Approach for Enhancing the Perception and Prediction of Traffic Dynamics with a Tactile Interface

Matti Krüger
Honda Research Institute Europe
Carl-Legien-Strasse 30
D-63073 Offenbach/Main,
Germany
matti.krueger@honda-ri.de

Christiane B. Wiebel-Herboth
Honda Research Institute Europe
Carl-Legien-Strasse 30
D-63073 Offenbach/Main,
Germany
christiane.wiebel@honda-ri.de

Heiko Wersing
Honda Research Institute Europe
Carl-Legien-Strasse 30
D-63073 Offenbach/Main,
Germany
heiko.wersing@honda-ri.de

Abstract

Participation in road traffic frequently requires fast and accurate understanding of environmental object characteristics. Here we introduce an assistance function and corresponding interface targeted at enhancing a driver's perception and understanding of environment dynamics in order to improve driving safety and performance. The core functionality of this assistance function lies in the tactile communication of spatio-temporal proximity information about one or multiple traffic participants that are on a collision trajectory with the ego-vehicle. We investigate effects of this assistance function on driver perception and performance in a driving simulator study. Preliminary results show that participants were able to intuitively understand and use the assistance function and that its utility seems to increase with task difficulty.

Author Keywords

Tactile Interface; Sensory Augmentation; Sensory Enhancement; Cooperative Driver Assistance; TTC; Eye-Tracking

CCS Concepts

•**Human-centered computing** → **Human computer interaction (HCI); HCI design and evaluation methods; Haptic devices;** *Interaction paradigms; Mixed / augmented reality; User interface design; Interface design prototyping; User studies;*

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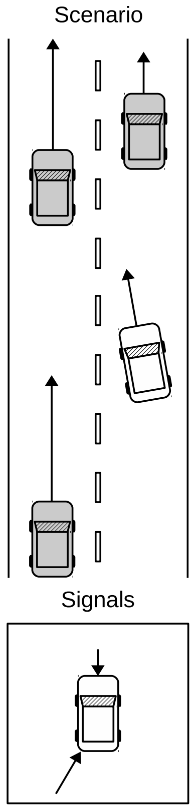

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Figure 1: Traffic scenario and assistance signals. Scenario: Outgoing arrows display the direction and velocity (length) of corresponding vehicles. Signals: Incoming arrows represent the directions and associated urgencies (length) encoded in the signals.

Introduction

Safe participation in road traffic imposes various requirements on a traffic participant. For instance, the driver of a car needs to accurately assess relative velocities and locations of other traffic participants and environmental elements for collision-free driving. When driving, people generally rely on the visual system to obtain environmental information. However, the sequential and directionally constrained nature of the visual system only allows for the perception of a portion of a situation at any moment in time. Monitoring one's surroundings thus places a high demand on the visual system which increases with situation complexity. Here we introduce an approach for an assistance system and corresponding user interface targeted at circumventing limitations of sequential visual situation assessment through multisensory enhancement.

Assistance System

The assistance system is designed to supplement a user's environment perception with two measures: The directions towards *relevant* entities in a user's surroundings and the *urgency* associated with each respective entity. Thereby we classify another traffic participant as *relevant* if the *time to collision* (TTC) between the ego-vehicle (EgoV) and that traffic participant (TP) falls below a safety-critical threshold. We define the *urgency* associated with the respective TP to be inversely proportional to the respective TTC (i.e. smaller TTC = higher urgency). We assume that the information provided by such a system allows a driver to develop a better understanding of the dynamics in his or her surroundings and adapt his or her behavior accordingly. In addition to supporting the understanding of present situations, the predictive nature of the TTC encoded in the signal is further intended to support drivers in anticipating future situations and better understand potential consequences of their own action choices.

Interface

As an interface for the assistance function we use an array of vibrotactile actuators worn like a belt around a driver's waist at seatbelt height. The location of each actuator encodes a direction relative to the EgoV and the intensity of vibration is set in proportion to each direction's *urgency*. Exploiting tactile perception to communicate the directions and urgencies of objects offers several advantages: The risk of producing an unperceived signal is low because it does not require active scanning [18] and is easily localizable [6]. The tactile modality around the core of the body is usually not engaged during common driving scenarios. It doesn't put additional sensory load on the often highly engaged visual and auditory modalities [19, 7, 24]. In addition, when used in conjunction with the visual modality, users may further benefit from multisensory facilitation which entails faster reaction times [22, 8, 14, 1, 4] and a reduced cognitive load [7, 24].

Vibrotactile displays have previously been suggested as promising interfaces for a variety of functions in the automotive [20, 5, 10, 15] and navigation domains [13, 23, 25]. Various approaches thereby encode directions (e.g. [23, 12, 21]) and spatial distances (e.g. [3, 2, 17, 16, 11]) in the presented signals. However, to our knowledge no other system has been designed to present signals which simultaneously encode direction and a TTC-contingent measure and which does so for multiple directions simultaneously. While a pure spatial distance encoding would need to be tuned to a specific speed range, a TTC-based encoding is flexible with respect to different relative velocities and distances. Whether a distance of a few meters should be classified as safety-critical or not is largely dependent on whether and when the trajectories of the respective objects intersect. The predictive TTC-, in contrast to a distance-based encoding, takes this information into account by design and can thus naturally couple signal variation to situation urgency.

Figure 2: Experimental scenario showing the driving simulator, eye-tracker (A), vibrotactile belt (B), and the driving scene from figure 1.

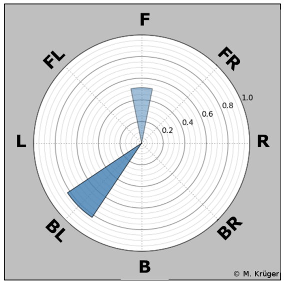

Figure 3: Online visualization of the intensity of tactile signals for the scenario from figure 2.

Table 1: Experiment components and durations.

Description	Duration
Block 1 (no assist)	8 min
System exploration (assisted)	4 min
Questionnaire 1	4 min
Block 2 (assisted)	8 min
Block 3 (no assist)	8 min
Questionnaire 2	4 min

To evaluate the described system and its effects on driver perception and performance we conducted a driving simulator study which will be described in the following sections.

Methodology

Participants
Data from 11 participants (1 female, mean age 33, [24-43]) have been recorded so far. Participants were required to have a valid driving license and corrected-to-normal vision.

Experimental Setup
Experiments were conducted in a static driving simulator with real-car controls for steering, braking and accelerating. Three (50 inch diagonal, Resolution: 3 x 1080p) display panels presented the front, side- and rearview-mirror views of a scene from a drivers perspective at 60 Hz and the SILAB 5.1 driving simulation software developed by the WIVW GmbH (http://www.wivw.de) was used to run the simulation. Participants were equipped with a wearable 120 Hz monocular pupil-labs [9] eye-tracker and a belt containing 16 equally spaced vibromotors (feelspace GmbH, https://www.feelspace.de [13]) with a firmware customized for the purpose of the experiment and the assistance function.

Procedure
Table 1 lists the different experiment components. The study was structured into three experimental blocks and one system exploration block.

Experimental Blocks
In each experimental block participants were given two objectives: The first objective was to drive accident free. The second objective was to maintain a velocity of 120 km/h whenever possible. The traffic on the experiment course was designed such that vehicles on the passing lane were driving noticeably above the given target speed while vehicles on the right lane were mostly driving at a speed of 120 km/h such that the task could best be fulfilled by sticking to the right lane whenever possible. However, individual vehicles on the right lane would occasionally slow down and thus force the participants to either overtake by entering the passing lane in order to meet the velocity goal or alternatively to slow down in order to avoid a crash (see figure 1). In blocks 1 and 3 participants had to complete the task without any further assistance (baseline). In block 2, the described assistance function was active.

System Exploration Block
Between the first and the second experimental block, participants were given the opportunity to explore the assistance function. They were equipped with the described tactile interface without being informed about its function or the meaning of its signals. Instead they were asked to freely explore the system and try to figure out what its signals could mean by driving through a prepared two-lane course with a variety of traffic situations. After the exploration phase, participants completed a questionnaire and took part in an interview targeting their perception and understanding of the assistance function. Finally the experimenter informed the participant about the true nature of the assistance function to ensure correct understanding before continuing with the second experimental block.

Conditions
Two independent variables were varied throughout the experiment: The availability of the assistance function (Block 1 and 3 vs. Block 2) and the task difficulty (*difficult* vs. *easy*). We defined difficulty in terms of the time available for a driver reaction once a front vehicle started to decelerate.

Measures
Overall we are interested in whether and how people adapt to the described assistance function. In a first step we in-

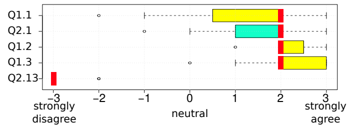

Figure 4: Boxplots (n = 11) for a subset of responses concerning interface understanding. Yellow: Questionnaire 1; Turquoise: Questionnaire 2; Red: Median response; Q1.1: *The belt signals felt comfortable to me.*; Q2.1: *The belt signals felt comfortable to me during the driving task*; Q1.2: *I understand the belt signals*; Q1.3: *I felt that I could change the belt signals with my own behavior*; Q2.13: *The meaning of the belt signals remained obscure to me.*

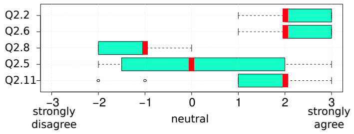

Figure 5: Boxplots (n = 11) for a subset of responses concerning system utility. Q2.2: *I made use of the belt signals for my driving behavior*; Q2.6: *I felt supported by the belt signals in the driving task*; Q2.8: *The driving task was easier without the belt signals*; Q2.5: *Easy situations became easier with the belt signals*; Q2.11: *Difficult situations became easier with the belt signals.*

vestigate if people are able to perceive and interpret the spatiotemporal information provided through the tactile interface. In a second step we test whether the provided information is integrated in peoples' perception of their surroundings and what consequences this integration can have on their experience and performance. For this purpose we collect the following objective and subjective measures:

Simulation Data
Data from the driving simulation were collected in order to evaluate task performance. Specifically the deviations from the target velocity as well as the ratios of successful overtaking scenarios, number of accidents and situations classified as critical will be assessed based on driving data.

Eye-Tracking Data
Eye-Tracking was used to provide further behavioral measures to assess changes in gaze behavior such as in the distributions of fixations and saccades between areas of interest that could indicate behavioral adaptations.

Questionnaires and Interviews
Participants were given questionnaires with seven point Likert scales after the system exploration phase and after the third experimental block. The first questionnaire was primarily designed to asses the intuitive understanding of the system and its subjective utility. In total, nine questions were asked, targeting function understanding (5), subjective comfort (2) and signal perception (2). In the second questionnaire, four questions concerning function understanding and comfort were repeated to assess potential changes after further exposure to the assistance function. In addition, ten questions were designed to mainly tackle the subjective experience of the scenario and the utility of the assistance function as a function of task difficulty. Interviews were further used to gain insights about the participants' perception and understanding or the assistance function.

Results and Outlook

Here we report only preliminary results from questionnaire data. Data from the first questionnaire show that the initial understanding of the assistance function and its perceived utility was high (see figure 4, Q1.2, Q1.3). This shows that participants were able to develop an intuitive understanding of the function without any prior explanation within only four minutes of system exposure. A comparison with the data from questionnaire 2 shows that the certainty on the function understanding increased further over time (figure 4, Q2.13). Comfort of the interface was rated as almost equally high in both questionnaires (figure 4, Q1.1, Q2.1), indicating that prolonged use does not lead to annoyance. All participants indicated making use of the signals (figure 5, Q2.2, Q2.6) and the driving task was overall rated as easier when driving with the system (figure 5, Q2.8). Data from the second questionnaire indicate that the perceived utility of the assistance function increased with task difficulty (figure 5, Q2.5, Q2.11). However, the variance in the responses suggests that some participants could subjectively benefit more from it than others. A first subsequent inspection of the metadata indicates that individual driving experience might be a moderating factor and should be considered in future analyses. Overall, the subjective data suggest that the assistance function can support a driver's understanding of dynamic traffic situations. Interview responses confirm these indications. Many participants reported having more freedom in monitoring their environment and being able to better assess situations with the system, resulting in an elevated sense of safety. In a next step, we will further analyze the recorded objective data. In particular, we will investigate whether the utility of the function also objectively increases with task difficulty in terms of task performance. Furthermore, we want to explore whether the function usage leads to behavioral adaptations such as changes in strategic gaze behavior compared to our control conditions.

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