A comparison of vehicles user interface modalities in terms of User Experience

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***Abstract*— In this paper we report on a user study which focuses on user experience when users interact with In-Vehicle Infotainment System (IVIS) through three different input modalities. We compared two relatively new approaches such as touchpad-based input and free hand gesture input to the widely used input interface based on buttons on the steering wheel. In order to evaluate the user experience provided by three different input interfaces of IVIS the User Experience Questionnaire (UEQ) was used. The results of the study are showing clear differences between different input devices favoring the conventional buttons on the steering wheel.**

I. Introduction

Human-machine interaction in vehicles is challenged by rapid development of technologies and is improving fast. The in-vehicle infotainment system (IVIS) is moving from interaction with buttons and rotary knobs to touchscreen and free hand interaction. In addition, the functionalities of infotainment systems are increasing and need to be presented to the driver in a practical non-confusing way. Some vehicle manufacturers are moving completely to a touchscreen based user interface, others are using a combination of buttons, knobs and touchscreen[1,2]. They are introducing different input modalities of the control system as touchpad, speech recognition or free hand recognition. The manufacturers are not united which user interface modality is best for their infotainment system. There are many factors which need to be taken into account – usability, simplicity, aesthetics, distraction from driving and user experience quality.

Loehmann et al. are showing the importance of user experience in the automotive industry is steadily growing. They state that especially free hand gestural interaction could enhance the user experience without causing any safety related problems. They also introduce different concepts of how to implement free hand gesture into vehicles, mainly for intention detection which could help to reduce visual distraction of the driver [3]. Research of BMW also shows that gestures can be recognized by simple state of the art hardware and easy gestures can be used for simple interactions with the IVIS [4]. BMW already implemented a simple free hand gesture interaction system in the IVIS of the 2016 Series 7 [5].

Touchpads are also showing promising results as a device used in the vehicles infotainment system. Burnet et al. showed that using a touchpad is much better than touchscreens and rotary knobs f or simple tasks as setting a cabin temperature [6]. Norberg & Rahe found in their study that a rich user interface could be developed which users accepting and liking [8]. Audi is already using a version of a touchpad for interaction with the infotainment system in some premium models [7].

To minimize visual distraction we decided to present IVIS information on a Head-up Display (HUD). A study of Liu and Wen compared a HUD with a head-down display and showed that when using the HUD the user response times are better, there are less driving speed variances and it causes less mental stress [9].

The research questions for this study were:

- Do free hand gestures and touchpad interaction offer better user experience than accessible buttons on the steering wheel when operating an IVIS?
- Does difficulty of driving conditions (easy vs. hard) impact the perceived user experience of any of the evaluated input modalities?

II. Methodology

A. Driving simulator

The study was performed in a high-performance compact driving simulator, which can be seen on Figure 1. The simulator consists of a real car seat, a Fanatec steering wheel [10], model ClubSport Steering Wheel Porsche 918 RSR [11], Fanatec ClubSport pedals V2 [12] and three Samsung 48’’ curved TV screens[13]. This presents a near to real driving environment with more than 120 degrees horizontal field of view covered. The software used to create the driving scenario was SCANeR Driver Training form OKTAL [14], which was provided by Nervteh [15]. It enables creation of custom driving scenarios and implementation of the infotainment system and controls directly into the simulator software.

Figure 1: Driving simulator setup

B. *User interface*

For this user study we designed a simple interface based on a hierarchical menu structure consisting of five items on each level. The menu has 3-5 levels, dependent on the task. It was presented to a driver through a HUD in the lower left region of the windshield. The selected item was always highlighted with neutral green color.

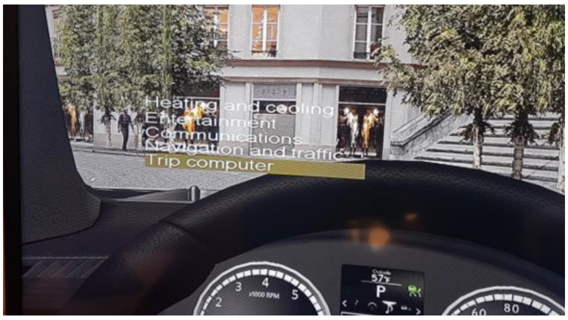

Figure 2: HUD: five lines are representing the menu items and the green bar highlights the selected element

The interface was operated through three different input modalities (i.e. buttons on the steering wheel, touchpad and freehand gestures interface). The first interface was a Fanatec steering wheel where the directional button on the right side of the wheel was used for performing input functionalities. This button could be pushed up and down to move the selection bar up or down in the menu, or pushed left or right to confirm the selection and return to the previous level.

The second input device was the touchpad which was in our case implemented on an Android smartphone. A custom application tracked the finger movements on the screen and sent the data to the simulation software. The phone was mounted on the right side of the seat on an ergonomically appropriate location. We choose this location based on observations in existing vehicles where similar devices are mounted. This position enables to rest the elbow on the armrest and the touchpad can be reached with the finger without a big effort. Sliding forward and back represented moving up and down in the menu. Tapping on the device represented confirming the selection and sliding to the left was returning to the previous menu level.

The third input device used for a freehand gesture interaction was the Leap Motion Controller. It tracked the right hand's palm position and direction. Changing the palms pitch up or down enabled the user to choose an element by pointing to its direction. In order to confirm the selection the user had to hold the palm still in the desired position for 1000 ms. In order to return to the previous menu level the user had to roll the palm in the right direction for 90 degrees.

C. *Participants and study design*

16 male and 14 female subjects participated in this study. The participants were divided into two groups. Group A was driving in an easy environment on a landside road. There were no intersections in this scenario and user's task was only to follow the leading vehicle. Group B was driving in a difficult traffic environment in a city center with high-density traffic. A navigation system guided the driver on a route through intersections. While driving, each participant was instructed to perform seven different tasks (e.g. set the temperature to a specific value, change the radio station, check a message, etc.). The traffic conditions represented a *between subject variable* and the interface type represented a *within subject variable*. Each participant performed a slightly different set of tasks three times, each time with a different input interface but the same traffic conditions. The sequence of the interfaces/modalities was counterbalanced.

D. *Tasks*

Three different set of tasks were prepared. Each set contained three simple tasks, where less than five individual actions were required to complete the task. The last action was always in the second or in the third level of the menu, e.g. `Temperature->Seat warmers->On`. Additionally four difficult tasks were also performed which needed more actions to be completed and the final item was on deeper levels of the menu, e.g. `Entertainment->Music->Authors->Justin Bieber->Baby`.

E. *User Experience Evaluation*

The user experience was evaluated with the User Experience Questionnaire (UEQ) [16]. The whole study was performed in Slovenian language and the Slovenian version of the UEQ was used. The participant filled the UEQ three times, every time immediately after completion of one set of tasks using one input modality.

The UEQ is a set of 26 questions on a scale from -3 to 3, where the extremes represent two opposite descriptions for

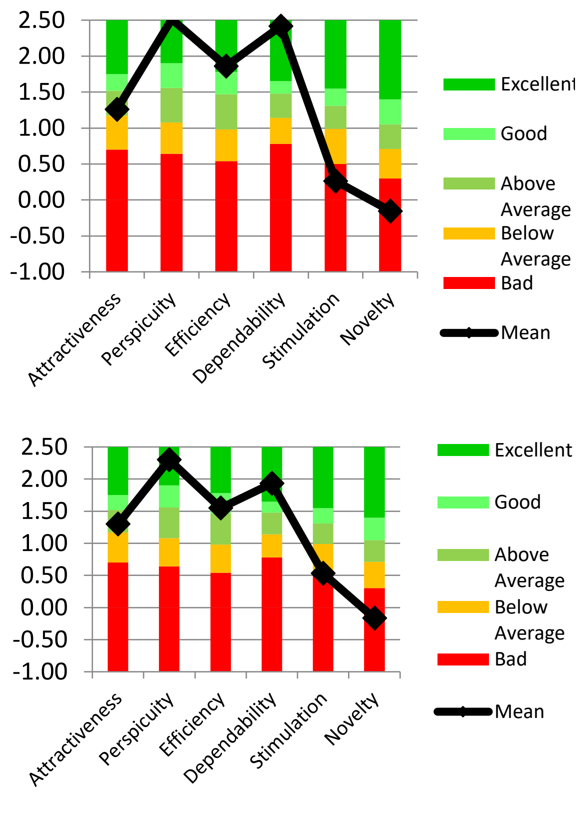

Figure 3: Results of the UEQ for the button on steering wheel. Top - easy traffic. Bottom - heavy traffic

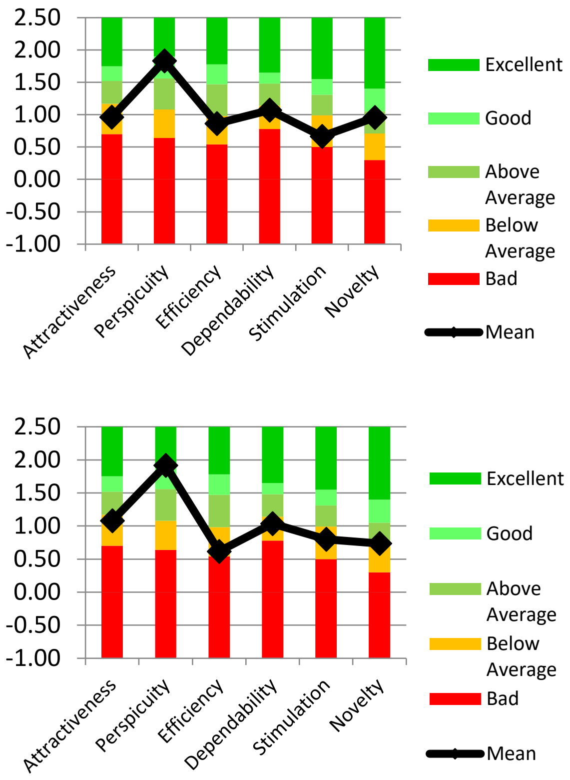

Figure 4: Results of the UEQ for the touchpad interaction.
Top - easy traffic, Bottom - heavy traffic

Figure 5: Results of the UEQ for the free hand interaction.
Top - easy traffic, Bottom - heavy traffic

one feature. For example, the pairs for evaluation attractiveness are attractive-unattractive, friendly-

unfriendly or pleasant-unpleasant. The UEQ evaluated six different categories: attractiveness, perspicuity, efficiency, dependability, stimulation and novelty. The set of questions and an evaluation tool is provided online [16].

III. Results

The results presented on Figures 3-5 were calculated with the UEQ Data Analysis tool provided on the UEQ homepage. The colored histograms on all figures are based on existing values from a benchmark data set and represent some sort of a baseline to which all other results can be compared. This baseline data set contains data from 9905 persons from 246 studies concerning different products and is provided in the UEQ data analysis tool [16]. Excellent describes the 10% of the best results; good means that 10% results are better and 75% are worse; above average means that 25% results better, 50% worse; below average means that 50% results are better and 25% results are worse; bad is in the range of the 25% worst results.

We applied the UEQ tests for two groups of users (driving in easy and difficult traffic conditions) and for each input interface. The results of each interface are presented in a separate figure, showing easy traffic condition on the top and difficult traffic condition at the bottom. The black line in each figure represents the mean value of UEQ scores.

IV. Discussion

Wrapping everything together - we evaluated the user experience of using different input modalities in a vehicles infotainment user interface using the UEQ.

The results are showing clear differences between different input devices, which are quite expected and now experimentally confirmed. The pragmatic quality, which is a combination of perspicuity, efficiency and dependability and describes task related quality, is highest for the button on the steering wheel, which is expected as those buttons are widely used in the automotive industry that indicates its quality. Pragmatic quality is for the touchpad interaction above average and for the free hand interaction bad.

The hedonic quality, which is the combination of stimulation and novelty, represents non-task related quality aspects. Evaluation of this quality shows that those results are opposite to the pragmatic quality. The button on the steering wheel has a bad score, while the free hand interaction has a good score. The touchpad is again in between the other two results.

We expected better results in the easy traffic condition because there are no distractions and almost no vehicle manipulation is needed. Opposite to those expectations, the results are showing no differences between user ratings of using the devices using in easy or heavy traffic. Comparing the benchmarks above there are no major differences between graphs for easy and heavy traffic.

Overall, the well-established interaction with buttons on the steering wheel which is most commonly used in modern cars shows the best results in terms of usability and task related quality. The free hand interaction has very good ratings for its originality and shows perspective to be used in vehicles. However, the current implementation is not efficient enough to be used for the main input modality of an infotainment system. Perhaps a different set of gestures and simpler set of controlling functions would make free hand interaction more appropriate and usable in vehicle environments. The touchpad also did not show excellent results but is still above average with its current implementation in this study. Probably it is not perfect as a main input device for the infotainment system but could be used as part of a multi-modal user interface.

We conclude that the widely used button interface on the steering wheel is the most efficient in terms of user experience and has the best task related quality. However, touchpad and free hand gesture interaction are very attractive and with an implementation, which would consider its limitations, it could be accepted by a lot of drivers.

Acknowledgment

This research was supported by Slovenian Research Agency. The authors would like to thank NERVteh for providing the simulator software.

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