Deriving User Requirements for Haptic Enhanced Automotive Touch Screen Interaction

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Abstract

User demand for seamless touch interfaces in cars is ever increasing. The European project HAPPINESS targets the introduction of haptic feedback on touch surfaces with printed actuators. Initial user studies were conducted at Bosch to define requirements for virtual haptic push buttons and the proper layout of touchscreen controls.

Author Keywords

HMI; touch interfaces; haptics; user technologies

1. Objective and Background

Over the last years, the automotive dashboard has changed tremendously due to the enormous increase of functions that drivers can control while driving, e.g. [1]. While it was common to add a new control when introducing new functionalities – predominantly with a 1-to-1-mapping – this is obviously no longer suitable in current cars [2]. User demand for aesthetically pleasing and seamless interfaces is ever increasing, with touch sensitive interfaces to interact with multifunctional systems now being commonplace, e.g. [3].

The loss of mechanical feedback, which is a consequence of the displacement of real physical controls with virtual controls, leads to a reduced interaction quality and user experience. Even more important are safety concerns arising from the increased need to shift gazes towards the infotainment system in order to visually capture control elements. The vital approach to address these concerns is thus to enrich touch screens with haptic feedback in a way that enables eyes-free capturing of controls with the sense of touch.

The goal of the research project HAPPINESS (Haptic Printed and Patterned Interfaces for Sensitive Surfaces), funded by the European Commission under the H2020 program, is to replace mechanical components and take advantage of touch technology with printed TOLAE (thin and organic large area electronics) technologies, while restoring haptic feedback and achieving an integrated product directly assembled for the final manufacturer. To achieve and promote this goal, the HAPPINESS project will demonstrate a small-scale prototype of an automotive dashboard with touch sensing and realistic, multi-facetted haptic feedback capabilities.

Several concepts to haptify virtual UI (user interface) control elements have been presented prior to the HAPPINESS project, with a strong focus on haptifying push buttons [4], which are considered as the primary UI control element for touch based interaction. The most mature approach to date is to actuate the complete display with a moving mass actuator mounted behind the display. While this approach has some constraints that motivate the HAPPINESS project, it is well suited to analyze user requirements on haptic feedback design.

As stated previously, one of the main goals of the haptification of virtual in-vehicle touch controls is the reduction of visual driver distraction, i.e. enabling drivers to capture control elements without having to look at them. To achieve this goal, a simplified model of user touch screen interaction is developed, leading to a holistic approach of virtual button haptification. A first user study was conducted to parametrize a single haptified virtual button on the given prototype. The implications arising from the simplified model of user touch screen interaction on multiple button layout are addressed in a second user study.

2. Single button haptification

A simplified model of user touch screen interaction with virtual push buttons, shown in Figure 1, is used throughout the initial stage of the HAPPINESS project to identify key success parameters for natural haptic enhanced touch interaction. This model enables interaction designers to identify the interaction states that can be enhanced with haptic feedback by looking at a human finger moving over a touch surface to find and activate a desired virtual push button.

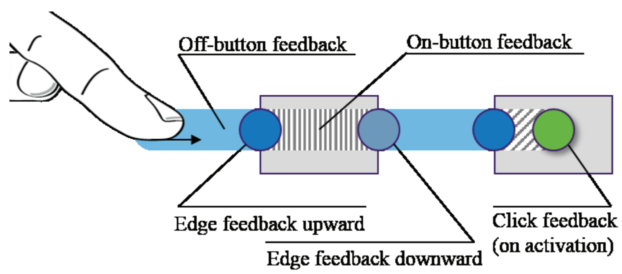

Figure 1. **Simplified model of user touch screen interaction, visualizing interaction states that can be enhanced with haptic feedback**

The best studied synthetic haptic cue for virtual buttons is a click feedback signaling the activation of a button, which is focused in various previous studies, e.g. [5], [6]. The process of pushing down a button can be further enhanced with haptic feedback designed to mimic the force-displacement-curve [4]. The transition of a button edge, i.e. moving the finger from the non-interactive background on a button and vice-versa, can be enriched with an edge feedback, where further differentiations between upward and downward movements are possible [7]. Different haptic cues can be provided to enable users to differentiate between an on-button and off-button finger movement, where it is straightforward to have no haptic feedback in the latter case [8]. Finally, different textures can be used on different buttons to enable the identification of buttons, which was presented in the Bosch CES 2016 haptic feedback touchscreen demonstrator, but is not further captured in this paper.

General recommendations on the design of the aforementioned haptic cues can hardly be made, as the parametrization strongly depends on mechanical properties of the actuated system, e.g. resonant frequencies. Nevertheless, psychophysical findings e.g. on maximum skin sensitivity should be taken into account when designing haptic cues, if possible. To optimize the haptic feedback on the available prototype system, a first user study was conducted focusing on the user-centered design of edge and click feedback. A symmetric edge feedback was chosen, with no further differentiation between upward and downward edges (cf. [7]). Furthermore, different types of on-button feedback were applied in a position-based manner (i.e. vibration during on-button movement, no vibration during off-button movement). While some kind of haptic feedback on buttons was found to be desired by subjects, further investigations on a more natural application of on-button feedback are ongoing.

A prototype haptic feedback touchscreen was assembled at the User Technologies Research lab at Robert Bosch Corporate Research, utilizing a voice coil actuator (Visaton EX45S) for haptic actuation. This type of actuator offers a broad design freedom and is thus well suited to study the aforementioned questions. The prototype haptic feedback touchscreen utilizes a 7” resistive touchscreen, which is replaced with a capacitive touchscreen in the meantime, as a further outcome of the user studies.

The initial design space for haptic signals is made up by frequency *f*, amplitude *a,* and duration *d* of the haptic actuation. Some possibilities exist to shape the haptic signal, e.g. with patterns of increasing or decreasing vibration etc., which further increases the design space. Several steps were performed to reduce the design space in order to be efficiently handled by end users. Pretest were conducted, where a duration of $d=2/f$ was identified to produce crisp click-like feedback in the given prototype system setup. The amplitude of the edge feedback was set to 80% of the amplitude of the click feedback as a further outcome of the pretests. Experts in human-machine interaction and haptic design further made a preselection of 4 different click feedback signals C1-C4 and four different edge feedback signals E1-E4, which differed only in frequency, ranging from 125 Hz (E1) to 200 Hz (E4) in steps of 25 Hz, and from 150 Hz (C1) to 225 Hz (C4) in steps of 25 Hz respectively.

Four buttons were aligned horizontally across the 7” touchscreen. In a first setup, the four different edge signals were applied on the buttons, while no click feedback was provided on the buttons. In a second setup, the four different click feedback signals were applied on the buttons accordingly, with no edge feedback at that time. End users were asked to select their favorite edge and click signal based on their subjective preference. The results are shown in Figure 2.

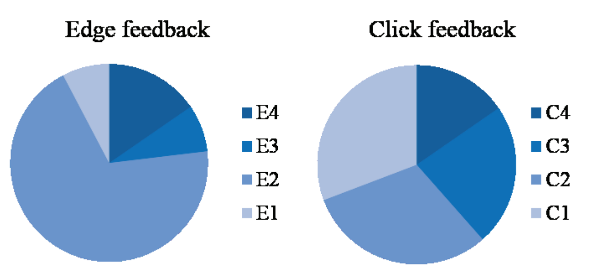

Figure 2. **User preference of different haptic signals for edge and click feedback**

The edge feedback E2 was preferred by more than 70% of end users. According to the comments made by the users, the perceived strength of the edge feedback was the key parameter, with both E1 and E4 being too weak, hardly perceivable and imprecise, and E3 being too strong. The results of the click feedback selection study were less clear with both C1 and C2 being equally preferred by users, and even C3 and C4 not being strongly disliked. As an interesting side note, C1 was only preferred by female subjects, while the major reason for other subjects to not prefer C1 was its weakness. C2 was chosen for the final implementation, also supported by the fact that it got least negative comments by users.

3. Multi button arrangement

The simplified model of user touch interaction, especially the edge feedback concept, has an influence on the size and arrangement of buttons in UI layouts covering more than one button, which is considered as the standard case. When multiple buttons are arranged with a non-zero spacing in-between, and edge feedback is provided at the physical location of virtual button edges, a minimum button size and spacing needs to be kept to allow for a clear recognition of adjacent edges. The maximum button size and spacing is mainly determined by visual design aspects. A second user study was carried out to evaluate the effect of button size and spacing on end user subjective preference.

The minimum button size is mainly influenced by the low pointing accuracy of the human fingertip, which is further impaired under driving conditions [9], and the touch bias caused by parallax [10]. Button widths of 15 and 20 mm (fixed ratio between height and width) were chosen in the second user study. These sizes are in the range of 17.5 mm, a value below which some performance measures of in-vehicle touch interaction severely degrade [11]. Button spacing of 5, 10 and 15 mm were chosen in the second user study mainly for visual design aspects, as the authors are not aware of any published study on minimum button spacing so far.

The experimental design of the second user study required users to select their preferred button arrangement, defined by 3 horizontally aligned buttons at a given size and spacing. 6 different arrangements were achieved by combining each size with each spacing. All arrangements were evaluated in pairwise comparison, resulting in a total of 15 choices users had to make between two different arrangements presented in the top and bottom half of the touch screen, respectively. While users were asked to focus on the haptic characteristics while capturing the buttons with a moving finger, the visual appearance of the different arrangements certainly plays a role in user preference, which is however also the case in real world applications.

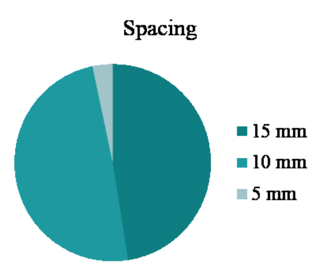

Figure 3. **Preferred button spacing**

A slight tendency towards larger buttons was observed in the user preference. However, both 15 mm and 20 mm button sizes allow for a clear recognition of adjacent button edges. Users did not report on any issue they had with identifying the adjacent button edges on both the smaller and the larger button. Concerning button spacing, a minimum value of 10 mm was found to be preferred by users (see Figure 3). Note that this figure only shows the results of comparisons of different button spacing. Results of the user choice between equally spaced arrangements (e.g. 15 mm buttons with 15 mm spacing and 20 mm buttons with 15 mm spacing) are excluded from this evaluation. A 5 mm spacing was selected in less than 5% of cases. There was no clear preference for 10 or 15 mm spacing.

4. Impact and Outlook

The user studies we conducted at Robert Bosch Corporate Research provide initial design rules for haptic enhanced touch based interaction with virtual buttons. Most previously published studies focus on the haptic design of selected interaction states, mainly on the design of click feedback signals. The simplified model of touch based interaction provides a holistic view on the haptification of virtual buttons.

The results of the first user study on single button haptification depend on the special characteristics of the demonstrator setup, which should be taken into account when transferring these results. The results of the second user study however, especially the minimum button spacing, are to be considered as a design rule for future UI layouts. To the best of our knowledge, results on minimum button spacing due to haptic feedback provided at the button edges, were not published before.

Work is currently in progress to expand the simplified model of touch interaction, and to evaluate the effect of real-road driving conditions on touch-based user interaction.

5. Acknowledgements

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