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Leveraging peripheral interactions to improve drivers' situation awareness and NDRT efficiency

Key words: Automated driving; Situation awareness; Non-driving-related tasks; Peripheral interaction; Surround sound; Airflow

Corresponding author: Lingyun SUN
E-mail: sunly@zju.edu.cn
ORCID: https://orcid.org/0000-0002-5561-0493

Motivation

- L3 automated driving enables drivers to engage in non-driving-related tasks (NDRTs), but this also weakens situation awareness (SA) and creates risks during takeover. A core motivation is therefore to help drivers reconstruct SA without sacrificing NDRT efficiency.
- Drivers need to understand both surrounding road users and the vehicle's intended behaviors, yet prior work has not adequately communicated these two streams of information in a dynamic and integrated way.
- Conventional visual cues often compete with NDRT for attention, which motivates the exploration of peripheral interactions, such as surround sound and airflow, to support SA reconstruction more naturally.

Main idea

- We propose a multimodal peripheral interaction framework for L3 automated driving, using peripheral cues rather than visually demanding displays, to deliver situational information while drivers engage in NDRT.
- We convey two types of key information by two modalities: surround sound encodes road user information such as category, direction, and distance, while airflow encodes the vehicle's intended behaviors such as braking and steering.
- A further main idea is to organize the interaction around dynamic risk: these two modalities are jointly modulated by time to collision (TTC)-based risk levels, with changes in sound rhythm and airflow frequency continuously reflecting how the traffic situation evolves over time.

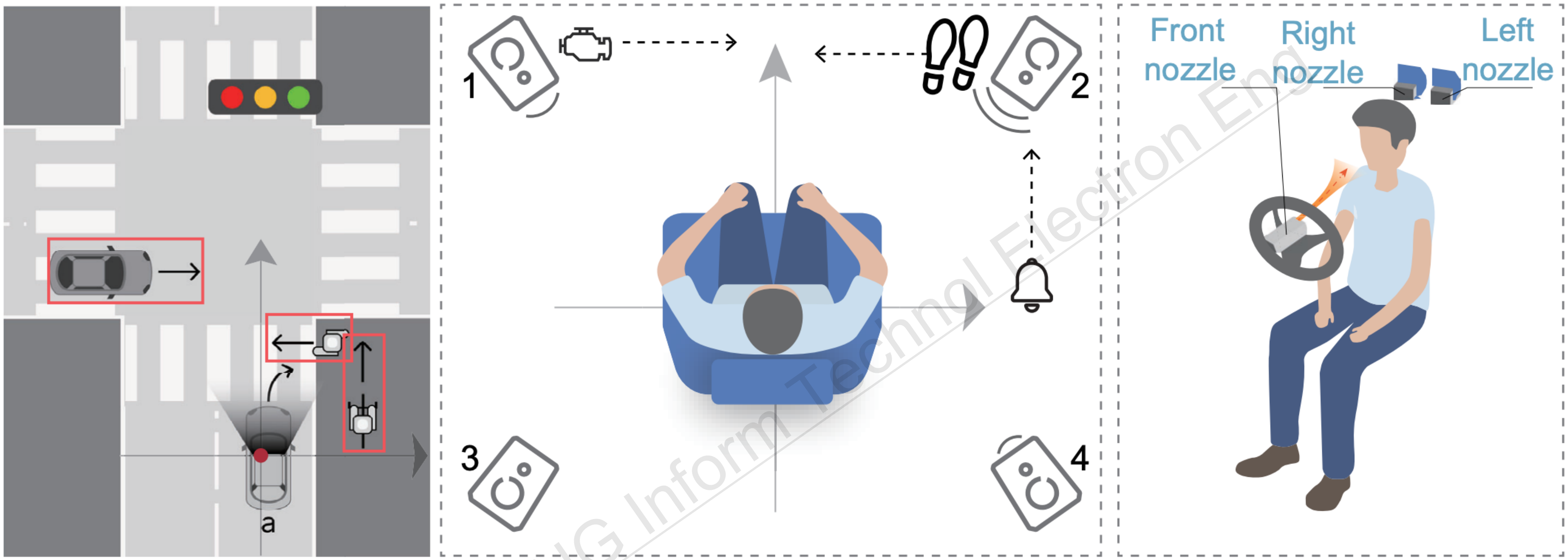
Method

We encode surrounding road users' category, direction, distance, and risk level into surround sound cues, while encoding the vehicle's intended behaviors such as braking and steering, together with their risk level, into airflow cues.

Mapping between driving information and encoded auditory and airflow

Driving information	Attribute	Value	Cue type	Cue value
Road user information	Category	Pedestrian Bicycle Vehicle	Sound effect	Footsteps Ringing bells Motor roar
	Direction	–	Sound angle	–
	Distance	–	Sound volume	–
	Risk level	Low Medium High	Sound rhythm (duration/interval)	60 beats/min (600/400 ms) 120 beats/min (300/200 ms) 240 beats/min (150/100 ms)
Intended behaviors	Behavior	Braking Left movement Right movement	Airflow direction	Front Rear left Rear right
	Risk level	Low Medium High	Airflow frequency (duration/interval)	60 times/min (800/200 ms) 120 times/min (400/100 ms) 240 times/min (200/50 ms)

System overview



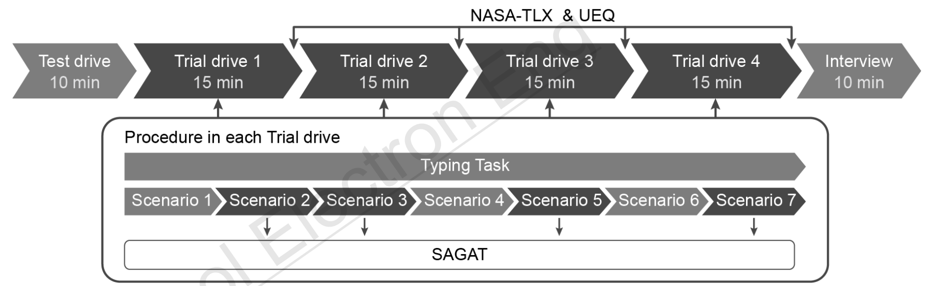
(a) (b) (c)

Conceptual illustration of the proposed multimodal coding for conveying road user information and intended vehicle behaviors through surround sound and airflow cues. (a) A scenario. (b) According to (a), drivers hear the sound of a footstep from speaker 2, a motor roar from speaker 1, and a ringing bell mainly from speaker 2. The sound will move along the dotted line in the speakers. (c) When drivers hear the footstep sound from the right front, they will feel the airflow from the front nozzle, which indicates braking

Study design

We evaluate the proposed interaction design through two consecutive studies:

- Study 1 aims to compare the effects of surround sound, airflow, and their integration.
- Study 2 further tests whether the integrated interaction remains effective under different levels of NDRT difficulty.



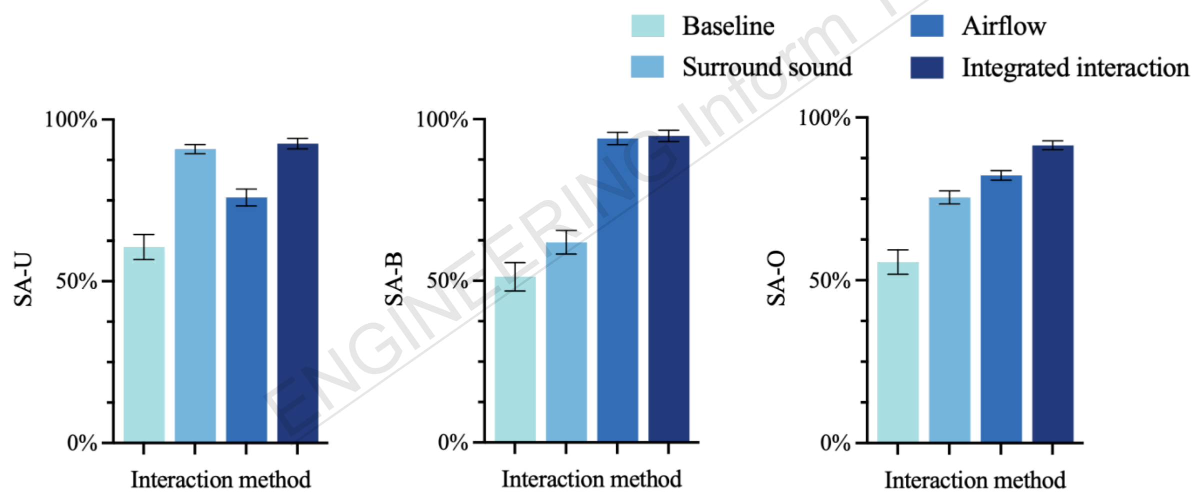
Overview of the study procedure

(a) (b) (c)

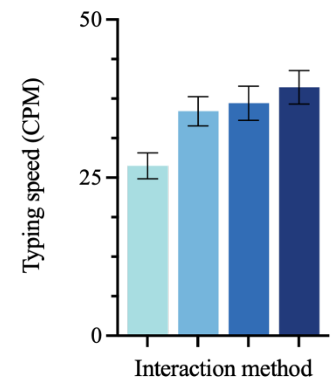
Implementation of the proposed system in the driving simulator

Major results

- ➢Surround sound was more effective for awareness of road user information, whereas airflow was more effective for awareness of intended vehicle behaviors, with a more pronounced gain under the hard task.
- ➢Both surround sound and airflow improved NDRT efficiency.



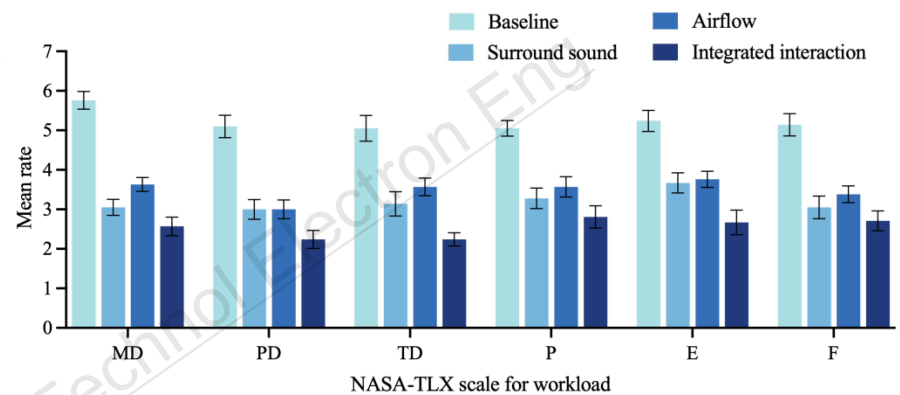
Average scores of SA-U (score of road user information), SA-B (score of vehicle behaviors), and SA-O (overall SA)



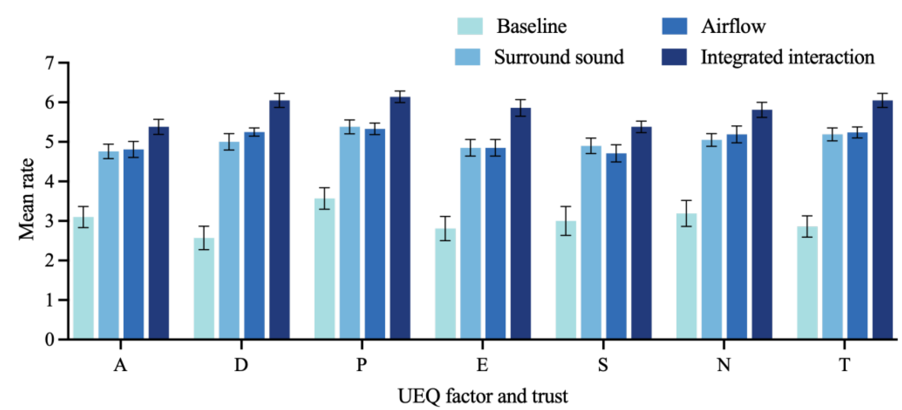
Average performance of NDRT efficiency

Major results

- Both surround sound and airflow reduced workload, and airflow showed slightly higher mental demand than surround sound.
- Both surround sound and airflow improved user experience, trust, and sense of control; notably, airflow outperformed surround sound in sense of control.
- Task difficulty showed no significant effect on UX.



NASA-TLX results in different conditions



Mean values for UEQ factors and trust

Conclusions

- This paper aims to address the tension between reconstructing SA and maintaining NDRT efficiency in L3 automated driving. We propose a peripheral interaction method, using surround sound to convey road user information and airflow to convey intended vehicle behaviors.
- The results showed that both surround sound and airflow improved SA and NDRT performance, while their integration achieved the best overall performance. Across different NDRT difficulty levels, the integrated interaction still improved SA and NDRT efficiency, reduced subjective workload, and enhanced user experience, with a more pronounced SA benefit under harder tasks.

Hanfei ZHU is currently pursuing the PhD degree at Zhejiang University, China, under the supervision of Wei XIANG and Lingyun SUN. His research interests include in-vehicle interaction for automated driving, large-language-model-supported design, and translation of academic research into applications. His work has been published in leading conferences and journals, including CHI and AutoUI.

Wei XIANG is an associate professor with the College of Computer Science and Technology, Zhejiang University, China, where he also serves as a PhD supervisor. His research interests include intelligent design and human–AI interaction, especially human–machine collaboration in complex and high-risk scenarios such as automated driving, intelligent cockpits, and surgical systems. His recent work focuses on collaborative perception in complex contexts, large-model-based experience computing and design, and AI-agent-enabled intelligent hardware. He has led more than 10 national and provincial research projects, conducted extensive industry collaborations, published over 20 papers, and obtained more than 10 invention patents.

Lingyun SUN is a Professor and PhD supervisor at Zhejiang University. His research focuses on artificial intelligence, design intelligence, information and interaction design, and AI-generated content. His work centers on empowering the design industry through AI and advancing design paradigms for the age of artificial intelligence. He has made notable contributions in the formal modeling of sketch thinking, crowdsourced innovation in creative design, automated advertising design, and emotional information expression through multimodal perceptual channels. He has led more than 10 national and provincial research projects, including grants from the National Natural Science Foundation of China and the National Key R&D Program, published over 30 papers in leading venues such as CHI and *Design Studies*, and obtained more than 20 invention patents. His work has also received more than 10 major design awards, including the Red Dot: Best of the Best Award, the iF Design Award, and the China Intelligent Manufacturing Award.