On the Evaluation of Auditory and Head-up Displays While Driving

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***Abstract* — In this paper, we propose a low cost, laboratory based testing framework for in-vehicle interfaces. Exemplified by a comparison between an auditory interface, a Head-up display, and a combination of both we show how task completion times, driving penalty points, mental workload, and subjective user evaluations of the interfaces can be collected through different logging systems and user questionnaires. The driving simulator used in the experiment enables the simulation of varying traffic conditions as well as different driving scenarios including a highway and a busy city center. Only some preliminary results are reported in this paper.**

Keywords-Human-computer interaction; auditory interface; head-up display; car simulator; driving performance.

I. INTRODUCTION

Driver distraction is estimated to contribute to up to 25 percent of vehicle crashes [1]. It is defined as the direction of attention away from safely handling the vehicle towards an object or event in the internal or external vehicle environment [2]. In many cases this distraction originates from in-vehicle tasks that are unrelated to driving such as making a phone call, sending text messages, or adjusting controls within the car. Distraction generated by interacting with smartphones is likely to increase as these devices are not only becoming more popular and affordable, but also offer services tailored towards in-vehicle use such as GPS (Global Positioning System) based navigation and real time traffic information [3].

According to the multiple resource theory of attention [4], humans only have limited amounts of attention available at any given time. Different tasks can use different attention resources or share them. If resources are shared interferences may occur leading to decreased performance in all tasks. For example, driving a car demands a significant amount of visual attention. Operating a navigation system or mobile phone through a visual interface while driving competes for the same resource associated with visual perception and is therefore likely to cause distraction from the primary (driving) task [5] [6]. It has also been shown that physical and cognitive distraction significantly impair the driver's visual search patterns, reaction times, decision-making processes, and the ability to maintain speed, throttle control, and lateral position on the road [1][7].

Integrating the smartphone handset with in-car electronics and merging the access to all car and mobile device functions in one haptic interface, such as a multifunctional steering wheel, can help to reduce the haptic distraction. Head-up displays (HUD) have been proposed as a solution to reduce the frequency and duration of the driver's eyes-off-the-road by projecting information on the windshield. HUDs, when compared to HDD (Head-Down Displays), have been shown to reduce the response times to unanticipated road events and lead to smaller variances in lateral acceleration and steering wheel angle [8]. However, they have also been shown to increase mental load as indicated by longer response times in high workload situations [9][10].

To reduce visual distraction, speech-based interface have been proposed [11][12] as they demand resources associated with auditory perception and are therefore less detrimental [13]. However, extensive user testing with particular emphasis on the evaluation of the distractive potential and the user experience of individual services or interfaces is crucial and can only be partially derived from prior research. Therefore, we propose a testing framework that allows for low cost, laboratory based usability testing. Using the example of a comparison between three different interfaces for interacting with an in-vehicle communication, navigation, and entertainment system while driving, a HUD display, an auditory interface, and a combination of both, we demonstrate how these interfaces can be prototypically realized and thoroughly evaluated.

II. USER STUDY

The design rationale of this study is to investigate the impact of multimodal interfaces for in-vehicle control systems on driving and task solving performance. In particular, an audio only interface is compared to a visual only HUD and a combination of both. To simulate a realistic use case, the experiment is running in a driving simulator. Participants perform tasks of different complexity while they drive the simulated vehicle on different routes and with different traffic conditions. The driving simulator depicted in Figure 1 consists of a large projection screen, a steering wheel, accelerator and brake pedals, and the HUD shown in Figure 2.

Figure 1. The car simulator consisting of a large projection screen, a steering wheel, foot pedals and a gear stick.

By means of a custom-made interaction device attached to the steering wheel (shown in Figure 3, left) participants can navigate through a menu structure as illustrated in Figure 3, right.

Figure 2. The visual interface implemented as a HUD.

Three different experimental conditions are created by using three different user interfaces. The same menu structure is used with all three interfaces. There are up to 8 items on each level with the top level containing the following items:

- Heating and Cooling
- Entertainment
- Communications
- Navigation and Traffic
- Trip computer

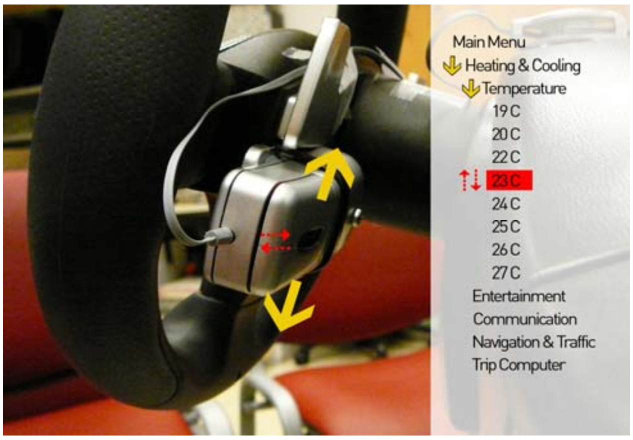

Figure 3. The interaction device and its use for navigating the menu structure.

III. EXPERIMENT DESIGN

The study design is a within subjects 3 x 2 (Interface x Task Complexity) design with participants randomly allocated to one of six groups. To prevent learning effects each group has a different combination of route difficulty and conditions.

For example, one group starts with the auditory interface in a low traffic situation, proceeds with the visual interface in a low traffic situation, and ends with the audio-visual interface in a high traffic situation. A second group starts with the audio-visual interface in a low traffic situation, proceeds with the visual interface in a high traffic situation, and ends with the auditory interface in a high traffic situation and so on.

A. *Experiment Apparatus*

1) Computer Setup: Three different computers are used for the experiment running:

- A driving simulator (DS),
- User interaction (UI) application and
- Management and logging (ML) software suite

The computers are communicating via TCP/IP protocol stack in a private network. The DS machine is used for running the driving simulator and for logging driving errors.

The UI machine is running the user interaction application and constantly reports the events connected with the interaction device (button clicks, mouse wheel turns) to the ML computer.

The ML computer is used as a main machine for conducting the experiment. The operator of the ML machine can control the driving simulator using remote desktop software. The ML computer is also used for collecting driving and interaction device events, measuring task completion times, and for filling-in the user questionnaires.

The software running on the UI and ML machines was developed on the Java platform. The input data required by the UI application are stored in an XML (eXtensible Markup Language) file. The file contains hierarchical menu structure, textual content that is displayed in visual interface, and references to pre-recorded sound clips for the auditory interface.

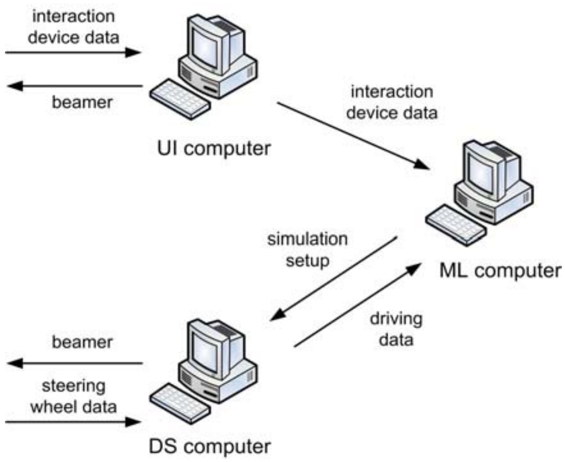

Figure 4. Experiment setup

2) Beamers: The visual interface and the image of the driving simulator are projected on a projection screen using two beamers. The beamer projecting the simulator image is mounted on the ceiling of the room, while the beamer projecting HUD is placed on the driver’s right side in the height of his/her shoulders.

3) Car Simulator: The essential component of the experiment is a driving simulator software. We chose City Car Driving version 1.2 [14], which was projected on the big screen. It

supports the simulation of multiple driving environments, such as different regions of a city center, a motorway or a highway. It also enables a variety of different driving routes and traffic intensity conditions. The Thrustmaster's "RGT Force Feedback CLUTCH Racing Wheel" is used as the input device, which comprises of a steering wheel, three foot pedals and a gear stick. Car and environment sounds are played using Genelec's "8030A bi-amplified monitoring system" consisting of two loudspeakers placed on both sides of the projected image.

Test subjects are driving a left-handed Peugeot 206 CC with automatic gearbox. The traffic is right-handed. The route named "Motorway" with 10 percent traffic intensity is used for the "low traffic" condition while the route named "Modern district" with 50 percent traffic is used for "high traffic" condition. Test subjects are given loose navigation instructions ensuring comparable driving experience.

B. *Visual Interface*

The visual interface (Figure 2) is a 20 x 20 cm HUD projected to the right-central position of the windshield (above the car's central LCD display which was not used in the study). The HUD displays five of the available items of the selected menu or submenu. When there are more than five items available, the user can access them by "scrolling" up or down in the current menu level. The menu is designed to be non-circular with the peg at both ends of the menu or submenu. The menu items are displayed in a high contrast yellow color. The selected item is highlighted with red fonts with slightly increased font size compared to non-selected items. On the top of the HUD a green colored title indicates the currently selected submenu. The setup was designed and programmed to allow for a quick adjustment and accommodate required changes of the menu structure, position, size, and content.

C. *Auditory Interface*

The auditory interface is based on prerecorded sound clips generated by AT&T Labs TTS Demo (text-to-speech) technology. A male voice called "Mike" is used for the main menu structure while other voices are used for imitating various tasks (voicemail messages, traffic report service, etc.). The OpenAL and JOAL libraries are used for the creation of dynamic sound sources. Sounds are played through two computer loudspeakers, which are placed at the usual position of car speakers mounted in vehicle doors.

D. *Interaction Device*

The navigation within the menu is enabled by using a custom-made interaction device – a small mouse attached to the steering wheel (Figure 3, left). The interaction device consists of two buttons and a scrolling wheel, which can also act as a third button if pressed. The scrolling wheel is used to navigate among the items available at a certain level of the menu structure. If the scrolling wheel is pressed while using the acoustic interface, the title of the current submenu is played. The other two buttons are used to confirm the current selection or to exit the current submenu and move up one level in the menu structure (cf. illustration in Figure 3).

E. *Experiment Conditions and Tasks*

Three different experiment conditions were defined. The conditions "A" and "V" are based on the acoustic and visual interfaces described in previous sections while the condition "AV" is based on the combination of both. Five tasks are performed within each experimental condition. Each group of tasks consists of three simple "atomic" and two "complex" or difficult tasks. The difficulty of the tasks is defined by the effort and physical activity required to finish the individual task (number of mouse clicks and wheel turns). A sample set of five tasks is listed in Table 1.

TABLE I. SAMPLE SET OF TASKS

Atomic tasks	
Task 1	Change the fan speed to "3".
Task 2	Play the song "Yesterday" by The Beatles.
Task 3	Check your fuel level.
Complex tasks	
Task 4	You want to travel to New York City. Please check the traffic report for New York City and tell the name of the street mentioned in the report to the experimenter.
Task 5	Please set your navigation system to take you to New York City. When asked, verbally enter (dictate) the name of the street suggested by the traffic report into the navigation system.

F. *Logged Data & Questionnaires*

1) Driving errors: The driving errors and anomalies are recorded by the driving simulator software and saved into a database. The records in the database contain the information about the occurrence of an error, its description, and severity. The later is described using penalty points. The ML machine is responsible for organizing and archiving the driving data for each subject per experimental condition.

2) Task Completion Times: Task completion times are measured manually by the operator of the ML machine using a logging application. The measurement starts when the instruction "Please start now!" is given to the test subject and it is completed when the task is completed successfully.

3) Video Recordings: The entire user study is recorded with a HDR-XR105 Sony digital video camera. The recordings are used to perform an additional post-evaluation of driving performance and general safety. This allows for a recap and further analysis of situations in which severe driving errors were recorded by the system.

4) NASA TLX: Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five seven-point Likert scales [15]. It is a subjective, multidimensional assessment tool that rates perceived workload on six different subscales: Mental demand, physical demand,

temporal demand, performance, effort, and frustration. An example of the TLX is given in Figure 5.

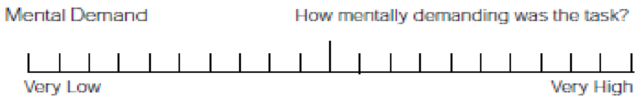

Figure 5. Example of items in the NASA Task Load Index.

5) User Experience Questionnaire (UEQ): The UEQ [16] is a tool for the user-driven assessment of software quality and usability. It consists of 26 bipolar items, each to be rated on a seven-point Likert scale. It has been developed to measure six factors: Attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. An example of three items is presented in the Figure 6.

Annoying	○	○	○	○	○	○	○	enjoyable
Predictable	○	○	○	○	○	○	○	unpredictable
Efficient	○	○	○	○	○	○	○	inefficient

Figure 6. Example of items in the User Experience Questionnaire.

G. *Experiment Procedure*

Before the experiment participants are given a thorough introduction to the driving simulator, the interaction device, and the menu structure. After they familiarize themselves with the simulator and the menu (approx. 20 minutes) they begin the experiment by either first using the visual, the audio-visual, or the auditory interface depending on their random assignment to one of six groups. During the experiment, participants are asked to drive either on a motorway or through a busy city center while they are given first a set of atomic tasks followed by a set of complex tasks. After each condition, participants complete the electronic version of the NASA TLX followed by a complete UEQ to evaluate their experience of the particular interface they just used. After participants complete all three conditions they are asked to fill a short post-study questionnaire on their overall perception of the interfaces, the readability of the projection, the sound design, the realism of the driving simulator, and the task design.

IV. PRELIMINARY RESULTS

A total of 30 test subjects participated in the experiment. The proposed experimental setup and apparatus have proven to be robust, flexible, and suited for evaluating the interfaces.

The brief analysis of task completion times identified the audio-visual interface as the fastest and the audio interface as the slowest of all three.

On the other hand, the best control of the car was noticed when using the audio interface and the worst when using the visual interface. We also noticed a higher compliance with the traffic rules when the test subjects were performing the tasks compared to just driving. This could partly be explained by a reduction in driving speed when performing the tasks.

Based on the preliminary results, the participants show an overall preference for the audio-visual combination. However, one fourth prefers only the audio or the visual interface respectively. The thorough analysis of all data collected in the experiment will bring more detailed insights that will enable further adjustments and user testing of the proposed interfaces.

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