



Manually Driven Vehicle Encounters with Autonomous Vehicle in Bottleneck Roads: HMI Design for Communication Issues

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ABSTRACT

Human drivers (HDs) need to negotiate the right-of-way when they encounter in bottleneck roads. Since driver-less autonomous vehicles (AVs) in the foreseeable future will lead to mixed traffic, the communication between AV and HD may become more difficult than the two HDs communication. How to make an effective communication method to convey the intention of AV to HD is an unsolved problem. In this study, we investigate the usefulness of three HMI-based communication methods from the viewpoint of HDs, i.e., the internal HMI (iHMI) based on vehicle-to-vehicle communications on head-up display in manually driven vehicle, the external HMI (eHMI) on AV, as well as using both of them synchronously. Participants, as the HDs, experienced these three HMIs through videos on the online-survey and performed subjective evaluations. We found that although there were no significant differences in the subjective evaluation results of participants for the three HMIs, iHMI gave better evaluations of understanding, safety, and stress, while eHMI had the lowest evaluation of trust.

CCS CONCEPTS

• **Human-centered computing** → **HCI design and evaluation methods**; *Empirical studies in interaction design*.

KEYWORDS

Bottleneck road; Autonomous vehicle; Communication method; HMI concepts

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Figure 1: AV and MV encounter in a bottleneck road.

1 INTRODUCTION

Bottleneck roads are characterized by an unclear right-of-way [5] and always lead to congestion and traffic jam in urban environment [15]. A typical scenario for bottleneck road is a double parking street, which means two vehicles reach the bottleneck on narrow roads with parking cars on both sides simultaneously (see Fig. 1). Human drivers (HDs) need to negotiate the right-of-way by both explicit and implicit communication when they encounter each other in this scenario. Communication methods provide a clear and consensual decision / intention among the road users in manual-driven traffic environment. While implicit communication conveys the information about the status of the vehicle, the explicit communication could provide intention and suggestion from the HD directly. The explicit information from drivers, e.g., hand gestures and head nod, could express clear suggestions to the other road users of yielding or not, while implicit information such as deceleration only conveys the vehicle's status and driver's intention [8]. Previous studies [2, 16] showed that it is uneasy for pedestrians to communicate with a driver when losing the the explicit communication from them. Since the implementation of driver-less autonomous vehicles (AV) leads to a mixed traffic environment in urban areas, the established traffic may face new challenges with respect to human drivers' feeling of safety, traffic efficiency and frequent communication when manually drivern vehicles (MVs) encounter AVs.

The following issues with respect to their interactions should be considered: 1) Ambiguous implicit communication. In low-speed



Figure 2: A video of AV-MV encountering in a bottleneck road is used in the online survey. Three types of HMI are used for AV-HD communication. The blue cylinders on both sides of the road simulate two parking cars.

driving scenarios, it is difficult for HDs to convey an intention from an AV because the dynamic movement is not obvious [12].

2) Lack of explicit communication methods. Since drivers are not involved in AV driving tasks, loss of hand gestures and head nods can make it difficult for HD to recognize AV intention [9, 14, 17].

3) These issues may lead to the HDs hesitant make decisions [10] due to insufficient understanding, bad feeling of safety [7] and distrust [4] in communicating to the AV, which may decrease the AV acceptance.

Prior studies provided some potential solutions including motion setting recommendations to AV [6], and new eHMIs-based communication methods [3, 14]. Rettenmaier et.al. illustrated that eHMI can reduce the passing time significantly when two vehicles pass through the bottleneck [15]. However, compared to AV-VRU communication research, the communication between AV and HD has not received enough focus yet.

In this study, we focused on the HMI design for the communication between AV and HD in bottleneck roads. Compared to pedestrians, HD can receive the traffic information through vehicle to vehicle (V2V) technology, which provides other communicative possibility. Head-up display in MV could be utilized to show the communication information from AV. No literature has elaborated whether iHMI in MV or eHMI on AV is more helpful for AV-HD communication so far. In our study, three types of HMI-based communication methods i. e., iHMI, eHMI as well as using both of them synchronously were proposed and then evaluated by subjective evaluations to find the appropriate type of HMI in AV-HD communication. This study aims to explore if iHMI as a potential HMI-based communication method is more efficient than eHMI, and further could help improve the acceptability of AV and promote its popularity.

2 EXPERIMENT

Based on the analysis of existing issues, three HMIs: V2V-based iHMI on MV, eHMI on AV and iHMI+eHMI on both MV and AV were proposed to explore which type of HMI is more helpful to AV-HD communication, in order to find an appropriate AV-HD communication method. An online survey was designed for evaluating these three HMIs by participants' subjective report. 50 participants (42 males and 8 females) within the age range of 24–51 (mean: 30.48, standard deviation: 4.29) were invited to the questionnaire. Every participant has the driving license.

2.1 HMI-based communication methods

Three types of HMI (see Fig. 2) were used to compare which communication method has a better communication perception for HD when encounter with an oncoming AV in bottleneck roads. The V2V-based iHMI displays on the HUD of the MV with a green arrow (see Fig. 2 a) while the eHMI displays on the bumper of the oncoming AV with a green dot (see Fig. 2 b). Besides the eHMI and iHMI mentioned above, a combined HMI with both eHMI and iHMI (see Fig. 2 c) was used to see if multiple information could have a better subjective evaluation or if it is considered redundant information by HD. All the three HMIs mean “the oncoming AV is yielding to you”.

2.2 Online survey

A within-group design experiment was used to evaluate the AV-HD communication via the iHMI, eHMI and iHMI+eHMI.

Firstly we used the demonstration videos from the viewpoint of HD recorded by Imbsweiler et al. in 2018¹ as an example to demonstrate the double parking street and help the participants recall their experience and immerse themselves in this driving scenario. The video started once the oncoming vehicle appeared on the right corner, two vehicles approached the bottleneck with the speed around 15-20km/h and then stopped before the bottleneck. Based on this video, we added three types of HMI through the video editing. Then the videos with different HMIs displayed to the participants randomly to avoid the study effect. Before showing the videos with HMI, we first provided the figures (shown as the grey rectangles in Fig2) with the specific explanation of each HMI including the meaning of the elements and the location of the HMIs i. e., iHMI on HUD in MV, eHMI on the bumper of AV to the participants. Guaranteeing they do the subjective evaluations without confusion, only focus on comparing the types of HMI.

After showing each video with different HMIs, eight evaluation items were used for helping the participants to answer the question “How do you think the communication between you and the oncoming vehicle”? A 7-point Likert scale (i. e., 1 “strongly disagree”, 2 “disagree”, 3 “somewhat disagree”, 4 “neutral”, 5 “somewhat agree”, 6 “agree”, 7 “strongly agree”) was used for evaluating these eight evaluation items. These eight evaluation items are:

- 1: The communication is adequate.
- 2: The communication is clear.
- 3: The communication is effective.

¹https://www.ifab.kit.edu/1516_2403.php

- 4: I trust the oncoming vehicle to make appropriate actions.
- 5: I trust the oncoming vehicle more because it communicates.
- 6: I trust the oncoming vehicle more than a human driver.
- 7: I feel safe in this situation.
- 8: I feel stressed in this situation.

Note that the evaluation items 1-7 are in line with [13]. These evaluation items provided feedback on how the three types of HMI were perceived and how it changed the way that the participants interacted with the AV. Specifically, the evaluation items 1-3 were used to evaluate the understanding information displayed by HMIs. The evaluation items 4-6 were used to evaluate the trust in the AV while item 7 was used to evaluate the feeling of safety. In addition, considering stress can reduce human cognitive efficiency [11], participants would feel frustrated and nervous when they were stressful [1], we also designed the evaluation item 8 to evaluate the driver's stress feeling in this situation.

2.3 Results

The results of the subjective evaluations informed that the 62% of the participants gave positive scores (including 5 “somewhat agree”, 6 “agree”, 7 “strongly agree”) in the 1-3 evaluation items (i. e., the communication was adequate, clear and efficient) of the iHMI, which had the highest understanding level among the three HMIs. The positive score of the evaluation items 4 (60%) and 5 (54%) for the iHMI+eHMI were similar to those for the iHMI in both items. Besides, in the evaluation item 6, the positive score for the iHMI+eHMI (54%) was the highest. The eHMI in the items 4-6 had the lowest positive score (46%, 50%, 36%) compared to the iHMI and the iHMI+eHMI. In addition, the eHMI had a large number of neutral (evaluation item 4-6: 32%, 26%, 20%) compared to the other two HMIs, which might be due to the eHMI making the participants confused in the communication perception. The result of item 4-5 illustrated that the HD trusted in the iHMI and the iHMI+eHMI was close while they trust the eHMI less. Further, the evaluation item 6 showed that the 70% of the participants agreed that the iHMI brought a feeling of safety which had the highest positive score among HMIs. The negative scores (including 1 “strongly disagree”, 2 “disagree”, 3 “somewhat disagree”) of stress for the eHMI was highest (42%), which illustrated that the eHMI brought the highest stress in AV-HD communication compared to the other HMIs.

In order to test if the three types of communication method have a significant difference in the results of the eight evaluation items, ANOVA via Kruskal-Wallis H test (two-sided) was used for estimating the corresponding statistical significance. From the results, there was no significant difference among the three HMIs evaluated by the following: evaluation item 1 ($H=1.067$, $p=0.448$), evaluation item 2 ($H=2.682$, $p=0.262$), evaluation item 3 ($H=3.352$, $p=0.187$), evaluation item 4 ($H=0.856$, $p=0.652$), evaluation item 5 ($H=0.322$, $p=0.851$), evaluation item 6 ($H=1.687$, $p=0.430$), evaluation item 7 ($H=2.069$, $p=0.355$) and evaluation item 8 ($H=0.148$, $p=0.929$) as well.

2.4 Discussion

The above results indicated that the iHMI had higher positive scores in understanding, feeling of safety and stress while the eHMI had the lowest evaluation of trust compared to the other types of HMI.

From the ANOVA via Kruskal-Wallis H test results, we found that there was no significant difference among the iHMI, eHMI and iHMI+eHMI in the items of subjective evaluation, thus, the pairwise comparison was not be used in this test. It may be because the demonstration video with the bottleneck road scenario on the online survey was not as complex as the real traffic environment which had more other road users and potential emergencies. In this case the HMI communication method may not be necessary.

3 CONCLUSION AND FUTURE WORKS

In this paper, we preliminarily discussed the communication methods between the HD of the MV and the AV for negotiation in a bottleneck road. An online survey with demonstration videos was used to ask participants subjectively evaluate the three communication methods, i. e., the iHMI, eHMI and iHMI+eHMI, by eight evaluation items. We found that although there were no significant differences in the subjective evaluation results of participants for the three HMIs, iHMI still gave slightly better evaluations of understanding, safety, and stress, while eHMI showed the lowest evaluation of trust.

In the future study, iteration of the HMIs will be proposed based on user experience test. We will still focus on the effectiveness of different types of HMI for the AV-HD communication in the unclear right-of-way driving scenario. Not only focus on simple situations the bottleneck road, but also in more complex situations, such as encounter with different sizes of vehicle, and the scenario with obscured view (with other vehicles in front of AV) versus with non-obscured view. Furthermore, considering the participants' behavior gap, which means the participants do not have a unified answers between subjective and objective evaluations, quantitative experiment on a driving simulator to obtain objective data is under planning.

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