Autonomous Driving with an Agent: Speech Style and Embodiment

Seul Chan Lee
Virginia Tech
Blacksburg, VA 24061, USA
seulchan0926@gmail.com

Sangjin Ko
Virginia Tech
Blacksburg, VA 24061, USA
sangjinko@vt.edu

Harsh Sanghavi
Virginia Tech
Blacksburg, VA 24061, USA
sangjinko@vt.edu

Myounghoon Jeon
Virginia Tech
Blacksburg, VA 24061, USA
myounghoonjeon@vt.edu

AutomotiveUI '19 Adjunct, September 21–25, 2019, Utrecht, Netherlands

ACM ISBN 978-1-4503-6920-6/19/09.
https://doi.org/10.1145/3349263.3351515

Abstract
A driving agent can be an effective interface to interact with drivers to increase trust towards the autonomous driving vehicle. While driving research on agent has mostly focused on the voice-agent, little empirical findings on the robot-agent were reported. In the present study, we compared three different agents (informative voice-agent, informative robot-agent, and conversational robot-agent) to investigate their effects on driver perception in Level 5 autonomous driving. A driving simulator experiment with an agent was conducted. Twelve drivers experienced a simulated autonomous driving and responded to Godspeed questionnaire, RoSAS questionnaire, and social presence. Drivers rated the conversational robot-agent as significantly more competent, warmer, and providing higher social presence than the other two agents. Interestingly, despite this emotional closeness, drivers' attitude toward the conversational robot-agent was contradictory. They mostly chose the conversational robot-agent as the best option or the worst option. Findings of the present study are meaningful as a first step of exploring the potential of various types of in-vehicle agents in the context of autonomous driving.

Author Keywords
Autonomous driving; voice agent; robot agent; speech style; embodiment

CCS Concepts

Hardware → Emerging technologies Analysis and design of emerging devices and systems, Emerging interfaces

Introduction

As automated systems become more common, the concept of human-computer interaction has evolved in a cooperative way to increase convenience in people's lives. This trend can also be found in the context of driving. In the past, drivers were required to perceive information, make decisions, stay in their lane, and maintain the speed all by themselves. These days, however, advanced driving assistant systems enable vehicles to assist drivers in many sub-tasks required for driving, such as lane keeping, speed control, and route planning. The development of autonomous vehicles is further accelerating these changes. In other words, human-vehicle cooperation is an essential element of future driving [3].

Nevertheless, many drivers are still reluctant to handover control to the vehicle because of a lack of trust [5]. They have doubts about a novel system that they have never experienced before. Therefore, for the adoption of the automated driving system, it is important to increase drivers' trust in the automated system using the techniques of human-vehicle interaction. One of the effective ways to increase acceptance is using a tangible interface to show the intentions of the system and allow users to understand the system's behavior. Implementing a physical or virtual agent to interact with drivers can increase the feeling of co-presence toward the system and give the drivers confidence that the system is working properly.

To date, voice-agents have been widely implemented and tested in the context of manual driving for the purpose mentioned above [7,9]. Recently, researchers have tried to explore the use of robot-agents in the autonomous driving context [2,10–12,15,16]. Karatas et al. [10] showed that the existence of a social robot system, equipped with three movable heads with one degree of freedom, reduced the reaction time to accident situations in the context of autonomous driving. Kraus et al. [11] revealed that driver's trust towards automated driving systems can be enhanced more by using a robot-agent than using a voice-only agent. Zihsler et al. [16] tried to give information about the system status of an automated driving vehicle by using a virtualized avatar. This research, although in its nascent phase, has shown the possible use cases of having a robot-agent interact with drivers in an automated driving context.

In the present study, as a first step of exploring the potential of various types of in-vehicle agents in the context of autonomous driving, we compared the effects of three different agents on driver's perception. The role of the agents was to give driving-related information so that the driver can notice the intention and status of the automated driving system. The informative voice-agent had no physical entity and conveyed driving information via dry speech. The informative robot-agent was an embodied robot and conveyed the same information via dry speech. The conversational robot-agent provided the same information with more conversational speech, which is more human like.

Literature shows that drivers prefer interactions with the agents that show more human like features, giving a positive effect on the driver's perception of trust towards the autonomous driving system [6,11]. Based on these findings, we hypothesized that drivers would prefer the robot-agent to the voice-agent and the conversational type to the simple information type.

Table 1: Driving events in the scenario

Event list
1. Exit from the road and enter a new road
2. Road construction
3. Swerving a car
4. Tunnel
5. Jaywalking
6. Waiting for traffic signal
7. Turning left / right
8. All way stop intersection

Table 2: Informative agent's script

Script list
1. Exit ahead
2. Road construction ahead
3. A car is swerving
4. Tunnel ahead
5. Jaywalker ahead
6. Red traffic light
7. Turning left / right ahead
8.This is a four-way stop intersection

Table 3: Conversational agent's script

Script list
1. We are entering a new road
2. We are slowing down because of road construction
3. I am sorry for the sudden slow down. A car swerved into traffic
4. We are entering a tunnel
5. Are you okay? A man suddenly popped out onto the road
6. We are waiting for the signal to turn green
7. We are turning left / right
8.We've reached a four-way stop intersection. We are waiting for other cars to go first

To test these hypotheses, a driving simulator experiment was designed and conducted. We collected and analyzed the subjective evaluations from participants after they experienced an automated driving situation with the agents.

Method

Experimental design A within-subject design was implemented with three conditions (informative voice-agent (IVA), informative robot-agent (IRA), and conversational robot-agent (CRA)). In each condition, participants experienced an autonomous driving journey in a driving simulator with one of three agents. Participants ran into eight driving events in each condition to show that the automated driving system enables to appropriately control the driving events (Table 1). Participants were given verbal feedback from one of the agents in each condition before or right after the events. Two informative agents gave information to drivers in a simple manner; in contrast, the conversational robot-agent conveyed information in a way that would replicate a usual conversation with a human collaborator (e.g., "we are entering…", "I am sorry…") (Tables 2 and 3). The driving scenarios were designed based on a straight and curved road including some traffic, traffic signals, intersections, and road users (Figure 1). In order to minimize the learning effects, we used one of three different driving scenarios designed with the same city map and the same events, however, the route and the order of events were different for each condition (approximately 6.5 minutes). The order of the conditions was also randomized to prevent the learning effects.

Dependent measures To collect drivers' perception on the in-vehicle agent, subjective ratings of three different agents were collected using the Godspeed questionnaire (five factors with 24 items, 5-point Likert scale) [1], RoSAS questionnaire (three factors with 18 items, 7-point Likert scale) [4], and social presence (five items, 10-point Likert scale) [13]. Also, the preference ranking among three agents was measured.

Participants Twelve participants (4 female) between 20 and 42 years old (mean = 30.25, *SD* = 5.80) with a valid driving license participated in this study. The mean driving year was 6.92 years and they drove an average of 5.83 times per week.

Apparatus and stimuli The driving simulator used was a motion-based driving simulator (Nervtech™, Ljubljana, Slovenia) as shown in Figure 2. It was equipped with three 48'' Samsung displays, a steering wheel, an adjustable seat, gas and brake pedals, and a surrounded sound dome. A humanoid robot, Nao, was used in the two robot-agent conditions (V6 standard edition, height: 22.6 in., width: 10.8 in.). Amazon Polly text-to-speech software was used to design the agent's voices (https://aws.amazon.com/polly, name: Sallie, gender: female voice, nationality: USA).

Procedure All the details about the experiment were explained after welcoming the participants. Then, the consent form confirmed by the Institutional Review Board (IRB) of the university was signed and demographic information was collected. Participants were assumed to be in a Level 5 autonomous driving car; they were told that they can do non-driving-related tasks if they want, such as Internet surfing on smartphone. After every condition was completed, participants responded to the questionnaires. When they finished all three conditions, their preference and the reason was lastly asked. It took approximately 45 minutes to complete all procedures.

Data analysis We could only include a small sample size as this study is the starting point of the project. Accordingly, a

Figure 1: Screenshot of driving scenarios

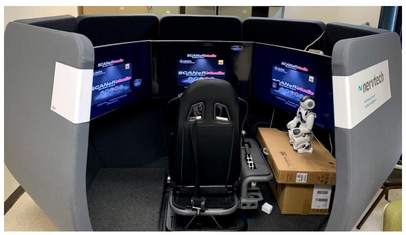

Figure 2: Experimental Settings

non-parametric Friedman test was performed to analyze the differences among the conditions for each measure. If a significant difference was found, a Wilcoxon signed-ranks test was used for the pairwise comparisons. The 0.05 significance level was applied. All statistical analyses were performed by IBM SPSS 25.0.

Results

The results showed there are no significant differences among the three conditions in measures of Godspeed. However, drivers rated the CRA as significantly more competent and warmer than the other two types. In addition, the social presence of the CRA was significantly higher than the other conditions. Table 4 presents the summary of statistical analyses. Preference rankings for each condition were not significantly different from each other (Table 5).

Table 4: Subjective evaluation results

Items	Agent condition			Sig.	Pairwise comparisons
	IVA	IRA	CRA		
Anthropomorphism	3.03	2.95	3.82	$p = .166$	-
Animacy	2.76	2.68	3.53	$p = .063$	-
Likeability	3.6	3.42	3.97	$p = .307$	-
Perceived intelligence	3.82	3.87	3.98	$p = .614$	-
Perceived safety	3.39	3.14	3.61	$p = .179$	-
Competence	4.61	4.89	5.47	$p < 0.01$	A = B < C*
Warmth	3.08	3.25	4.93	$p < 0.01$	A = B < C*
Discomfort	2.54	2.47	2.47	$p = .928$	-
Social Presence	4.97	4.92	6.80	$p < 0.01$	A = B < C**

Note. *: $p < 0.05$, **: $p < 0.01$

Table 5: Preference rankings for each condition

Preference	Condition		
	IVA	IRA	CRA
1st	4	3	5
2nd	5	6	1
3rd	3	3	6

Note. Unit: no. of participants

Discussion and Conclusion

We explored the drivers' subjective evaluations to three agents in the context of autonomous driving. We were able to identify some possibilities of the use of the robot-agent in the autonomous driving.

First, drivers felt more intimate about the guidance of the CRA than the informative agents. The close emotional band is likely to play a key role in the acceptance of the system. Second, despite this emotional closeness, drivers' attitude toward the CRA was contradictory. They mostly chose the CRA as the best option or worst option (Table 5). In the case of preferred drivers, "friendly", "natural", and "emotional touch" were reasons. However, in the opposite case, they pointed out that "it gives too much information" and "distracted". Therefore, it is necessary to make sure that the agent should be familiar to drivers but not irritating drivers.

In future study, we can extend the approach to more accurately understand the driver's interaction with an agent. In the present study, we only include subjective evaluations. Drivers' behaviors, such as glance behaviors, can be used to observe their interaction with an agent. In addition, different characteristics of the voice-agent suggested by previous literature [8,14], for example, gender, urgency, voice emotion, and speaking style (command vs. suggestive/notification) should be tested in a robot-agent.

References

1. Christoph Bartneck, Dana Kulić, Elizabeth Croft, and Susana Zoghbi. 2009. Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *International Journal of Social Robotics* 1, 1: 71–81. https://doi.org/10.1007/s12369-008-0001-3

2. Xiaojun Bi, Yang Li, and Shumin Zhai. 2013. FFitts law: Modeling Finger Touch with Fitts' Law. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*: 1363. https://doi.org/10.1145/2470654.2466180

3. Francesco Biondi, Ignacio Alvarez, and Kyeong Ah Jeong. 2019. Human–Vehicle Cooperation in Automated Driving: A Multidisciplinary Review and Appraisal. *International Journal of Human-Computer Interaction* 35, 11: 932–946. https://doi.org/10.1080/10447318.2018.1561792

4. Colleen M Carpinella, Michael A Perez, Alisa B Wyman, and Steven J Stroessner. 2017. The Robotic Social Attributes Scale (RoSAS): Development and Validation. *ACM/IEEE International Conference of HRI*: 254–262. https://doi.org/10.1145/2909824.3020208

5. Jong Kyu Choi and Yong Gu Ji. 2015. Investigating the Importance of Trust on Adopting an Autonomous Vehicle. *International Journal of Human-Computer Interaction* 31, 10: 692–702. https://doi.org/10.1080/10447318.2015.1070549

6. Philipp Hock, Johannes Kraus, Marcel Walch, Nina Lang, and Martin Baumann. 2016. Elaborating Feedback Strategies for Maintaining Automation in Highly Automated Driving. In *8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. (AutomotiveUI '16)*, 105–112. https://doi.org/10.1145/3003715.3005414

7. Myounghoon Jeon, Bruce N. Walker, and Thomas M. Gable. 2015. The effects of social interactions with in-vehicle agents on a driver's anger level, driving performance, situation awareness, and perceived workload. *Applied Ergonomics* 50: 185–199. https://doi.org/10.1016/j.apergo.2015.03.015

8. Myounghoon Jeon, Bruce N. Walker, and Thomas M. Gable. 2015. The effects of social interactions with in-vehicle agents on a driver's anger level, driving performance, situation awareness, and perceived workload. *Applied Ergonomics* 50: 185–199. https://doi.org/10.1016/j.apergo.2015.03.015

9. Yeon Kyoung Joo and Roselyn J. Lee-Won. 2016. An Agent-Based Intervention to Assist Drivers Under Stereotype Threat: Effects of In-Vehicle Agents' Attributional Error Feedback. *Cyberpsychology, Behavior, and Social Networking* 19, 10: 615–620. https://doi.org/10.1089/cyber.2016.0153

10. Nihan Karatas, Soshi Yoshikawa, Shintaro Tamura, Sho Otaki, Ryuji Funayama, and Michio Okada. 2017. Sociable driving agents to maintain driver's attention in autonomous driving. In *RO-MAN 2017 - 26th IEEE International Symposium on Robot and Human Interactive Communication*, 143–149. https://doi.org/10.1109/ROMAN.2017.8172293

11. Johannes Maria Kraus, F Nothdurft, P Hock, D Scholz, W Minker, and M Baumann. 2016. Human after all: Effects of mere presence and social interaction of a humanoid robot as a co-driver in automated driving. In *8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2016*, 129–134. https://doi.org/10.1145/3004323.3004338

12. Johannes Maria Kraus, Jessica Sturn, Julian Elias Reiser, and Martin Baumann. 2015. Anthropomorphic agents, transparent automation and driver personality: towards an integrative multi-level model of determinants for effective driver-vehicle cooperation in highly automated vehicles. *Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '15*: 8–13. https://doi.org/10.1145/2809730.2809738

13. Kwan Min Lee, Younbo Jung, Jaywoo Kim, and Sang Ryong Kim. 2006. Are physically embodied social agents

better than disembodied social agents?: The effects of physical embodiment, tactile interaction, and people's loneliness in human-robot interaction. *International Journal of Human Computer Studies* 64, 10: 962–973. https://doi.org/10.1016/j.ijhcs.2006.05.002

14. Clifford Nass, Ing-Marie Jonsson, Helen Harris, Ben Reaves, Jack Endo, Scott Brave, and Leila Takayama. 2005. Improving automotive safety by pairing driver emotion and car voice emotion. May 2014: 1973. https://doi.org/10.1145/1056808.1057070

15. Satoshi Okamoto and Shin Sano. 2017. Anthropomorphic AI Agent Mediated Multimodal Interactions in Vehicles. In *9th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '17)*, 110–114. https://doi.org/10.1145/3131726.3131736

16. Jens Zihsler, Philipp Hock, Marcel Walch, Kirill Dzuba, Denis Schwager, Patrick Szauer, and Enrico Rukzio. 2016. Carvatar: Increasing Trust in Highly-Automated Driving Through Social Cues. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct - Automotive'UI 16*, 9–14. https://doi.org/10.1145/3004323.3004354