HMI-based Communication Methods for Negotiation between a Manually Driven Vehicle Driver and an Autonomous Vehicle in an Ambiguous Traffic Scenario

Yang Li[1], Hailong Liu[2], and Barbara Deml[1]

Abstract— **Autonomous vehicles (AV) are considered to be applicable in a predictable future, especially in urban areas. Generally, two human drivers in manually driving vehicles (MVs) can negotiate the right-of-way through communications when they encounter in ambiguous traffic scenarios, e. g., equal narrow passage with an obstacle on each side. However, a human driver may face some communication issues when he/she needs to negotiate with a driver-less AV. To convey the intention of AV to MV drivers, a highly comprehensible communication strategy is necessary. This work proposed three types of HMI: a) internal HMI (iHMI) based on vehicle-to-vehicle communications; b) external HMI (eHMI) on AV and c) using both of them synchronously (iHM+eHMI). Participants experienced three HMIs through online survey videos and performed subjective evaluations. We found that the iHMI was significantly more effective for the communication between AV-MV driver than the eHMI and iHM+eHMI. Besides, although there were no significant differences among the three HMIs in the other subjective evaluation items, iHMI provided better evaluations of understanding, safety, and stress, while eHMI had the lowest evaluation of trust.**

I. INTRODUCTION

In the European Union, approximately 19.5% of the fatalities happened at junctions in 2016 [1]. Especially in some ambiguous traffic scenarios which are characterized by unclear right-of-way i. e., intersections, T-junctions without traffic lights and equal narrow passages with an obstacle on each side. Moreover, ambiguous traffic scenarios will cause traffic congestion and reduce traffic smoothness [2]. For above issues, several studies showed that communication was a critical method for road users to negotiate the right-of-way in these ambiguous traffic scenarios [3], [4].

Human drivers in manually driving vehicles (MVs) communicate with each other by using implicit and explicit communication methods, which could provide clear and consensual decisions and intentions. While implicit communication i. e., dynamic motion of vehicle, conveys the information about the state of the vehicle, the explicit communication e. g., hand gesture and eye contact, conveys the intentions and suggestions from the MV driver directly. Besides, the explicit communication methods also include signals from car lights regulated by law and highly standardized [5], such as turn signal blinkers and brake lights.

[1]Yang Li and Barbara Deml are with the ifab-Institute of Human and Industrial Engineering, Karlsruhe Institute of Technology, Engler-Bunte-Ring 4, Karlsruhe, Germany. {yang.li, barbara.deml}@kit.edu

[2]Hailong Liu is with Graduate School of Science and Technology, Nara Institute of Science and Technology, 8916-5 Takayama-cho, Ikoma, Nara 630-0192, Japan. liu.hailong@is.naist.jp

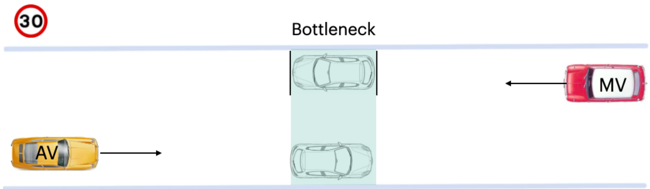

Fig. 1: AV and MV encounter in an equal narrow passage.

Nowadays, with the popularity of AVs, we are facing a mixture traffic climate consisting of AVs, MVs, pedestrians, cyclists, motorcycle riders, and automatic delivery cars *etc*. It means that human road users must interact not only with other human road users, but also with the devices with autonomous systems i. e., autonomous vehicles (AVs). Established traffic may face new challenges with respect to road users' feeling of safety, traffic efficiency and frequent communications when the road users encounter AVs. In the case of AV, only the implicit communication mimicking the dynamic motion from the MV [6], [7] may not be sufficient to build an understandable and reliable communication method between AV and MV drivers. Therefore, a novel extra explicit communication strategy is needed to compensate for the lack of human drivers in AV.

Imbsweiler et al. [8] and Rettenmaier et al. [9] did traffic observation studies of two vehicles encounter at an equal narrow passage. They provided some recommendations on how AV might communicate implicitly by adopting the communication processes. Both of the above studies showed that an external human-machine interface (eHMI) can significantly reduce the passing time when two vehicles pass through the bottleneck. Rettenmaier et al. [10] reported that timely communication could lead to a better impression of the AV and more efficient traffic flow compared to later start communication in bottleneck roads.

Besides, many studies focused on the communication strategies of AVs to vulnerable road users (VRU) e. g., AV-pedestrian communication, in order to find motion setting recommendations to AVs [11], and provided new eHMIs-based communication methods [12]. In comparison with the AV-VRU communication, the communication between the AV and MV driver has not yet received sufficient focus.

In this paper, we focused on the AV-MV driver communication in equal narrow passage. Compared to pedestrians, MV drivers can receive the traffic information via vehicle-to-vehicle communication systems (V2V), which provides another communicability for the MV driver to obtain communication information from the AV by using internal human-machine interfaces (iHMIs) in the MV.Some studies provided eHMI designs for AV-MV driver communication [13]. However, there is no study elaborated on whether iHMI in MV or eHMI on AV is more helpful for AV-MV driver communication. In our study, in order to find an appropriate type of HMIs in AV-MV driver communication, three types of HMI-based communication methods were proposed and evaluated by subjective evaluations. Through this study, we hope to explore new HMI designs except for eHMI on AV, but iHMI in MV based on V2V technology can also improve AV acceptability and promote its popularity.

A preliminary result of this study was reported in [14] as a poster. Based on it, we further analyzed the experimental results in this paper. Moreover, the correlations among subjective evaluation items were further examined.

II. BACKGROUND

A. Equal narrow passage

Equal narrow passage is characterized by an unclear right-of-way and located mostly in 30km/h speed limit zones in urban area. [8]. A typical scenario for the equal narrow passage is double-parked street, which means two vehicles reach the bottleneck on the narrow road with parking cars on both sides simultaneously (Fig. 1). Bottleneck roads always lead to the traffic jam [2]. In this scenario, the dynamic motion of the AV is not as obvious as in rural roads or motorways because of the low speed.

B. Issues of AV-MV driver communication

Interaction opportunities between AV and MV drivers are increasing due to future mixed traffic. In the case of level 3-5 AVs [15], drivers are allowed to do secondary tasks such as watching a movie while driving. The following interaction issues should be considered.

1) Referring to the issues of AV-pedestrian communication due to the unclear dynamic motion from low-speed driving [16], the MV driver as a human road user may also have difficulties in conveying intention from this kind of ambiguous implicit communication.

2) Moreover, since the communication of AV-MV driver occurs at a longer distance than that of AV-Pedestrian communication, it is difficult for MV driver to detect the AV intentions. This may make the implicit communication between them become more ambiguous.

3) Since the AV's driver is not involved in driving tasks, the MV driver loses its explicit communication methods, i. e., hand gestures, and head nods from human drivers. Corresponding to the cognitive issues of AV-pedestrian communication [12], [17], the lack of explicit signals from AV human drivers may also make it difficult for MV drivers to understand AV driving intentions. Similar to the issues reported by [18] in AV-pedestrian communication, the driverless AV may lead MV driver hesitant in making decisions due to insufficient understanding, bad feeling of safety, distrust and over workload in communicating with the AV, which may decrease the acceptance of the AV.

C. HMI designs for AV-road users communication

In order to apply AV to ambiguous traffic scenarios, two methods of AV-road users communication are currently being investigated. One method is using AV's dynamic motion to convey intentions, another is communicating with eHMIs on AV [5]. At present, many studies have focused on AV-pedestrians interactions and most of them have positively shown that eHMI supports the interaction especially effectively at low speeds where there is sufficient time for pedestrians to react. [19]. It could helpful in quicker decision making [18], [20], improving the feeling of safety [18], [21] and making the traffic climate friendly [4], [22].

Since multiple road users can see the information on eHMI, the information conveyed by eHMI may be misreceived by the non-target objects. It may result in the MV driver being confused. Besides, some studies indicate that eHMI is still a new area of research which is not clear yet to what extent eHMIs will be helpful [19]. For instance, eHMI may lead to over-trust which may cause accident [23]. It has technological, regulatory and standardization challenges and could be confusing and misleading due to different culture backgrounds [19]. Thus, eHMI could be considered as a secondary communication method paired with vehicle motion cues [4], [16], [19].

In addition to eHMI, iHMI is an on board interface providing information to drivers and passengers. It could be configured in the dashboard, central panel or HUD. iHMI could be considered as another potential communication method between AV and MV driver with the development of V2V. V2V is used among vehicles to exchange information between vehicles such as position, speed, acceleration, yaw rate, throttle position, brake status, steering angle [24]. V2V conveys the states and intentions of the vehicles which are essential for driving safety. Thus, the information displayed on iHMI could be transferred via the V2V from AVs to MVs.

III. PURPOSE

This study aims to find an appropriate AV-MV driver HMI-based communication method. Based on the summary of existing issues, three types of HMI were proposed: V2V-based iHMI in MV, eHMI on AV and iHMI+eHMI using synchronously. An online survey is designed for evaluating three HMIs (Fig. 2) by participants' subjective reports in order to compare which one has a better comprehensive communication for MV driver when they encounter an AV in equal narrow passages.

IV. EXPERIMENT BY AN ONLINE SURVEY

A. Design of HMI-based communication methods

In this study, we designed three types of HMI which are the V2V-based iHMI in MV, the eHMI on AV and the iHMI+eHMI displaying synchronously. To make the MV driver observe the information from iHMI+eHMI synchronously, the iHMI was designed on HUD of the MV.

Specifically, to show the information of AV yielding intention to the MV driver, the iHMI displays a green arrow on the HUD (Fig. 2 a) while the eHMI displays a green dot

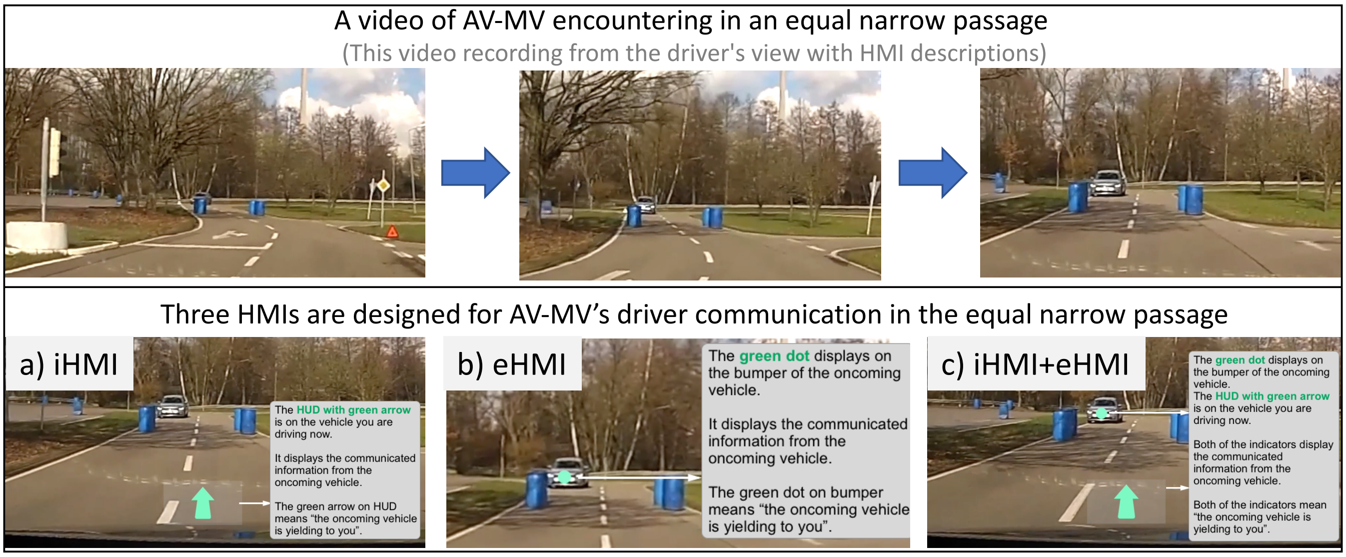

Fig. 2: A video of AV-MV encountering in an equal narrow passage is used in the online survey. Three types of HMI are used for the AV-MV driver communication. The blue cylinders on both sides of the road simulate two parking cars.

on the bumper of the AV (Fig. 2 b). Besides the eHMI and iHMI mentioned above, a combined HMI with both eHMI and iHMI (Fig. 2 c) was used to examine whether multiple information could have a better subjective evaluation or is considered redundant information by MV driver.

B. *Online survey*

In this online survey, we focused on the AV yielding intention in the equal narrow passage. A within-group design was used to evaluate how the MV driver precept the AV-MV's interaction with the iHMI, eHMI and iHMI+eHMI.

We used the demonstration videos from the view of MV driver recorded by Imbsweiler et al. [i] in 2018 as an example to demonstrate the equal narrow passage 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 below 30km/h and stopped before the bottleneck. 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 with the specific explanation of each HMI including the meaning of the elements and the location of the HMIs to the participants in order to guarantee they do the subjective evaluations without any confusions, only focus on comparing the types of HMI.

After each video with different HMIs, eight evaluation items were used to evaluate interactions between the AV and MV driver as following:

Evaluation item 1: The communication is adequate.
Evaluation item 2: The communication is clear.
Evaluation item 3: The communication is effective.
Evaluation item 4: I trust the oncoming vehicle to make appropriate actions.
Evaluation item 5: I trust the oncoming vehicle more because it communicates.
Evaluation item 6: I trust the oncoming vehicle more than a human driver.
Evaluation item 7: I feel safe in this situation.
Evaluation item 8: I feel stress in this situation.

For each evaluation item, 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. Note that the evaluation items 1-7 are in line with [25]. 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 understanding of information displayed in the HMIs were evaluated using evaluation item 1-3. To examine that the HMIs could improve the MV-driver's trust in the AV via the information on it, the evaluation items 4-6 were used. The evaluation item 7 was used to evaluate the feeling of safety. In addition, considering stress can reduce human cognitive efficiency [26], participants would feel frustrated and nervous when they are stressful [27], we also designed the evaluation item 8 for the driver's stress.

C. *Participants*

50 participants (42 males, 8 females) within the age range of 24–51 (mean: 30.5, standard deviation: 4.29) were invited to the questionnaire. There are 29 participants from Germany, 3 from the US and 18 from the UK who have driving licenses. Every participant was asked to do the questionnaire based on the scenario after watching the provided video.

V. EVALUATION RESULTS

A. *Subjective evaluations*

The subjective evaluation results from participants as MV drivers are shown in Fig. 3. The items 1-3 were used to evaluate the understanding of the communication from the AV.

[i]https://www.ifab.kit.edu/1516_2403.php

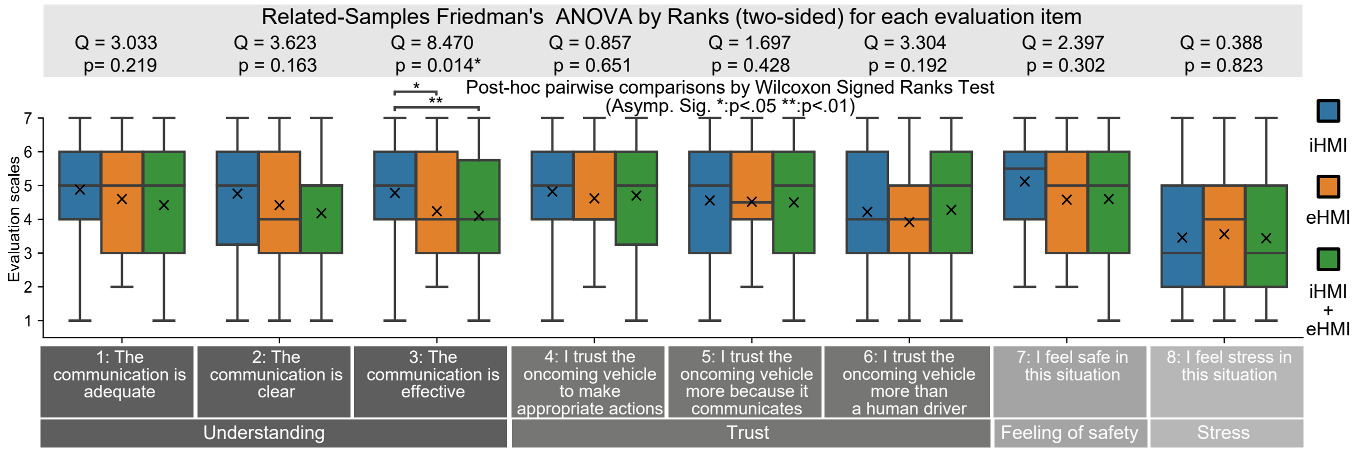

Fig. 3: Subjective evaluation results of the AV-MV's communication from MV driver. The "×" shows the mean value.

From the results of item 1, all of HMIs got the same median scores which were 5.00, while the mean scores were iHMI: $mean = 4.88$, eHMI: $mean = 4.60$ and iHMI+eHMI: $mean = 4.42$. The median of eHMI by item 2 ($median = 4.00$) was lowest in three HMIs, while the lowest mean of this item was iHMI+eHMI ($mean = 4.18$). For the item 3, the median for the iHMI ($median = 5.00$) was higher than others ($median = 4.00$, respectively). To test whether the three communication methods have significant differences in subjective evaluations, we conducted Friedman's ANOVA by Ranks (two-sided) for estimating the corresponding statistical significance. There was no significant difference among the items 1 and 2 for three HMIs: adequate ($Q = 3.033$, $p = 0.219$), clear ($Q = 3.623$, $p = 0.613$). The result of ANOVA for the item 3 showed a significant difference among HMIs ($Q = 8.470$, $p = 0.014$). Post-hoc pairwise comparisons by Wilcoxon Signed Ranks Test were used to examine the significant difference. The results showed that the communication by using iHMI was significantly more effective than by using eHMI ($p < 0.05$) and iHMI+eHMI ($p < 0.01$).

The items 4-6 were used to evaluate the trust in AV. The eHMI has the lowest median evaluation scores of item 4: $median = 4.00$ and item 5: $median = 4.50$ compared to the iHMI (item 4: $median = 5.00$; item 5: $median = 5.00$) and the iHMI+eHMI (item 4: $median = 5.00$; item 5: $median = 5.00$). For the item 6, the iHMI+eHMI got the highest median evaluation score which was $median = 5.00$, while the median evaluation scores of iHMI and eHMI were both $median = 4.00$. For items 4-6, there was still no significant difference among the three HMIs: I trust the oncoming vehicle to make appropriate actions ($Q = 0.857$, $p = 0.651$), I trust the oncoming vehicle more because it communicates ($Q = 1.697$, $p = 0.428$), I trust the oncoming vehicle more than a human driver ($H = 3.304$, $p = 0.192$).

Further, the item 7 showed the iHMI brought a feeling of safety which had the highest score ($median = 5.50$, $mean = 5.12$). The other two HMIs got a same median score ($median = 5.00$). Moreover, $mean = 4.58$ was for the eHMI and $mean = 4.60$ was for the iHMI+eHMI. The ANOVA result for item 7 showed that there was no significant difference of feeling of safety for those three HMIs ($Q = 2.397$, $p = 0.302$).

The results of item 8 showed that the stress of the eHMI had the highest score of $median = 4.00$ and $mean = 3.56$, which illustrated that the eHMI brought the highest stress in AV-MV driver communication compared to the other HMIs. However, the three HMIs had not significant difference in stress ($Q = 0.388$, $p = 0.823$) via ANOVA.

B. Spearman's correlation among the subjective evaluations

In this study, we analyzed the correlations among the eight evaluation items to analyze the interrelationships among them for each HMI. For instance, when using V2V-based iHMI, if there is a significant correlation between understanding and trust, then the information understanding of MV drivers may affect their trust in it. In addition, the correlations in utilizing different HMIs were compared. For example, if the correlation between understanding of information and trust of iHMI is higher than that of eHMI, iHMI is more likely to make MV driver trust in it through comprehensible information than eHMI. Therefore, Spearman's correlation coefficients were used to find correlations of the eight evaluation items for the different HMIs.

In Fig. 4, the Spearman's correlation coefficients (r) are shown as values in cells, the value in the cell is also shown as a green bar for positive values and a red bar for negative values. The p-value of each Spearman's correlation is indicated by ***: $p < 0.001$, **: $p < 0.01$, i. e., highly significant correlations; *: $p < 0.05$, i. e., significant correlation.

Evaluation items of understanding 1 & 2, 1 & 3 and 2 & 3 and trust 4 & 5, 4 & 6 and 5 & 6 had highly significant correlations ($0.60 < r < 0.90$ with $p < 0.001$, respectively) among iHMI, eHMI and iHMI+eHMI. There were highly significant correlations among evaluation items 4, 5, 6 & 1 and evaluation items 4, 5, 6 & 2, as well as evaluation items 4, 5, 6 & 3 ($0.40 < r < 0.70$ with $p < 0.001$ and $p < 0.05$) of three types of HMI. The results illustrated that subjective evaluations of understanding and trust have significant correlations.

		Evaluation item 1: The communication is adequate	Evaluation item 2: The communication is clear	Evaluation item 3: The communication is effective	Evaluation item 4: I trust the oncoming vehicle to make the appropriate actions	Evaluation item 5: I trust the oncoming vehicle more because it communicates	Evaluation item 6: I trust the oncoming automated vehicle more than a human driver	Evaluation item 7: I feel safe in this situation	Evaluation item 8: I feel stressed in this situation
Evaluation item 1: The communication is adequate	iHMI	1.00 ***							
	eHMI	1.00 ***							
	iHMI+eHMI	1.00 ***							
Evaluation item 2: The communication is clear	iHMI	0.80 ***	1.00 ***						
	eHMI	0.80 ***	1.00 ***						
	iHMI+eHMI	0.80 ***	1.00 ***						
Evaluation item 3: The communication is effective	iHMI	0.69 ***	0.69 ***	1.00 ***					
	eHMI	0.68 ***	0.72 ***	1.00 ***					
	iHMI+eHMI	0.78 ***	0.77 ***	1.00 ***					
Evaluation item 4: I trust the oncoming vehicle to make the appropriate actions	iHMI	0.46 ***	0.42 **	0.54 ***	1.00 ***				
	eHMI	0.65 ***	0.72 ***	0.80 ***	1.00 ***				
	iHMI+eHMI	0.53 ***	0.53 ***	0.42 **	1.00 ***				
Evaluation item 5: I trust the oncoming vehicle more because it communicates	iHMI	0.55 ***	0.58 ***	0.60 ***	0.43 **	1.00 ***			
	eHMI	0.56 ***	0.48 ***	0.65 ***	0.65 ***	1.00 ***			
	iHMI+eHMI	0.68 ***	0.72 ***	0.70 ***	0.70 ***	1.00 ***			
Evaluation item 6: I trust the oncoming automated vehicle more than a human driver	iHMI	0.35 *	0.34 *	0.54 ***	0.49 ***	0.33 *	1.00 ***		
	eHMI	0.39 **	0.49 ***	0.55 ***	0.63 ***	0.44 **	1.00 ***		
	iHMI+eHMI	0.32 *	0.36 **	0.48 ***	0.61 ***	0.64 ***	1.00 ***		
Evaluation item 7: I feel safe in this situation	iHMI	0.32 *	0.39 **	0.40 **	0.57 ***	0.27	0.37 **	1.00 ***	
	eHMI	0.57 ***	0.60 ***	0.73 ***	0.80 ***	0.51 ***	0.65 ***	1.00 ***	
	iHMI+eHMI	0.55 ***	0.54 ***	0.59 ***	0.65 ***	0.71 ***	0.65 ***	1.00 ***	
Evaluation item 8: I feel stressed in this situation	iHMI	-0.23	-0.15	-0.01	-0.20	-0.04	0.13	-0.13	1.00 ***
	eHMI	-0.27	-0.43 **	-0.49 ***	-0.40 **	-0.13	-0.19	-0.31 *	1.00 ***
	iHMI+eHMI	-0.56 ***	-0.44 **	-0.48 ***	-0.35 *	-0.34 *	-0.21	-0.36 *	1.00 ***

Fig. 4: Spearman's correlation coefficients (r) among the subjective evaluation results for the iHMI, eHMI and iHMI+eHMI. ***: $p < 0.001$ and **: $p < 0.01$, show highly significant correlations; *: $p < 0.05$ shows significant correlation.

Evaluation items 1, 2, 3 & 7 and 4, 5, 6 & 7 also had highly significant correlations ($0.2 < r < 0.80$, $p < 0.001$), except item 7 & 5 for the iHMI has no signifiacnt correlations ($r = 0.27$, $p > 0.05$). The results showed that understanding, trust and feeling of safety had significant correlations on all three HMIs. Evaluation item 8 had significant correlations with item 2, 3, 4, 7 on both eHMI and iHMI+eHMI ($0.3 < r < 0.50$, $p < 0.001$). However, there were no significant correlations between item 8 and all the other items on iHMI ($0.005 < r < 0.30$, $p > 0.05$).

VI. DISCUSSION

From the subjective evaluation results, as shown in Fig. 3. The iHMI gave a better evaluation in understanding, feeling of safety and stress compared to the eHMI and the iHMI+eHMI, while the eHMI had the lowest evaluation of trust, which indicated that eHMI was more difficult to be trusted by the MV driver. The understanding evaluation of "the communication is effective" on iHMI is significantly higher than both eHMI and iHMI+eHMI, which showed that the information on iHMI is more effective for understanding the communication between AV and MV driver. Moreover, we considered that the V2V-based iHMI had a better evaluation in understanding due to it being easier for the MV driver to perceive the information on HUD compared to the eHMI on the bumper of the oncoming AV. In addition, since iHMI was located inside of the MV, the information displayed on iHMI was directed to the MV driver only. It made the MV driver easily understand the driving intention and trust the AV via the communication by the iHMI. On the other hand, the information displayed on eHMI is less directional than it displayed on iHMI because all the road users can see the information displayed on the eHMI. Thus, the eHMI may make the MV driver difficult to understand that its information points to them.

The Spearman correlation results in Fig. 4 show that the feeling of safety and the understanding affected each other, while the feeling of safety and the trust also had mutual influence when communicating via HMIs.Equivalent to the study by Liu et al. [28] which reported that situation awareness affects driver's trust in the AV. Moreover, the driver's trust in AV is also affected by the feedback from his/her perceived risks. Compared to the iHMI, the trust and feeling of safety in HMIs have significant correlations to the clear and efficient of communication, which might be assumed that more clear and higher efficiency communication could have a higher trust and better feeling of safety. The stress of the MV driver has no significant correlation with other items by using iHMI. Moreover, there is no significant correlations between stress and feeling of safety when the eHMI and iHMI+eHMI were used. Participants may not feel stress because the designed scenario is not as complex as the real traffic environment including more road users and potential risks. There were significant correlations between understanding and stress on iHMI+eHMI, which showed that more clear and efficient information could reduce the stress.

VII. CONCLUSION

In this paper, we discussed the communication methods between the MV driver and the AV for negotiation in an equal narrow passage. We found that the iHMI was evaluated as an effective communication method for understanding, which is significantly better than the eHMI and iHMI+eHMI. Besides, the trust and feeling of safety on all HMIs have a significant correlation to the adequate, clear and efficient of communication. It could be assumed that more clear and more efficient communication from the AV could improve the MV driver's the trust in AV and the feeling of safety.

The limitation in this paper is the following. The different design elements with the same communication meaning used on iHMI and eHMI may have resulted in confusion even though specific explanations were given in the experiment. For instance, the green dot on AV may be understood as "the oncoming AV will go first" instead of "the oncoming AV is yielding to me". This limitation might lead to the result that evaluations of eHMI were lower than other two HMIs.

In the future, we will further analyze the causal relationship between the eight evaluation items. Besides, iterations of the HMI designs will be proposed based on the evaluation results. This study only focused on the situation of the AV yielding to the MV driver. The situation of AV driving first will be included in future's works. Further, more complex situations including AV, MV and other road users will be explored. Moreover, to investigate the impact of different types of HMI on MV driver behaviors, an experiment using a driving simulator is under planning.

ACKNOWLEDGMENTS

Yang Li is supported by China Scholarship Council (CSC) (No. 201906260302) at Karlsruhe Institute of Technology (KIT), Germany. This work was supported by JSPS KAKENHI Grant Numbers 20K19846, Japan.

REFERENCES

[1] E. R. S. Observatory, "Traffic safety basic facts 2018: Junctions," tech. rep., 2018.

[2] M. Rettenmaier, M. Pietsch, J. Schmidtler, and K. Bengler, "Passing through the bottleneck-the potential of external human-machine interfaces," in *2019 IEEE Intelligent Vehicles Symposium (IV)*, pp. 1687–1692, IEEE, 2019.

[3] J. Imbsweiler, K. Linstedt, R. Palyafári, H. Weinreuter, F. P. León, and B. Deml, "Quasi-experimentelle untersuchung des blickverhaltens und der fahrparameter von autofahrern in engstellen," *Zeitschrift für Arbeitswissenschaft*, vol. 71, no. 4, pp. 242–251, 2017.

[4] Y. Li, H. Cheng, Z. Zeng, H. Liu, and M. Sester, "Autonomous vehicles drive into shared spaces: eHMI design concept focusing on vulnerable road users," in *2021 IEEE Intelligent Transportation Systems Conference (ITSC)*, pp. 1729–1736, 2021.

[5] K. Bengler, M. Rettenmaier, N. Fritz, and A. Feierle, "From HMI to HMIs: Towards an HMI framework for automated driving," *Information*, vol. 11, no. 2, p. 61, 2020.

[6] A. Colley, J. Häkkilä, B. Pfleging, and F. Alt, "A design space for external displays on cars," in *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*, pp. 146–151, 2017.

[7] A. Habibovic, V. M. Lundgren, J. Andersson, M. Klingegård, T. Lagström, A. Sirkka, J. Fagerlönn, C. Edgren, R. Fredriksson, S. Krupenia, *et al.*, "Communicating intent of automated vehicles to pedestrians," *Frontiers in psychology*, vol. 9, p. 1336, 2018.

[8] J. Imbsweiler, T. Stoll, M. Ruesch, M. Baumann, and B. Deml, "Insight into cooperation processes for traffic scenarios: modelling with naturalistic decision making," *Cognition, Technology & Work*, vol. 20, no. 4, pp. 621–635, 2018.

[9] M. Rettenmaier, C. R. Witzig, and K. Bengler, "Interaction at the bottleneck–a traffic observation," in *International Conference on Human Systems Engineering and Design: Future Trends and Applications*, pp. 243–249, Springer, 2019.

[10] M. Rettenmaier and K. Bengler, "Modeling the interaction with automated vehicles in road bottleneck scenarios," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 64, pp. 1615–1619, SAGE Publications Sage CA: Los Angeles, CA, 2020.

[11] W. Ju, "The design of implicit interactions," *Synthesis Lectures on Human-Centered Informatics*, vol. 8, no. 2, pp. 1–93, 2015.

[12] N. Merat, T. Louw, R. Madigan, M. Wilbrink, and A. Schieben, "What externally presented information do vrus require when interacting with fully automated road transport systems in shared space?," *Accident Analysis & Prevention*, vol. 118, pp. 244–252, 2018.

[13] M. Rettenmaier and K. Bengler, "The matter of how and when: Comparing explicit and implicit communication strategies of automated vehicles in bottleneck scenarios," *IEEE Open Journal of Intelligent Transportation Systems*, 2021.

[14] Y. Li, H. Liu, and B. Deml, "Manually driven vehicle encounters with autonomous vehicle in bottleneck roads: HMI design for communication issues," in *Proceedings of the 9th International Conference on Human-Agent Interaction (HAI21)*, 2021.

[15] SAE Technical Standards Board, "J3016b:taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles," pp. 1–35, SAE International, 2018.

[16] N. Matsunaga, T. Daimon, N. Yokota, and S. Kitazaki, "Effect of external human machine interface (eHMI) of automated vehicle on pedestrian's recognition," *Proceedings of the International Display Workshops*, p. 1125, 11 2019.

[17] H. Liu, T. Hirayama, L. Y. M. Saiki, and H. Murase, "What timing for an automated vehicle to make pedestrians understand its driving intentions for improving their perception of safety?," in *The 23rd IEEE International Conference on Intelligent Transportation Systems (ITSC)*, pp. 1–6, 2020.

[18] H. Liu, T. Hirayama, and M. Watanabe, "Importance of instruction for pedestrian-automated driving vehicle interaction with an external human machine interface: Effects on pedestrians' situation awareness, trust, perceived risks and decision making," in *IEEE Intelligent Vehicles Symposium*, pp. 748–754, 2021.

[19] W. Tabone, J. de Winter, C. Ackermann, J. Bärgman, M. Baumann, S. Deb, C. Emmenegger, A. Habibovic, M. Hagenzieker, P. Hancock, *et al.*, "Vulnerable road users and the coming wave of automated vehicles: Expert perspectives," *Transportation Research Interdisciplinary Perspectives*, vol. 9, p. 100293, 2021.

[20] K. De Clercq, A. Dietrich, J. P. Núñez Velasco, J. De Winter, and R. Happee, "External human-machine interfaces on automated vehicles: effects on pedestrian crossing decisions," *Human factors*, vol. 61, no. 8, pp. 1353–1370, 2019.

[21] S. M. Faas and M. Baumann, "Light-based external human machine interface: color evaluation for self-driving vehicle and pedestrian interaction," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 63, pp. 1232–1236, SAGE Publications Sage CA: Los Angeles, CA, 2019.

[22] S. Sadeghian, M. Hassenzahl, and K. Eckoldt, "An exploration of prosocial aspects of communication cues between automated vehicles and pedestrians," in *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pp. 205–211, 2020.

[23] K. Holländer, P. Wintersberger, and 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*, pp. 211–221, 2019.

[24] J. Harding, G. Powell, R. Yoon, J. Fikentscher, C. Doyle, D. Sade, M. Lukuc, J. Simons, J. Wang, *et al.*, "Vehicle-to-vehicle communications: readiness of v2v technology for application.," tech. rep., United States. National Highway Traffic Safety Administration, 2014.

[25] M. Matthews, G. Chowdhary, and E. Kieson, "Intent communication between autonomous vehicles and pedestrians," *arXiv preprint arXiv:1708.07123*, 2017.

[26] K. Mandrick, V. Peysakhovich, F. Rémy, E. Lepron, and M. Causse, "Neural and psychophysiological correlates of human performance under stress and high mental workload," *Biological psychology*, vol. 121, pp. 62–73, 2016.

[27] N. H. Alsuraykh, M. L. Wilson, P. Tennent, and S. Sharples, "How stress and mental workload are connected," in *Proceedings of the 13th EAI International Conference on Pervasive Computing Technologies for Healthcare*, pp. 371–376, 2019.

[28] H. Liu and T. Hiraoka, "Driving behavior model considering driver's over-trust in driving automation system," in *The 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, AutomotiveUI '19, p. 115–119, Association for Computing Machinery, 2019.