# ThermalDrive - Towards Situation Awareness over Thermal Feedback in Automated Driving Scenarios


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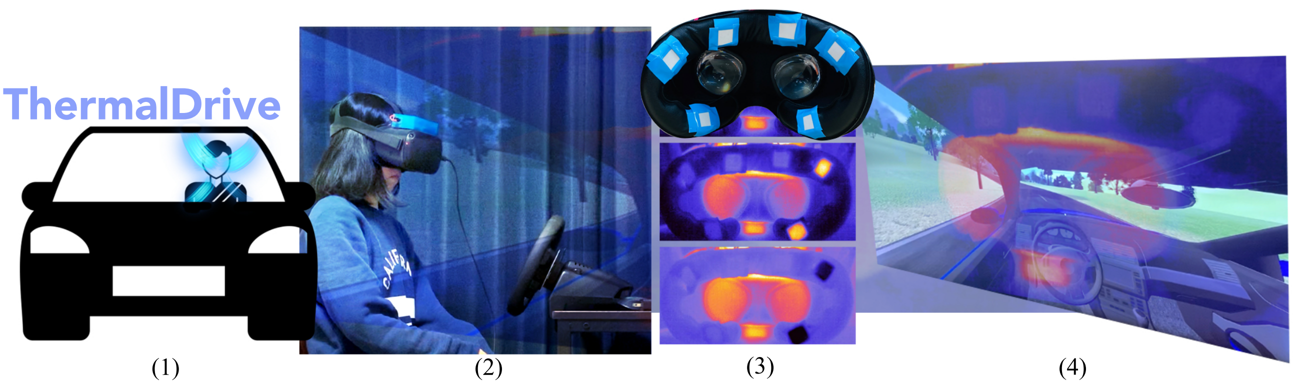


**Figure 1: (1) Concept of ThermalDrive (heat/cold feedback on the face). (2) Experimental Setup: User with the ThermalDrive VR headset in a simulated driving environment. (3) The ThermalDrive Headset Prototype: A VR headset with 6 peltier elements (showing hot and cold actuation on a thermal camera. (4) The virtual environment overlaid with the heat information, obstacles and other cars are encoded over cold/hot feedback accordingly.**


## ABSTRACT

We present ThermalDrive, a thermal interface that provided situational awareness information using thermal feedback on the face of the driver. A prototype is built to simulate the autonomous driving and the thermal interface in virtual reality. We conduct an experiment to investigate the impact of displaying system situation awareness information via the thermal feedback in a VR driving simulation (16 participants). The initial results indicate that the thermal interface might be a suitable feedback mechanism to convey some information in autonomous driving. In particular, cold thermal feedback was effective in terms of notability and user preference.


## CCS CONCEPTS

• **Human-centered computing** → *Haptic devices.*


## KEYWORDS

thermal Interface, human-vehicle interaction, highly automated driving, trust

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## 1 INTRODUCTION

As steering a vehicle is a highly demanding task, there are a lot of research efforts suggesting and evaluating different feedback methods [4, 15, 20]. We are also witnessing the transformation of the automotive industry from building cars towards building partially self driving autonomous systems [1, 19]. This change requires developing new interaction paradigms and driver/passenger interfaces [5, 6].

In driving scenarios where visual and auditory interactions are the main focus, haptic feedback has been introduced by some researchers to further improve human-vehicle interaction [4, 12, 15]. Kohei Sonoda and Takahiro Wada built a tactile display that contributes to driver trust by providing spatial information related



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**Figure 2: Schematic diagram of the driving route of the autonomous vehicle in scene A and scene B.**

to traffic objects [16]. Vibrotactile feedback in the context of haptic feedback has been much studied in autonomous driving situations. Researchers have provided vibration feedback in various vehicles through wearable devices, driver seats, and steering wheels [8, 10, 17]. Multiple vibration patterns have been designed and tested to respond to a variety of specific messages [3, 18]. There is also a lot of thermal feedback research in hci[2, 11], yet usually not applied to the driving context with a few exceptions[4, 13].

In our research, we are particularly interested communicating traffic situations in (semi-)autonomous driving, including transition periods between driver and auto pilot. To this end we present an initial study evaluating a novel feedback mechanism, thermal feedback on the face, to present traffic situations.

The contributions of this paper are as follows: (1) we present the concept of ThermalDrive, encoding the traffic situation (obstacles, cars) in thermal feedback to the face, raising the driver's awareness in regard to status of the autonomous vehicle. (2) We present an initial prototype and a VR simulation, using a headset equipped with 6 peltier elements. (3) We show initial insights from a user test (n= 14), evaluating the prototype, perceived trust etc.

Overall, we believe facial thermal feedback is an interesting modality for semi-autonomous driving and similar application scenarios.

## 2 APPROACH AND CONCEPT

There is a multitude of autonomous driving feedback mechanisms [14]. We believe that haptic, especially thermal, modalities are underused and not so well explored yet. Using haptics, we avoid overstimulating the limited visual and auditory perception channels.

For in car interactions, thermal feedback on the face is not explored so far. To this end we present the ThermalDrive concept, an in-vehicle thermal interface improving the driver's situational awareness of the system's selected actions. The interface provides spatial information related to traffic situation through thermal stimulation. Although our first prototype is integrated in a headset, we envision the future interface to be touch-less (see the concept picture in Fig. 1 ).

In driving scenarios, an autonomous driving system operates with a process that detects the traffic environment, makes decisions, and executes actions, such as controlling the steering wheel, acceleration or brake pedals at the appropriate time. Without a an appropriate interface, it is not easy for human drivers to know the next action of the autonomous driving system before it executes a specific action. For the driver, the lack of information on the future behavior of the automated system makes it difficult to trust the system and leads to anxiety [7]. We believe our concept can increase situational awareness for the driver and in the long run can positively impact trust of the driver in the system.

## 3 INITIAL USER-TESTS

In this study a virtual driving simulator was used, where thermal elements were attached to a VR headset to simulate the non-solid thermal interface, providing participants with thermal feedback in different pattern designs. The ethics board of Keio Media Design approved the study design and hardware setup.

**Apparatus:** Peltier elements (attached to a heatsink) were mounted into the removable foam face interface of the Oculus Quest HMD to set up the thermal interface, as shown in Figure 1. A total of 6 elements is assembled, each with a size of 15x15mm and rated at 2A 3.7V max. 6 elements are split into 3 channels that are controlled with an Allegro A3909 H-bridge chip. The feedback module is controlled by an esp32 module, acting as a Wi-fi Access Point (AP) with Oculus connecting to this AP directly and communicating with the thermal device over Wi-Fi. Computer graphics in VR driving simulations are generated using software (Unity 3D; Unity Technologies).

In the experimental setup, driving scenarios in which an autonomous vehicle passes over a mountain road with fallen rocks in the way were considered. The driving automation level was defined as level 4. There are two simulated automated driving systems set up in Unity. The self-driving car has different decisions and performance in different scenes, as shown in Figure 2.

The participants experienced the two automated driving systems under three conditions. The three conditions are: no thermal feedback, with hot thermal feedback, and with cold thermal feedback.

In hot and cold feedback conditions, the thermal pattern provided by the thermal interface map the location of the obstacle. For example, if an obstacle appears on the right side of the car, the thermal feedback on the right side of the interface will be activated. the thermal element is activated when it is possible for the participant to notice the rock. Thermal feedback lasts 3 seconds at a time and disappears before the autonomous vehicle takes steering action. At a room temperature of 23.5 degrees Celsius, the thermal element is usually 27 degrees Celsius, reaching a maximum of 28 degrees Celsius after heating and a minimum of 26.7 degrees Celsius after cooling.

**Participants.** So far, a total of 16 participants (8 male, 8 female, age 22 to 31) have taken part in the experiment. Two of the experimental runs were invalid (software and recording trouble), leaving us with n =14 (8 male).

**Procedure.** Participants read and signed the consent form and data protection policy. Participants are asked to fill in their basic information (age, gender, driving experience). They were informed about the experimental setup.

Then the participants began the simulated autonomous driving experience. The order of the scenes was counterbalanced. Each scene lasted 30 seconds. When participants experience the virtual driving scenario under hot thermal feedback or cold thermal feedback conditions, each time the self-driving car approaches a rock in the way, the thermal elements at the corresponding location on the VR headset will be passively activated and the participant's face will feel the thermal stimulus. The participant was equipped with only the VR headset and could interact with the virtual environment while sitting in the seat. No other means of interaction were provided.Every time participants completed an experience with a virtual scene, they filled out a twelve-item questionnaire developed by Jian et al. to evaluate the automated system in this scene on a Likert scale of 1 to 7 [9]. Participants were required to go through a total of six different virtual driving experiences and complete six questionnaires. After all virtual autonomous driving experiences were completed, participants were asked to share their overall opinions and comments on the entire experience.

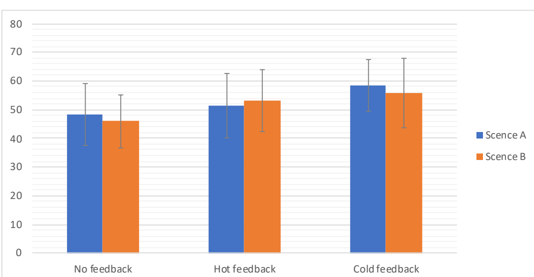


**Figure 3: Trust values in the automated driving system under 3 experimental conditions: no thermal feedback, hot thermal feedback , and cold thermal feedback.**

## 4 INITIAL RESULTS, DISCUSSION AND CONCLUSION

All participants reported that the thermal feedback was perceivable and effective in capturing their attention. Participants could understand the information conveyed by the thermal feedback and the correspondence between the thermal feedback pattern and the position of the rocks. 11 of the 14 participants mentioned their preference for cold feedback. Interestingly, one participant mentioned in the interview that he thought hot feedback was better, but the results of the questionnaire analysis showed that his perceived trust is higher for the system with cold thermal feedback. Seven participants mentioned that hot feedback had a warning effect on them.

A first statistical analysis of the questionnaire suggests that participants trust the autonomous driving system with cold thermal feedback more than the autonomous driving system without thermal feedback. It can be said that under the experimental conditions, cold thermal feedback did enhance people's trust in the autonomous driving system. Repeated measures factorial analyses of variance (ANOVAs), with thermal feedback (non-thermal feedback, hot thermal feedback and cold thermal feedback) and system type (system1 and system2) as the independent variables were used to determine the statistical significance of the independent variables on the dependent variable (participants' perceived trust in automated driving systems as given from the questionnaire [9]). The effect of thermal feedback on the perceived trust was statistically significant, $F(1.612, 20.953) = 10.222$, $p=0.01$. The difference in trust under the influence of non-thermal feedback and cold thermal feedback is statistically significant ($P=0.006$) with a mean difference of 10.036 (95percent confidence interval: 2.846 - 17.225), and the difference in trust under the influence of hot thermal feedback and cold thermal feedback is statistically significant ($P = 0.033$) with a mean difference of 4.857 (95percent confidence interval: 0.346 - 9.368). The comparison of participants' perceived trust values in the automated driving system under the influence of different independent variables in the experimental conditions is shown in Figure 3. The hot thermal feedback and cold thermal feedback provide the same information, yet were perceived quite differently from the users. This work shows an initial exploration of thermal feedback to the face for situational awareness. We presented an initial prototype and showed results from a first user simulation.

## ACKNOWLEDGMENTS

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