Interacting with the Steering Wheel: Potential Reductions in Driver Distraction

Sebastian Osswald, Alexander Meschtscherjakov, David Wilfinger, and Manfred Tscheligi

Christian Doppler Laboratory "Contextual Interfaces", ICT&S Center
University of Salzburg, Sigmund Haffner Gasse 18, 5020 Salzburg, Austria

Abstract. Driving a car has become a challenge for many people despite the fact that evermore technology is built into vehicles in order to support the driver. Above all, the increasing number of in-vehicle information systems (IVIS) is a main source of driver distraction. The fragmentation of IVIS elements in the cockpit increases the attention demand and cognitive load of the driver. In this paper, we present an approach to integrate most in-car interaction possibilities into a steering wheel, by combining a multi-button row with a single touch in an intelligent steering wheel. We performed an online study (N=301) to investigate the pre-prototype user acceptance of the three different steering wheel modalities (single touch, multi button, combi touch) as well as a lab-based driving simulator study (N=10) to assess the practicability of the single touch interaction. The results of the online study showed that especially the single touch was highly accepted by the participants. The driving simulator study revealed that touch-based interaction on a steering wheel is feasible for low demand tasks in terms of driver distraction. Especially, the single touch embedded into the steering wheel is a promising approach for ambient information in the automotive context.

Keywords: automotive user interfaces, touch interaction, steering wheel, driver distraction, acceptance, user studies.

1 Introduction

It is well recognized that driver distraction is a contributing factor in many road accidents. Recent research revealed the usage of mobile phones, for instance, as one of the most distracting issues in the car [15]. Thus, many states enacted laws, banning the use of mobile devices while driving. Regarding the increasing number of functionalities, developing interaction modalities that reduce the distraction and lower the driver's workload is becoming a central issue in HCI research. The integration of pervasive technology and ambient intelligence (AmI) could be a major contributor to increase safety on the roads. Therefore, different interaction modalities (input and output) have to be investigated. Regarding input and output modalities, research and industry so far have focused on the visual and auditive channel. Voice input and output has been mainly used to

D. Keyson et al. (Eds.): AmI 2011, LNCS 7040, pp. 11–20, 2011.

control the telephone or other tertiary tasks. Status information (e.g. speed, revolutions per minute, hazard lights) is often visualized in the dashboard or more recently on head-up displays. In-vehicle information systems (IVIS) such as radio, navigation, and climate control are mainly controlled via buttons all over the cockpit or on the steering wheel as well as by utilizing touch screens in the center stack. Other promising approaches to reduce driver distraction combined IVIS in the center console with multifunctional interaction devices (e.g. BMW iDrive, Audi MMI).

Most of these systems have two drawbacks. First, except for buttons on the steering wheel, they force the driver to bridge distances from the steering wheel to the input device by moving the arm. Second, the ever-increasing number of knobs and switches leads to a high fragmentation of interactive elements in the cockpit. We therefore propose to combine aspects of direct manipulation with the positioning of centralized interactive elements within the steering wheel.

Based on an intelligent steering wheel prototype with multi-button and single touch, which was developed by our partner AudioMobil Elektronik GmbH (http://www.audio-mobil.com) in the Christian-Doppler-Laboratory for Contextual Interfaces we conducted two user studies. The first study aimed at evaluating user acceptance of every single interaction modality as well as the user acceptance of the combi touch (buttons and touch). The second study aimed at investigating driver distraction through the single touch on the steering wheel by means of a simulator based lab study. This paper describes the prototype as well as the setup and results of both user studies.

2 Background Literature

2.1 AmI in the Automotive Context

The automotive context has been recently researched by the AmI community. Information about the environmental context, other drivers and social contacts is increasingly available for drivers, whereas the question of where information is displayed and the devices are operated in the best way is still unanswered. Schmidt et al. emphasize the challenging importance for pervasive computing research concerning the interaction with pervasive computing systems in the car [14]. Due to the increasing range of services that can be accessed in the car, Feld et al. stated that the claim of personal experience for the driver and the passengers can be satisfied by combining ambient speech and mobile personal devices [7]. Their approach uses speaker recognition to identify the passenger's position in the car to put the user in control. To make taxi transportation more efficient, [12] propose an ambient map-based service platform that provides real time environmental information about the availability of taxi transportation, predicting the number of vacant taxis for customers and operators. Displaying ambient information in the car requires meaningful devices that meet the safety standards of the car context. We believe that an interaction surface on the steering wheel can meet these requirements.

2.2 Interaction Modalities

Recently, many studies assessed the need of new concepts to deal with the complexity of current in-vehicle information systems. There are numerous studies comparing different interaction modalities for IVIS (see for example Harbluk et al. [8]). To reduce the visual demand of the driver, Ecker et al. developed a new concept using pie menus that serve as a visualization of gestures to interact with an IVIS [6]. For applying touch screens as an interaction modality in the car, Rydstrom et al. evaluated and compared three different IVIS, two operated by a rotary switch and one by a touch screen. A usability test with ten different tasks was conducted with the result that the naive users interacted more rapidly with the touch screen interface [13]. Gesture-, touch- and tactile-based interaction techniques have been investigated by [1]. Touch interaction presented itself as the fastest and easiest in supporting the driver. Investigating interaction techniques that aim to make it easier to interact with a IVIS, Doering et al. utilized the steering wheel as additional interaction surface. A developed set of multi-touch gestures was applied and compared with conventional user interfaces in terms of distraction, showing that the driver's visual demand is reduced significantly by the gestural interaction [5].

2.3 Driver Distraction and User Acceptance

Besides supporting the driver, IVIS can also be distracting. Distraction can concern different channels of sensory perception what increases the cognitive load [15]. Regarding the nature of tasks entering a navigation destination was most distracting. An increased distraction can even be observed for simply listening to the radio, without actual action on the driver's side. Regarding distraction related to input modalities, voice control turned out to be consistently less distracting than control via a display. Burnett et al. even assume a direct connection between the sheer availability of an IVIS and increasing unnecessary usage as well as an increasing distraction [3]. When developing novel interactive systems, it is necessary besides considering the driver distraction to address to what extent potential users will accept the system and its design. User acceptance (UA) in the context of information technology is described as the willingness of users to employ information technologies for their tasks. The technology acceptance model (TAM), which allows measuring and describing UA, is widely used. The TAM questionnaire delivers valid data on UA in a pre-prototype state of system development by measuring three scales, namely Perceived Usefulness (PU), Perceived Ease of Use (EOU) and Behavioral Intention of Use (BI) [4]. The importance of UA in the context of mobile and automotive user interfaces was besides others already identified by [11].

3 Intelligent Steering Wheel Prototype

To address the issue of accepting IVIS in the car context, this work introduces three design alternatives. Nowadays, many new cars have buttons on the steering wheel, some already have a touch screen in the central console. Thus, integrating and combining these elements in the steering wheel seems promising and that is why the single touch, multi-button and combi touch steering wheel concepts were designed (see section 3.1). First, the capabilities and features of the concepts were roughly described for the acceptance evaluation. The available features vary between the concepts from basic interaction like volume control via buttons to more complex interaction like starting a navigation. For the second study, an elaborated prototype was developed to address the issue of distraction (see section 5). The overall focus was inspired by the potential of the steering wheel as an easy interaction surface [5] and the promising results for steering wheel interaction techniques like handwriting recognition described by Kern et. al. [9]. We believe that the steering wheel can make an important contribution for instance in interacting with an intelligent agents who sense and react act upon the environment.

3.1 Design Concepts

- The *single touch (c1)* design concept allows direct manipulation of displayed interface elements. Common IVIS tasks can be performed like choosing a radio station as well as more sophisticated tasks. For example, navigation tasks can be performed directly on a scrollable map. The navigation to a desired city can be started by only tapping on the city name.
- The *multi-button (c2)* design concept contains short term interaction aspects like buttons for indicating or light control.
- The *combi touch (c3)* allows the driver to see additional information on the display while pressing an element of the multi-button row. For example the fuel gauge button not only indicates low fuel it rather displays customizable trip and distance information on the screen.

Fig. 1. Steering wheel design concepts: single touch (c1) multi-button (c2) and combi touch (c3)

3.2 Research Goals

The main aim of our study was to investigate the user acceptance of an intelligent steering wheel embodying an ambient device for contextual information.

RG1: Evaluate user acceptance of the design concepts in a pre-prototype stage.
RG2: Identify the distraction of tasks conducted with the single touch (c1).

It is addressed to which extent the user acceptance of three steering wheel design concepts differs and if there are other factors influencing the acceptance. Besides the measured acceptance of the presented modality concepts, the touch display steering wheel is chosen and applied in an end user study as it allows for more complex interaction.

4 Pre-prototype Technology Acceptance Study

4.1 Study Setup

To investigate how the three design concepts were perceived, we conducted an online survey measuring the user acceptance of the three design concepts with the help of the TAM scales. The TAM questionnaire was added for each design concept, who were distinctly explained to give the participant a good overview about the potential functionality of every modality. For a better understanding, every description was also accompanied by an explanatory picture. Recruiting the participants, the invitations for the online questionnaire were sent using a type of "snowball" sample. At first, known email distribution lists were used followed by announcements on two social networking sites as well as threads were started on five different car-related websites. These invitations not only asked to answer the questions, but also to pass it to other people who might be interested. After the first few days with less than 100 responses the "snowball" picked up momentum and we received 413 responses (fully and partially completed). The data from this study were used to calculated the TAM scales and to conduct a qualitative analysis.

4.2 Results

301 Participants (115 female, 186 male) fully completed the questionnaire for all three TAM scales. The participant age ranged from 17 to 76 (M= 28.55 years; SD = 9.46 years). Before computing the TAM scales (PU, EOU, BI) the internal consistency was computed (Cronbach's alpha: > 0.8). To calculate the differences in acceptance between the three design concepts, a repeated measures ANOVA was conducted. The results show a significant main effect for the within subject factor ($F[12.576] = 15.571$, $p < 0.005$) resulting in a greater acceptance of the single touch (c1). Factors influencing acceptance emerged from the general low values for EOU and BI in contrast to a high PU value. Related to the strong participant apprehensions found in the qualitative data, the analysis shows that perceived functionality, perceived security and perceived quality cover most of the users' apprehensions towards all innovative input modalities.

5 Touch Screen Steering Wheel Distraction Study

The following study was designed to investigate the effect of IVIS-related tasks on the primary driving performance. Putting the focus on the highly accepted and promising touch display approach, it was decided not to investigate the two other concepts. Studying the driving performance, ten secondary tasks were designed (seven single touch related tasks and three other not IVIS related tasks) and evaluated. The seven single touch tasks were: music source change (change the music source by choosing music from the hard drive); navigation entry (insert city name by entering the letters and start navigation); make phone call (open address book and call Steve), radio station (save the designated radio station); map navigation (search city on the map and start navigation); sound adjustment (set the volume fader settings to front), climate control (increase the ventilation setting). The three other tasks not IVIS related tasks were: take coins (take 3 coins with 30 cent out of a purse), unfold tissue (unfold a tissue and put it on the passenger seat) unwrap candy (unwrap a candy to eat it).

As proposed by Harbluk et al. the single touch tasks were separated in three different levels of complexity (low, medium and high demand) [8]. The classification was justified through a pretest and rated by the task durance, interaction steps and combination of different interaction styles (e.g. point and touch, drag and drop). In order of their increasing difficulty the tasks were assigned to the demand levels I-III.

5.1 Study Setup

Since the tasks were considered to be highly distracting for the subjects and therefore dangerous, a driving simulator was chosen. The presented study used a fixed-base driving simulator consisting of a driving seat, a steering wheel (including the prototype), pedals and a 50" monitor mounted on a console. One PC with a high performance graphic card was used for visualizing the lane change test (LCT) simulation. Another PC was needed for the software prototype on the steering wheel, while a third PC enabled a video surveillance of the simulator setup (see figure 2). To explore the distraction of touch interaction on a steering wheel, we implemented a fully functional piece of software within a touchscreen steering wheel prototype. The prototype consists of a flash-based software program (enables the interaction with e.g. music player, navigation, phone) and the hardware configuration (touch display 6,5" & steering wheel framework) the interaction characteristics were derived from state of the art in-car touch screen IVIS as well as the interface design. We measured the driver distraction with the standardized Lane Change Test (LCT), an assessment methodology that is easy to implement and quick to conduct [10]. The LCT simulates a straight three-lane road with a track distance of three kilometers. The driving speed is constantly limited to 60km/h to avoid speeding related distraction. Frequently appearing signs (18 in total) are marking the correct line the subjects have to use. Therefore, the subjects were instructed to change the lane as soon as they could recognize the designated sign. Simultaneously, they performed IVIS related tasks on the

Fig. 2. LCT test setup with a fixed-base driving simulator

steering wheel. As a result, it is assumed that the mean lane deviation from the ideal driving line provides the metric for comparison between the three different task demand levels (low, medium, high). Following the standardized LCT setup requirements, the driving performance under dual task conditions (driving & interaction) is calculated against a normative model of primary task performance to measure distraction. As a result the impaired lateral control (Mdev) reflects the extent to which each of the three demand levels results in increased distraction. A more in-depth description about the LCT can be found in Bruyas et al. [2]. The conduction of the ten secondary tasks were expected to influence the primary task performance (driving) according to their complexity. Hence a comparison with other IVIS designs seems fruitful to examine the distraction of the prototype. However, the study would mainly result in a rating of different IVIS in relation to their distraction level, a comparison with a baseline in-car distraction was considered as more promising in a first step. A standard driving task without performing any secondary task was defined as a baseline (no IVIS distraction) for comparison. The distraction caused by the three physical tasks (coin, tissue, candy) was determined as a second baseline for in-car distraction to be compared with the distraction of the secondary interaction tasks.

5.2 Experimental Design

The simulator part of the experiment was divided into three main stages. First, we acquainted the subjects with the simulator environment and allowed them to familiarize themselves with the simulator controls (about 3 minutes). Second, a complete turn (3 kms) was performed by each subject according to the lane change requirements to get a baseline condition without interaction influences. Third, they performed the ten secondary tasks. Assistance was given at the beginning of every task and the subjects could practice the task repeatedly until they felt comfortable with it. At the end of every task, the LCT software was reset and a new track was randomly chosen (different starting positions).

To investigate the subjective perceptions regarding the acceptance towards the touch screen steering wheel, we designed a questionnaire based on the same key elements as used in the first questionnaire study. The secondary task demand was the within subject factor. The learning effects did not need to be considered, since the scenarios did not involve any unexpected simulated traffic scenarios.

5.3 Analysis and Results

We invited 5 female and 5 male participants. The age ranged from 23 to 36 and their driving experience from 2 to 18 years. In terms of mileage, the subjects varied from below 5000 to 40000 kms annual distance travelled. We experienced no case of simulator sickness within our sample group. As a measure of distraction the deviation between a normative model and the driven path of the subject was calculated (as an example, figure 3 shows the normative model data (green line) the driven path (outer red line) and the deviation (red area)). The calculated deviation data represents the quality of the driver's performance, namely the perception (delayed or failed perception of the road signs), the quality of the maneuver (larger deviation trough slower lane changes) and lane keeping quality (unsteady lane keeping also results in increased deviation).The mean duration for task completion varied widely from 2.7s to 87.3s. We determined the participants' average deviation (see figure 4(a)) and carried out an Analysis of Variance (ANOVA). The main effect between the groups was significant ($F(2.48) = 64.3$, $p < 0.001$) indicating the affection by the different conditions (descriptives see figure 4(b)). Multiple comparisons (Post Hoc Scheffe) revealed significant differences between the baseline condition and all task demand levels ($p < 0.001$). Therefore, all tasks can be described as distracting. No difference in distraction appeared between baseline I & II and between baseline II and task demand level I (easy interaction). The results also revealed significant differences between all connections of task demand level I, II and III ($p < 0.001$). Based on the significant differences in lateral deviation (see figure 3), the task demand levels II (Mdev=0.71) & III (Mdev=1.03) turned out to decrease driving performance most. The analysis of the subsequently completed questionnaire revealed that the subjects rated the touch interaction on the steering wheel high (4,11 on a 5-point Likert scale). Based on the TAM questionnaire, the high acceptance of the touch display (c1) could be assessed.

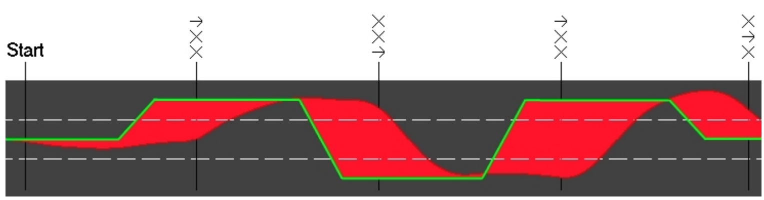
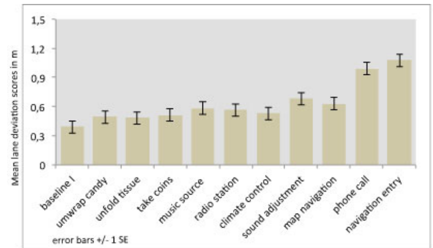


Fig. 3. Graphical representation of the lateral deviation between the normative model and the driven path



(a) Calculated mean lane deviation by tasks

LCT Deviation			
Condition	Mean (m)	SD	SD Error
Baseline I	0.39	0.08	0.02
Baseline II	0.49	0.09	0.03
Task D. Level I	0.55	0.94	0.03
Task D. Level II	0.71	0.09	0.03
Task D. Level III	1.03	0.14	0.04

(b) Mean lateral deviation for baselines and task demand levels

Fig. 4. Lateral mean deviation for single tasks and combined demand levels

6 Conclusion and Future Work

In this paper, we proposed the reduction of driver's distraction by applying automotive interaction modalities that can be found on the steering wheel. For all three systems, differences in user acceptance regarding all three UA factors were found, with the overall better rated single touch (c1). Focusing on concept (c1), the second study revealed enhanced distraction for the medium and high demand levels tasks. Low demand tasks showed distraction on the same level as the physical tasks. So we conclude that low demand tasks (e.g. list selection) on a touch screen steering wheel can be performed without increased standard distraction and hence such a device is ideal for an ambient environment.

Our findings show that the integration of a single touch in the steering wheel is a promising approach to centralize input and output modalities on one place. It provides the user with the possibility to interact with a IVIS without the need to move the hand off the steering wheel. So far we have focused on already existing tertiary task in the car (e.g. navigation entry). Another possibility of the touch screen is the visualization of ambient information like the adaption of information visualization on the context (e.g. a tachometer changes size or color depending on speed or the driver's condition). Regarding the range of available context information we are optimistic that this will bring the development of the intelligent steering wheel a step further.

In future work we plan to support the reliability of our results with a prototype iteration. While the simulator study reported in this paper focused on differences in task demands, another benefit might have a bigger impact on the deployment of ambient information: By separating physical input and visual output, the driver is supported in focusing on the primary driving task. The limitation of the peripheral sight through the acute viewing angle on the steering wheel could be abrogated trough the positioning of an ambient display as visual output in the top of the central console. This constellation allows the driver to control the IVIS via touch on the steering wheel while having the ambient output in the road related field of view.

Acknowledgements. The financial support by the Federal Ministry of Economy, Family and Youth and the National Foundation for Research, Technology and Development is gratefully acknowledged (Christian Doppler Laboratory for Contextual Interfaces).

References

1. Bach, K.M., Jaeger, M.G., Skov, M.B., Thomassen, N.G.: You can touch, but you can't look: interacting with in-vehicle systems. In: CHI 2008: Proc. SIGCHI on Human Factors in Computing Systems, pp. 1139–1148. ACM, NY (2008)
2. Bruyas, M., Brusque, C., Auriault, A., Tattegrain, H., Aillerie, I., Duraz, M.: Impairment of lane change performance due to distraction: effect of experimental contexts. In: Proc. of Humanist 2008 (2008)
3. Burnett, G., Summerskill, S.J., Porte, J.: On-the-move destination entry for vehicle navigation systems: unsafe by any means? Behaviour and Information Technology 23, 265–272 (2004)
4. Davis, F., Venkatesh, V.: Toward preprototype user acceptance testing of new information systems: implications for software project management. IEEE Engineering Management 51(1), 31–46 (2004)
5. Döring, T., Kern, D., Marshall, P., Pfeiffer, M., Schöning, J., Gruhn, V., Schmidt, A.: Gestural interaction on the steering wheel: reducing the visual demand. In: Proc. of CHI 2011, pp. 483–492. ACM, NY (2011)
6. Ecker, R., Broy, V., Butz, A., De Luca, A.: Pietouch: a direct touch gesture interface for interacting with in-vehicle information systems. In: Proc. of MobileHCI 2009, pp. 1–10. ACM, NY (2009)
7. Feld, M., Schwartz, T., Müller, C.: This Is Me: Using Ambient Voice Patterns For In-Car Positioning. In: de Ruyter, B., Wichert, R., Keyson, D.V., Markopoulos, P., Streitz, N., Divitini, M., Georgantas, N., Mana Gomez, A. (eds.) AmI 2010. LNCS, vol. 6439, pp. 290–294. Springer, Heidelberg (2010)
8. Harbluk, J., Mitroi, J., Burns, P.: Three navigation systems with three tasks: using the lane-change test (LCT) to assess distraction demand. In: Human Factors in Driver Assessment, Training and Vehicle Design (2009)
9. Kern, D., Schmidt, A., Arnsmann, J., Appelmann, T., Pararasasegaran, N., Piepiera, B.: Writing to your car: handwritten text input while driving. In: Proc Human Factors, CHI EA 2009, pp. 4705–4710. ACM, New York (2009)
10. Mattes, S.: The lane change task as a tool for driver distraction evaluation. In: Strasser, H., Rausch, H., Bubb, H. (eds.) Quality of Work and Products in Enterprises of the Future, pp. 57–60. Ergonomia Verlag, Stuttgart (2003)
11. Meschtscherjakov, A., Wilfinger, D., Scherndl, T., Tscheligi, M.: Acceptance of future persuasive in-car interfaces towards a more economic driving behaviour. In: Proc. of AutomotiveUI 2010, pp. 81–88. ACM (2009)
12. Phithakkitnukoon, S., Veloso, M., Bento, C., Biderman, A., Ratti, C.: Taxi-Aware Map: Identifying and Predicting Vacant Taxis in the City. In: de Ruyter, B., Wichert, R., Keyson, D.V., Markopoulos, P., Streitz, N., Divitini, M., Georgantas, N., Mana Gomez, A. (eds.) AmI 2010. LNCS, vol. 6439, pp. 86–95. Springer, Heidelberg (2010)
13. Rydström, A., Bengtsson, P., Grane, C., Broström, R., Agardh, J., Nilsson, J.: Multifunctional systems in vehicles: a usability evaluation. In: Proc. of CybErg 2005, pp. 768–775(8). Ergonomics Association Press, Johannesburg (2005)
14. Schmidt, A., Spiessl, W., Kern, D.: Driving automotive user interface research. IEEE Pervasive Computing 9(1), 85–88 (2010)
15. Strayer, D.L., Drews, F.A.: Cell-phone induced driver distraction. Current Directions in Psychological Science 16(3), 128–131 (2007)