Robot-Like In-Vehicle Agent for a Level 3 Automated Vehicle

XINGJIAN ZENG and PAVLO BAZILINSKYY, Eindhoven University of Technology, The Netherlands

With the rapid development of automotive technology and artificial intelligence, in-vehicle agents have a large potential to solve the challenges of explaining the system status and the intentions of an automated vehicle. A robot-like in-vehicle agent was developed to explore the in-vehicle agent communicating through gestures and facial expressions with a driver in an SAE Level 3 automated vehicle. An experiment with 12 participants was conducted to evaluate the prototype. Results showed that both interactions of facial expressions and gestures can reduce workload, and increase usefulness, and satisfaction. However, gestures seem to be more functional and more preferred by the driver while facial expressions seem to be more emotional and preferred by passengers. Furthermore, gestures are easier to notice but hard to understand independently and facial expressions are hard to notice but more attractive.

Additional Key Words and Phrases: In-Vehicle Agent, Robot-Like Agent, Gesture, Facial Expression, Voice Interaction

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1 INTRODUCTION

With the development of automotive technology and artificial intelligence, in-vehicle agents (IVAs) have emerged as a transformative innovation for intelligent transportation systems. These agents are often embodied as driving assistants and integrated into the driving system. IVAs are classified as voice agents, virtual agents, and physical agents. The purpose of integrating IVAs of any type is to help the driver with driving tasks and improve the driving experience [18].

1.1 In-Vehicle Agents in Manual and Automated Vehicles

In the manual driving context, the IVAs can not only help with driving-related tasks like vehicle-to-vehicle communication (both vehicles need to install IVA) [6], or non-driving related tasks like comfort children to reduce distractions for the driver [4], but also minimize driver's distraction by decreasing the number of directed utterances with a set of robots [11], reduce driver's fatigue through social communication [15], and mitigate drivers' negative affective status through giving positive comments about the situation [20].

IVAs can explain the system status and intentions of an automated vehicle (AV) [8, 13, 19, 21, 29]. The user interface (UI) of IVAs can be a voice UI [13], a visual UI [8], or a physical UI [3]. Lee and Jeon [18] suggest that physical agents aid better results in driving behaviour and overall experience, especially in the context of automated driving (AD). Zihsler et al. [29] and Chakravarthi et al. [3] showed that physical agents with facial expressions and gestures, respectively, can increase trust in AVs.

Authors' address: Xingjian Zeng, x.zeng1@student.tue.nl; Pavlo Bazilinskyy, p.bazilinskyy@tue.nl, Eindhoven University of Technology, PO Box 513, Eindhoven, The Netherlands, 5600 MB Eindhoven.

In an AD context, IVAs perform better in improving overall experience [18], such as explaining the system status with animation of a chauffeur avatar and a world in miniature [8], or using "How + why message" to lead better driving performance [13]. On the other hand, IVA can act as a companion by having a more conversational dialogue with an emotional tone and using first person [16], giving the driver a sense of a "human-agent relationship". Furthermore, IVAs can increase trust and acceptance in AD using social cues and anthropomorphism to translate the car's state into human behaviour and expressions, which can be interpreted intuitively by the driver [29].

The physical agents can be divided into consumer products in the market and prototypes in research. The physical agents do not seem to be popular in Europe. However, Chinese and Japanese companies already published a few physical agent products in the market. Nomi (https://www.youtube.com/watch?v=SAZ2Dd9lrVc, accessed: 19.06.24), Xiaodu (https://developer.apollo.auto/platform/dueros_cn.html, accessed: 19.06.24), and Mochi (https://dasai.com.au/pages/meet-mochi, accessed: 19.06.24) all have geometric appearance and digital screens for facial expressions. Nomi can access the CAN bus. However, these products have no gestures and act as virtual agents to improve the driving experience. Intelligent Puppet (https://www.nissan.co.jp/SP/INTELLIGENTPUPPET, accessed: 19.06.24) is a comfort robot for babies rather than helping drivers with driving tasks. Kirobo Mini (https://global.toyota/en/detail/19880995, accessed: 19.06.24), RoBoHoN (https://robohon.com, accessed: 19.06.24), and NAO (https://us.softbankrobotics.com/nao, accessed: 19.06.24) are usually applied as humanoid agents in IVA studies [14, 19, 23, 25, 26]. However, Kirobo Mini and RoBoHoN are initially companion robots, and NAO is used for coding education, which means all of the humanoid robots are not designed specifically for driving scenarios. The Affective Intelligent Driving Agent (AIDA) [27, 28] is the first physical agent designed especially for driving scenarios. AIDA can act like a human passenger, communicate with the driver, and help the driver with some tasks. Robot Human-Machine Interface (RHMI) [23] can use eye colour and body motions to remind the driver of a take-over request 5 seconds ahead to prepare. Carvatar [29] is another physical agent aimed at AD scenarios, using facial expressions to convey information and improve trust.

1.2 Interaction with In-Vehicle Agents

Voice interaction is a common communication method for IVAs in SAE Level 3 AD vehicles due to its minimal visual distraction [26]. Research on IVA voice interaction, including speech emotion and gender, indicates that no single voice suits all listeners and situations [10]. found that voice agents aligning with social role stereotypes (informative male and social female) enhance perceived ease of use (PEU) and perceived usefulness (PU) [17]. Jeon et al. showed the effectiveness of an in-vehicle software agent in mitigating effects on driver situation awareness and performance [9]. Ruijten et al. showed that conversational interfaces are more trusted, liked, anthropomorphized, and perceived as more intelligent than graphical UIs [21].

As IVAs evolve from voice-only to physical agents, the interactions become more complex. Both virtual and physical agents can engage in visual interactions, with virtual agents being 2D or 3D characters and physical agents having a physical appearance and facial expressions [5, 8, 12, 23, 27, 29]. However, the interesting thing is except for AIDA published in 2014, other concepts are all under the context of AD.

Gestures are a unique feature of physical agents compared to other agents. The robot developed by Srivatsan et al. [3] shows that robotic objects are a promising technology for enhancing passengers' experience in AVs. RHMI developed by Tanabe et al. [23] can adjust the turning angle, speed, and lid opening angle to inform different levels of emergency: normal state, unstable state, and suspended state.

Social interactions, such as small talk, significantly increase driver trust compared to voice interactions alone [14]. While robot agents can be visually distracting yet increase trust, voice agents are preferred in low-speed situations [26].

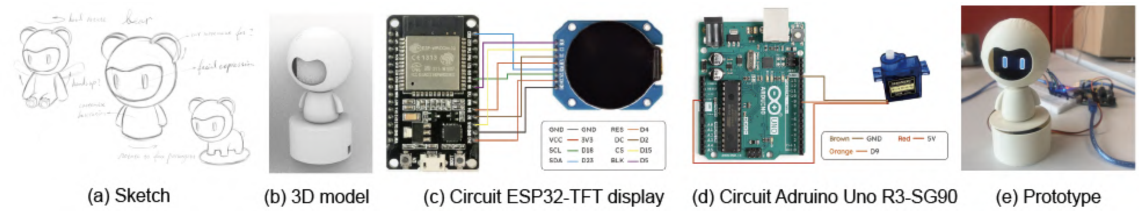

Fig. 1. The design concept of the robot-like IVA.

Drivers have mixed attitudes toward conversational robot agents [19]. Both voice and robot agents improve likability and perceived warmth, with voice agents better at anthropomorphism and robot agents offering higher competence and lower workload [25].

IVAs (especially physical IVAs) have significant potential to help with driving tasks and improve the driving experience, as well as a solution to the challenges raised in the AD context. There is a research gap in exploring the advantages and challenges of combining facial expressions and gestures with voice interaction in physical IVAs. This project explores this area. Two research questions were defined: **RQ1:** *How to develop a robot-like IVA for the SAE Level 3 AD scenario?* and **RQ2:** *What are the advantages and challenges of comparing gestures and voice interaction with facial expressions and voice interaction in SAE Level 3 AD scenarios?* In the context of this work, AD is assumed to be SAE Level 3 [22]. A robot-like IVA was designed and developed in this project to answer these two questions.

2 INTERVIEW AND DESIGN OF IN-VEHICLE AGENT

To understand the attitudes and expectations about IVA and driving behaviour in Asian countries and Europe, five participants (5 males, M = 28.8, SD = 3.42) were invited to an interview (see supplementary materials). Four of the participants had experience driving in Europe, and one of the participants had experience driving in both Japan and Europe. Results showed that long-distance driving can be boring and can prompt to get distracted. Even though only one of them had heard of IVA (Nomi of NIO), others were interested in the concept.

The sketch (Figure 1 (a)) presents three modalities, and the middle one was developed further. The face shows expressions and the body rotates to present different gestures according to seven highway scenarios [2] (Figure 2). The IVA prototype is not a robot that acts independently but a physical form of the whole driving assistant system [19]. Figure 1 (b) shows the 3D model created in Rhino 8 (STL files are in supplementary material). The shell is 3D printed and it contains a 1.28-inch round IPS-TFT display (240*240 pixels, IPS GC9A01) inside the round head (r=31mm) connected to ESP32 (Figure 1 (c)). Gestures are driven by an SG90 servo motor inside the stand connected to Arduino Uno R3 (Figure 1 (d)). No speaker was installed in the prototype because, in the real vehicle, the sound comes from the vehicle's audio system, rather than a physical robot. Figure 1 (e) shows the whole prototype.

The TFT display was connected to an ESP32 board and controlled by the Arduino IDE (v.2.3.2, https://www.arduino.cc, accessed: 19.06.24) on Apple Macbook A2442. See supplementary material for code. Five facial expressions (normal, smile, excited, realizing, sad) were designed in Adobe Illustrator (Figure 2).

The SG90 servo motor was connected to an Arduino Uno board and controlled by Arduino IDE on the laptop. The library Servo (v. 1.2.1) was installed in Arduino IDE to run the code in the servo motor. Three gestures were designed in this project according to the scenarios [2] in Figure 2: (1) greeting: turn to the driver (starting position), then turn front (100°/s, clockwise) to check the surroundings (66.7°/s, clockwise and counterclockwise) and turn back to the

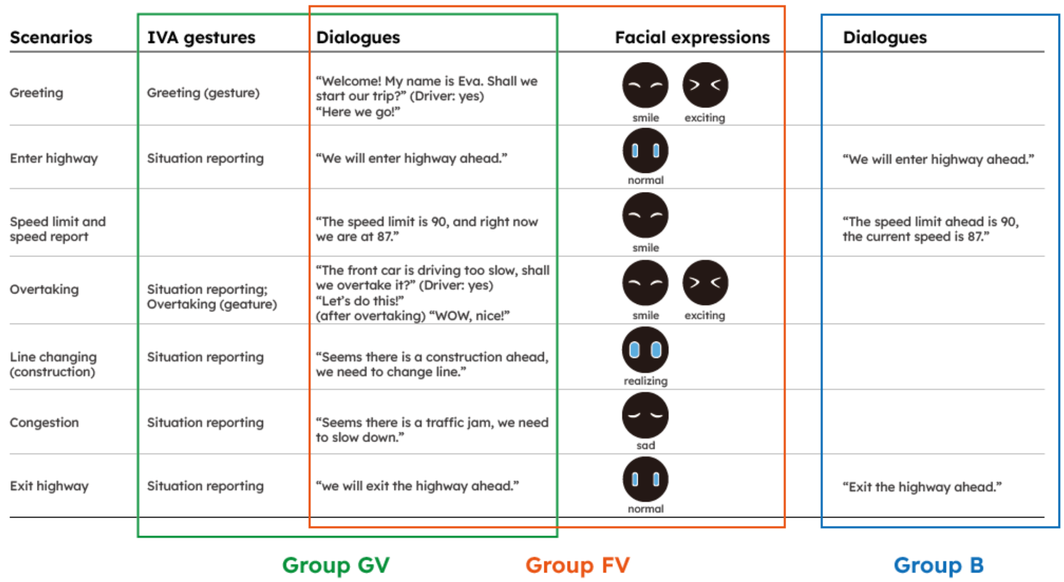

Fig. 2. IVA behaviour (gestures, facial expressions and dialogues) in seven highway scenarios.

driver (100°/s, counterclockwise); (2) situation reporting: turn front (100°/s, clockwise) and turn to the driver (100°/s, counterclockwise); (3) overtaking after got permission: turn front and rotate to face the vehicle be overtaken (100°/s, clockwise, only 30 degrees with SG90), then turn back to the driver (100°/s, counterclockwise).

3 METHOD OF EXPERIMENT

An experiment was conducted to evaluate the final design. The experiment had three groups: Group *B* (baseline), Group *FV* (facial expressions and Voice), and Group *GV* (gestures and voice). The behaviour of IVA in different groups is shown in Figure 2. *B* as a baseline had robotic voice interaction, which made it sound like a conventional in-vehicle navigation system and convey limited information. Thus *B* presented the Tesla Full Self-Driving (supervised) driving-assistance system. All the audio was generated from PlayHT (https://play.ht/, accessed: 19.06.24) and was edited as another soundtrack in a 4.5-minute video recorded in GTA V. The study was approved by the Ethical Review Board of Eindhoven University of Technology and participants gave their informed consent to use their data.

The video of scenarios was recorded in the GTA V videogame (https://www.rockstargames.com/zh/gta-v, accessed: 19.06.24) running on a Windows PC according to Figure 2, and the highway route is chosen from downtown to Beeker’s Garage. To get an inside view of AD, two mods were applied: (1) Dynamic Vehicle First Person Camera Mod (https://www.youtube.com/watch?v=jwxgmAHtwIY, accessed: 19.06.24), allowing the camera inside the vehicle to get the driver’s perspective and (2) Enhanced Native Trainer Mod (https://www.youtube.com/watch?v=UHHXTh0Xdow, accessed: 19.06.24), which makes characters invisible (i.e., no hands holding the steering wheel were visible, providing a sense of driving in an AV).

A total of 12 participants (age: M = 27.42, SD = 2.11; 7 females and 5 males) from Eindhoven University of Technology joined the user test. All of them were over 18 years old and had driver’s licenses (issued in different countries). Three participants had experience in driving with Tesla autopilot. Figure 3 shows the experimental setup. A screen (RCA

Fig. 3. Experimental setup.

RS32F3), headphones (Sennheiser MOMENTUM 4), and the robot-like IVA prototype were connected to the laptop (Apple Macbook A2442). For each participant, the lowest point of the prototype was adjusted by stacking up books (5.5 cm from the desk surface) until the participant could see the whole TFT display. The position of the robot-like IVA prototype is settled on the front right of the participant, corresponding to the position above the dashboard in a real car.

The author briefly introduced the background information about SAE Level 3 AD to the participants. Next, the participants took a seat and had three groups of tasks to complete: *B* (baseline), *FV* (facial expressions and voice), and *GV* (gestures and voice). *B* was a baseline and was always first but for half of the participants, the sequence of *FV* and *GV* was switched. The prototype was controlled by the author during the experiment. After each group of tasks, participants were asked to fill in the NASA Task Load Index scale [7] to measure the workload and the acceptance scale [24] to measure overall experience on an iPad. Finally, a semi-structured interview was conducted to collect the user test experience. During each group of tasks, participants were asked to imagine themselves in the SAE Level 3 AV and do their daily work as a secondary task (either replying to messages, watching videos on a mobile phone/iPad, or reading a book). They were allowed to look up and check the situation at any time. If they felt that they wanted to take over the control immediately, they were asked to inform the author about it.

4 RESULTS OF EXPERIMENT

Table 1 shows the results obtained from the NASA TLX scale and Table 2 outlines the usefulness and satisfaction scores.

According to the results of the interview (see supplementary materials), 7 participants preferred *GV* (gestures and voice), 5 participants preferred *FV* (facial expressions and voice), and no one preferred *B* (baseline). The reason for choosing gestures could be summarized as follows: (1) they are easier to notice than facial expressions (P1, P2, P3, P6, P9); (2) gestures move before the voice conveys information, providing more time to get out of the work and concentrate on the road situation (P1, P11); (3) facial expression make people distracted (P8); (4) understand facial expressions needs time (P1, P6, P8). The others who chose facial expressions suggested: (1) facial expressions are more interesting and intuitive than gestures (P4, P5, P10); (2) Facial expressions do not have the noise of rotating (P7); (3) cannot understand the meaning of gestures (P12).

Table 1. Results from the NASA TLX scale [7].

	B M(SD)	FV M(SD)	GV M(SD)
Mental demand (%)	34 (23)	25 (25)	20 (18)
Physical demand (%)	33 (27)	30 (27)	13 (12)
Temporal demand (%)	22 (18)	24 (22)	16 (12)
Performance (%)	34 (27)	23 (23)	19 (13)
Effort (%)	30 (26)	24 (22)	26 (21)
Frustration (%)	50 (25)	22 (14)	21 (14)
Average (%)	34 (21)	24 (23)	20 (14)

Note: B=Baseline, FV=Facial expressions and voice, GV=Gestures and voice.

Table 2. Results from the acceptance scale [24].

Negative (-2)	Positive (+2)	B M(SD)	FV M(SD)	GV M(SD)
Useless	Useful	1.00 (1.04)	1.33 (0.78)	1.08 (1.16)
Unpleasant	Pleasant	0.67 (0.98)	1.67 (0.39)	1.08 (0.67)
Bad	Good	0.83 (0.94)	1.25 (0.45)	1.08 (0.79)
Annoying	Nice	1.08 (0.67)	1.25 (0.62)	1.33 (0.65)
Superfluous	Effective	0.92 (1.00)	1.25 (0.75)	1.25 (0.75)
Irritating	Likeable	0.67 (0.78)	1.08 (0.79)	0.83 (1.03)
Worthless	Assisting	1.00 (0.95)	1.17 (0.58)	0.92 (0.90)
Undesirable	Desirable	1.00 (0.60)	1.17 (0.83)	0.83 (1.19)
Sleep-inducing	Raising Alertness	-0.33 (0.89)	0.75 (0.75)	0.17 (1.27)
Overall usefulness score		0.68 (0.06)	1.15 (0.14)	0.90 (0.23)
Overall satisfaction score		0.85 (0.17)	1.17 (0.20)	1.02 (0.27)

Note: B=Baseline, FV=Facial expressions and voice, GV=Gestures and voice.

5 DISCUSSION

We developed a robot-like IVA capable of voice interactions for an SAE Level 3 AV with five facial expressions and three gestures and evaluated it in an experiment.

There were notable results. (1) Both interactions of facial expressions and gestures can reduce workload in an SAE Level 3 AD scenario, and increase the usefulness and satisfaction of the driver. Both *FV* and GV were effectively in the reduction of workload, and the effect of *GV* was better than *FV*. Furthermore, *GV* greatly reduced the workload of Physical demand. The reason may be that the gestures were always triggered before voice interaction, and can be easily noticed by the participants, which leaves some time for them to get out of their work and focus on the road. The facial expression was shown at the same time as the voice was played, which may have caused the participants to check both road situations and expressions, resulting in a higher score of Temporal demand. As for the great reduction in Frustration, probably because IVA provide a sense of companionship, either through voice interaction, facial expressions or gestures. On the other hand, the acceptance scale shows better results in *FV* than GV, even though both groups can improve usefulness and satisfaction. This may indicate that gestures work better in reducing the workload (functionally), and facial expressions work better in enhancing usefulness and satisfaction, providing more affective support (emotionally).

Participants who preferred gestures also indicated that gestures could remind them that something was going to happen before the voice informed them about it; while participants who preferred facial expressions argued that expressions were more intuitive (P5) and cute (P4). (2) Though voice interaction is a more efficient way for an IVA to convey information, gestures can provide more time to get out of the secondary task and concentrate on the traffic situation. (3) Gestures seem to be more functional and more preferred by the driver while facial expressions are more emotional and preferred by passengers. (4) Gestures are easier to notice but hard to understand independently and facial expressions are the opposite.

After the experiment, two engineers from Nissan were interviewed to discuss the project from a vehicle manufacturer's perspective. They noted that installing physical IVAs in vehicles is challenging, especially if connected to the CAN bus. Privacy concerns arise if an IVA accesses vehicle functions, and the IVA's position must be considered to prevent injuries during airbag deployment.

The secondary task was not defined in the experiment because people have different driving habits. However, some people would look at the view outside while others were reading a paper. They had different levels of commitment to the secondary task, which may have led to errors. Different secondary tasks and different sitting postures also influence the participants' field of view. That is why some participants could easily notice the IVA while others could not. Different driving modes of IVA could be defined to suit different workloads of secondary tasks. The experiment was conducted with a video, rather than in a real vehicle. Two participants (P10, P12) mentioned that they may have acted differently if they could have felt the acceleration and deceleration of the vehicle. Since exposure to each group was only 4.5 minutes per participant, it is hard to predict if participants would get bored or fall asleep in case of extended duration. Some participants were curious about the video and always looked up in all groups. Even switching FV and GV to reduce the error, they knew what would happen when they tested FV and GV.

For future work, combining facial expressions and gestures could enhance the concept. Designing more intuitive gestures and 3D facial expressions is also recommended. Integrating IVA with other in-vehicle human-machine interfaces could make IVA the manager of all in-vehicle communication. Different driving modes should be defined based on participant feedback. Additionally, exploring IVA's potential in interacting with vulnerable road users (VRUs) like cyclists and pedestrians is suggested. The IVA was placed above the dashboard, where it can also be visible to people outside. So it could convey information to them by gestures and facial expressions, aiding in interactions with VRUs [1].

6 SUPPLEMENTARY MATERIAL

Interview, STL files, analysis code, materials used in the experiment, and raw data can be found at: https://www.dropbox.com/scl/fo/8xz3ok1s4zsagf7nytky5/AJQPehMbzmQAZ8ncz3LqjfQ?rlkey=25dct1vyd3dzqyxyvihy34h4u&st=zu8ty1mn.

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