controlled, we will be able to capture the variance of cyclist behavior that is related to the interaction with the approaching vehicle.

During the experiment, the participants will be provided with an instrumented pedelec recording their position and riding dynamics as well as video data of their behavior. Furthermore, their gaze behavior will be recorded using eye-tracking glasses. They will be told to participate in a study to improve the pedelec's drive system. The participants will be instructed to ride along a predefined 500 m circuit for several times at constant speed and to behave naturally as they would in real traffic. Along the route, they will have to perform a lane merging maneuver, evade a static obstacle on the road and turn left into a driveway. During some of the situations, an instrumented vehicle driven by a confederate at constant and slightly faster speed will follow the participants. The position and driving dynamics of the vehicle will be obtained as well. At the end of the experiment, the participants will be informed that the study focuses on interaction behavior during vehicle–cyclist encounters. To account for the fact that cyclists are a heterogeneous group, cyclists with various backgrounds (e.g., cycling frequency, type of bicycle usually used, etc.) will be recruited to participate in the study and the effect of personal characteristics on the observed cycling behavior will be analyzed.

The results of the exploratory study will be used to identify relevant behavioral cues and communication signals by cyclists that HAVs should be able to sense and interpret. The results of the study will then be used to derive a first set of HAV driving maneuvers to be further tested and improved in subsequent user studies.

4 CONCLUSION AND IMPLICATIONS FOR THE RESEARCH COMMUNITY

In this work, we highlighted the importance of investigating HAV-cyclist interactions for a broader understanding of HAV-VRU interactions. We introduced a research project focusing on the investigation of cyclist-vehicle interactions in urban longitudinal traffic, with the aim to derive implications for the user-centered design of HAV driving maneuvers. We further argued that test track studies are an adequate method to explore cyclist-vehicle interactions in a controlled and simplified setting. During the poster presentation, we will share our experience on planning and conducting the experimental study and discuss important considerations and first findings with the research community.

ACKNOWLEDGMENTS

The German Federal Ministry for Economic Affairs and Energy funded this research within the project '@City: Automated Cars and Intelligent Traffic in the City' (grant number: 19A18003D).

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