Evaluation of Variables for the Communication of Uncertainties Using Peripheral Awareness Displays

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Abstract

The communication of system uncertainties may be key for overcoming challenges related to overtrust in automated driving. Existing approaches are limited to conveying uncertainties using visual displays in the instrument cluster. This requires operators to regularly monitor the display in order to perceive changes which impedes the execution of non-driving related tasks and thereby degrades the user experience. This study evaluates variables for the communication of uncertainties using peripheral awareness displays, considering changes in brightness, hue, position, size, pulse frequency, and movement speed. All variables were assessed in terms of how well participants can distinguish different instances, how logical they are, and how interrupting to a secondary task. With the exception of changes in position, all variables were ranked highly in terms of logic while changes in pulse frequency were perceived as most interrupting. The results inform the development of unobtrusive interfaces for uncertainty communication.

Author Keywords

Peripheral awareness displays; uncertainties; trust

CCS Concepts

•**Human-centered computing** → **User interface design;** *HCI theory, concepts and models; Interaction techniques; Visualization design and evaluation methods;*

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Key Term

Uncertainties: Refer to the confidence of the automated system, whereby uncertainties are induced during data acquisition, transformation, and output generation.

Introduction

Vehicles equipped with automated driving allow users to engage in non-driving related tasks (NDRTs), leading to a significant shift in the driving experience of human operators [12]. Instead of executing the dynamic driving task (DDT), other activities may become the primary task of the user [13]. Upcoming vehicles equipped with conditionally automated driving systems entail substantial human factors challenges as they demand users to be fallback-ready and perform the DDT in cases of system failures or other critical situations within a reasonable amount of time [7, 29]. Previous research has indicated that it is beneficial to communicate the uncertainties of a system to prepare users for such takeovers despite the engagement in NDRTs [1, 10]. The existing proposals, however, do not explore various interface options but solely rely on visual information presented in the instrument cluster. This requires users to constantly shift their attention between road, instrument cluster, and NDRT, leading to an increased probability of missed critical events. As pointed out by Moray and Inagaki [24], users are likely to miss important information in highly reliable systems even if they employ an optimal attention allocation strategy. Consequently, an interface is needed that allows users to acquire information about the uncertainty of the system without having to regularly monitor a display. Thus, users can fully focus on NDRTs while the system is safe and will be notified as soon as this changes. The unobtrusive uncertainty communication can be achieved using peripheral awareness displays, which can be defined as interfaces that are mostly in the periphery of the user's attention and convey information regarding one or more tasks of a user [20, 19, 22, 21, 18, 30, 28, 34, 31]. To enable users to fully engage in their primary task, the interface must remain unobtrusive unless the information it conveys is urgent. This should then be indicated with an increasing salience. To achieve this, Matthews et al. [19] define four distinct notification levels that correspond to differences in importance: change blind, make aware, interrupt, demand action. For users to be able to peripherally monitor a display, the information must further be displayed in a manner that allows its comprehensibility at a glance. This requires the modification of the raw input towards an increased abstraction [28]. The more abstract the conveyed information, the faster it is to perceive at a glance [17]. Principal evaluation criteria for peripheral awareness displays are *awareness* and *degree of interruption* [22].

Related Work

Several research projects have investigated the use of peripheral awareness displays in driving. Löcken, Heuten & Boll [14], for instance, designed a peripheral light display to support lane change decisions. Further studies used light patterns to support drivers with maintaining a specified driving speed [23], others explored the use of peripheral light to help operators handle multiple tasks at once [4] and to communicate takeover requests [5]. The majority of approaches used light strips to communicate information as these can easily be fitted into existing cockpits and do not take up much space. Löcken et al. investigated nine different locations for light strips in a vehicle cockpit. The results suggest that particularly locations on the dashboard are well-suited, whereby a placement in the instrument cluster was preferred by most participants. Further, a position on the upper part of the centre console received high ratings.

Concept and Preliminary Evaluation

Ideally, peripheral awareness displays should address human sensory channels that are not preoccupied in order to avoid bottle necks [33]. While operators are likely engaged in NDRTs that require (focal) visual and auditory attention [27], the haptic as well as peripheral visual channel remain unoccupied. Communicating content solely relying on pe-

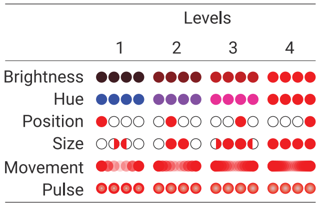

Figure 1: Schematic representation of the levels implemented for each light variable

Figure 2: Apparatus: (A) tablet with fixation point attached to its centre; (B) peripheral light strip

	HSL	ΔE^*_{00}
1	(240, 100, 50)	22.20
2	(280, 100, 50)	29.41
3	(320, 100, 50)	34.22
4	(360, 100, 50)	-

Table 1: Colour codes for hue variable; ΔE^*_{00} indicates the colour difference between the colour in the same row and the row below

ripheral vision, however, entails several problems. Foremostly, what users see depends on their attention allocation and state of mind. Phenomena such as change blindness and inattentional blindness highlight that operators may miss even salient changes in their field of view. The *change blindness* phenomenon highlights that users cannot perceive changes in the environment if they occur during eye saccades, blinks, or other interruptions to vision [9]. However, even if users' vision is not interrupted, they may fail to perceive salient cues because no attention is placed on them. This is referred to as *inattentional blindness* [26]. Further, peripheral light displays that rely on colour may be characterised by an insufficient accessibility for users with colour vision deficiency. In contrast, dynamically communicating content solely relying on haptic feedback is equally problematic, as haptic stimuli result in attentional spikes and an interface that vibrates cannot be in the periphery of the users' attention [11]. Thus, a combination of both modalities can be addressed by the interface: peripheral vision as a means for providing dynamic feedback, haptic stimuli to indicate changes for higher notification levels. This paper focuses on the preliminary evaluation of peripheral light variables. In a first step, variables with a maximum degree of abstraction were analysed. These variables are expected to be easier perceptible at a glance than more complex representations, for example words. In order to achieve maximum abstraction, variables derived from the most basic building blocks for visual interfaces, *visual variables*, were analysed [2, 8, 16, 25, 15]: brightness, colour hue, size, position, movement, and pulse. This study evaluated (a) how well users can distinguish between different levels of cues based on each of the variables, (b) to what degree the variables can be considered logical for the representation of uncertainties, and (c) how much the user feels interrupted.

Design, Method, Procedure and Apparatus

A total of 25 participants (7 female) with an average age of 30.72 years (SD=9.02) and no diagnosed visual impairment participated in the experiment. For the duration of the study, participants were seated in a driving simulator in automated mode to generate context. Variables were communicated using a light strip attached to the top of the centre console (length: 50 cm, 77 LEDs, see Figure 2) and the experiment was conducted in a soundproof laboratory with controlled lighting. All questions were displayed on the centre of a tablet attached to the centre console and participants had to respond via touch input without focusing directly on the light strip. To assess awareness, participants were required to demonstrate that they can confidently distinguish between different notification levels. For each of the variables, four distinct instances were designed (see Figure 1). As a base colour, red (RGB: 255, 0, 0) was chosen as it is often used to represent danger or urgency. *Brightness* was varied linearly from RGB(255, 0, 0) to RGB(64, 0, 0). *Colour hue* was assigned based on the hot-cold metaphor, varying the hue value linearly from red to blue (RGB: 0, 0, 255) (see Table 1). Traffic light colours were avoided due to the prevalence of protanomaly and deuteranomaly, i. e. red-green colour blindness. *Size* and *position* were varied linearly based on the number of activated LEDs. The flashing rate for *pulse* and *movement* was limited to 3 Hz to prevent triggering seizures related to photosensitive epilepsy [6]. Similar to the approach for the other variables, the pulse frequency and movement speed were then linearly reduced to one fourth of the maximum value. For each variable, the participants were initially shown all four levels in the intended order. Then, participants were shown the four levels in a randomised order. To evaluate if participants can distinguish levels, fuzzy membership functions were used [3]. This enables the researcher to assess the confidence of users in assigning a level. On a scale from 0 to 10, users indicated to which degree the currently displayed level corresponds to each of the four introductorily shown levels. For instance, if users were not able to distinguish if the light was blue (level 1) or purple (level 2), they indicated this with intermediate scores for membership levels 1 and 2 and low scores for the remaining levels. Once participants had evaluated all variables in this way, they were asked to indicate on a 7-point Likert scale (a) to which degree they considered the variable to be logic for uncertainty communication and (b) how interrupted they would feel by it.

Variable	% (✓)	min MD
Brightn.	100	0.04 (lvl 2)
Hue	100	0.60 (lvl 3)
Position	100	3.15 (lvl 2)
Size	100	0.32 (lvl 2)
Movem.	50	-
Pulse	100	0.60 (lvl 3)

Table 2: Level assignment scores; %(✓): percentage of correctly assigned levels as indicated by mean scores (i. e. correct if membership level with highest mean score corresponds to actual level); mind MD: minimum mean difference between correct membership level (indicated in parantheses) and the membership level with the next largest mean score

Variable	Logic	Interrupt
Brightn.	4.32	2.92^{**}
Hue	5.32^{**}	2.24^{***}
Position	**3.52**	2.84^{***}
Size	5.04^{*}	3.00^{**}
Movem.	5.04^{*}	3.52
Pulse	5.24^{**}	**4.60**

signif. of p-values: *.01, **.001, ***<.001

Table 3: Mean scores for logic and perceived interruption, asterisks indicate significance of p-values for Holm-corrected post-hoc t-tests relative to the bold, red value in the column

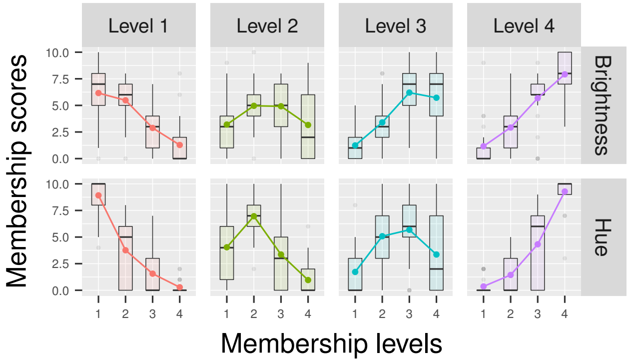

Figure 3: Membership functions for *brightness* and *hue*; subplot columns depict the responses for each level, for example the subplot in the second row of the leftmost column depicts the membership levels participants assigned to the *hue* level 1

Results and Discussion

It must be noted that no generalisations about the comparability of the variables can be made as they are on different scales. Specifically, it is unclear which difference in hue maps to which change in, for instance, position. However, the cockpit dimensions confine the physical size of the light strip and other aspects, such as photosensitive epilepsy, limit the flashing rate. Thus, the results of the study can be considered valid for the special case in which a light strip is placed on top of the centre console in the specified lighting and usage situation. Figure 3 shows the fuzzy membership functions for *brightness* and *hue*. For a correct sorting result, participants should have rated membership level 1 highest for level 1, membership level 2 for level 2, etc. To assess confidence, mean values and differences to the next highest score were computed. Table 2 summarises the results. The results indicate that participants were able to distinguish between four different levels for all variables, with the exception of *movement*. Mean differences suggest different confidence levels. Specifically, *brightness* was characterised by low mean differences, followed by *size*, *hue*, and *pulse*. *Position* was rated with the highest confidence. Within-factors one-way ANOVA were performed to assess the difference in logic and annoyance between variables [32]. The scores for both logic $(F(5, 24) = 4.539, p < .001)$ and annoyance $(F(5, 24) = 9.265, p < .001)$ differed significantly (see Table 3). This shows, that animation based variables work well for higher notification levels such as *interrupt* or *demand action*. Using a change in position as an indicator for system uncertainties should be avoided as it is not deemed logical for users.

Conclusion

The presented study evaluated six abstract variables in terms of their suitability for communicating uncertainties of automated driving systems in a vehicle cockpit. The results indicate that particularly changes in light position, pulse frequency, and hue are easily distinguished by participants engaged in a secondary task. With the exception of *position*, all variables were rated as somewhat logic for uncertainty communication, while *pulse* was perceived as most interrupting. The findings inform the design of peripheral awareness displays for uncertainty communication.

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