A Multi-Touch Enabled Steering Wheel – Exploring the Design Space

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CHI 2010, April 10–15, 2010, Atlanta, Georgia, USA.
ACM 978-1-60558-930-5/10/04.

Abstract
Cars offer an increasing number of infotainment systems as well as comfort functions that can be controlled by the driver. With our research we investigate new interaction techniques that aim to make it easier to interact with these systems while driving. In contrast to the standard approach of combining all functions into hierarchical menus controlled by a multifunctional controller or a touch screen we suggest to utilize the space on the steering wheel as additional interaction surface. In this paper we show the design challenges that arise for multi-touch interaction on a steering wheel. In particular we investigate how to deal with input and output while driving and hence rotating the wheel. We describe the details of a functional prototype of a multi-touch steering wheel that is based on FTIR and a projector, which was built to explore experimentally the user experience created. In an initial study with 12 participants we show that the approach has a general utility and that people can use gestures for controlling applications intuitively but have difficulties to imagine gestures to select applications.

Keywords
Multi-touch interaction, gesture input, automotive interfaces

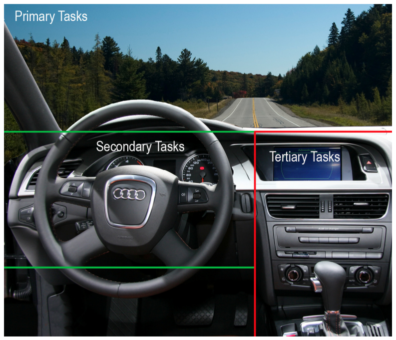


Figure 1. Distribution of primary (how to maneuver the car, secondary (e.g. setting turning signals) and tertiary tasks (interacting with enter- and infotainment systems) [8].

ACM Classification Keywords
H.5.1 Multimedia Information Systems

General Terms
Human Factors

Motivation & Introduction

Infotainment systems are common components in modern cars. They help to make the trip more enjoyable, less monotone and thereby let it seem to be shorter. New media and communication devices (like mobile phones, internet access, MP3 player) provide more and more entertainment and communication opportunities while driving. Furthermore, driver assistant functions like adaptive cruise control and lane keeping assistance support the drivers and reduce their mental workload, so that it seems adequate for most of the drivers to share their attention between the driving itself and consuming media content. Nevertheless these tasks (also called tertiary tasks; see [2]) demand attention as they force the driver to interact with built-in systems (e.g. navigation system) or with nomadic devices (e.g. a phone) to operate them (e.g. type an address or make a call). Interacting with tertiary tasks is handled differently by the automobile manufactures. Some provide buttons around a central display and other use multifunctional controllers or touch displays. One trend that can be observed is that input devices for tertiary tasks are placed into the space that was a long time reserved for primary and secondary devices (see figure 1 and [8]). The available space on the steering wheel for example is now often used for interacting with the entertainment system, the navigation system or the mobile phones [8]. The advantage of using the space on the steering wheel can be seen in the fact that buttons or thumbwheels are very close to the driver's hand so that there is no need to move the hand away from the steering wheel, which improves the safety of driving. However the arrangement of physical input devices is fixed and the space for mechanical buttons is limited. To explore this further we built a fully functional prototype of a multi-touch enabled steering wheel to investigate a more flexible arrangement of input devices or areas on the steering wheel for interacting with tertiary tasks. Our overall goal is to find suitable input and output paradigms to interact with the steering wheel taking driver's safety and driver distraction [4] into account. In this paper we present an initial study that investigates advantages and disadvantages of gesture based input on multi-touch steering wheels. We discuss design challenges that arise for multi-touch input on a steering wheel and present initial user feedback for this concept.

Related work

The usage of the steering wheel as an interaction opportunity beyond simple button and thumbwheel use has been researched amongst others by [3], [7] and [9]. Their focus is on text input through the steering wheel. Kern et al. [7] investigated different places for a touch display for inputting text during driving and found out "that handwritten text input using fingers on a touchscreen mounted on the steering wheel is well accepted by users and lead to 25% fewer corrections and remaining errors compared to text input in the central console". Sandnes et al. [9] kept the button as input device but provide text input by three finger chord sequences. González et al. [3] used a thumb-based input technique on a small touchpad mounted at a fixed position on the steering wheel to allow gesture interaction. They used clutching, dialing, displacement and EdgeWrite gestures for selection items from a list.

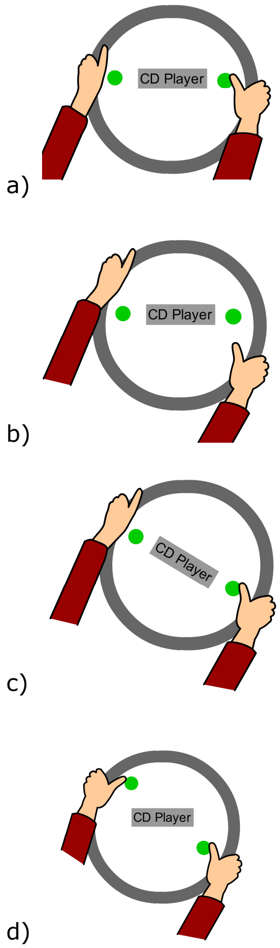


Figure 2. Representation of visual feedback in a) a straight forward driving situation, in turning situations with b) a rotation stable projection, c) a rotation following projection, d) a flexible visual output following the hand.

An approach towards gesture interaction in the car has been presented by Bach et al. [1]. They compared haptic, touch, and gesture interaction for controlling a radio. For gesture input they used a touch screen mounted on the vertical center stack. Their results indicated that gesture interaction is slower than touch or haptic interaction but can reduce eye glances while interacting with the radio.

Today multi-touch technologies allow direct gesture-based interactions with fingers on interactive surfaces [10]. While widely used on tabletops and interactive walls, the potentials of this technology in special contexts like the car can be found in ideas for concept cars (e.g. Chrysler's 200C concept[1]) but have not investigated in more detail so far. As gestures potentially can support a natural and intuitive form of interaction, an important research topic has been the design of free hand gestures on tabletop surfaces. Nevertheless, the design of consistent and suitable sets of gestures is a challenging task for system designers. Thus, Wobbrock et al. [12] have conducted a study, where non-technical users had to develop their preferred gestures for certain tasks on a tabletop surface. Among their results was a user-defined gesture set with gestures for 27 tasks and the insight that users generally do not care about the number of fingers used for a gesture. In contrast to related work, we focus on the possibilities of multi-touch input on a steering wheel and on interacting with specific functions typically for in-car use.

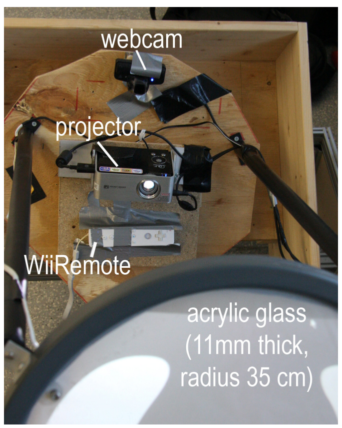
[1] http://wheels.blogs.nytimes.com/2009/04/09/chrysler-concept-imagines-a-car-without-buttons/

Design Challenges

The conditions for multi-touch interaction with a steering wheel while driving differ significantly from common tabletop settings. It is a challenging question how to realize effective and pleasant interaction in this context. In the following we derive design challenges and questions we want to investigate further. As the driving task is the primary task in cars, one challenge is to design multi-touch interactions in the steering wheel that are not distracting from the primary task and that are suitable as tertiary tasks. This implies that the cognitive load of the interaction should be low and, furthermore, that the driver basically should not have to move her hands from the steering wheel as well as her eyes from the street. Obviously, the functioning of the steering wheel as well as the visibility of all instruments should not be affected. Converting the steering wheel into a multi-touch surface, the whole space can be used for touch input and graphical output. This leads to the questions, where to define interaction areas and what kind of visual feedback should be displayed. As drivers should keep their hands at the steering wheel, a closer look at thumb gestures appears to be promising. To enhance these, a more precise touch information like contact area, size and orientation (see [11]) of the thumb could be of interest. Furthermore, as buttons can be displayed on the steering wheel, it has to be decided how or if to combine buttons and gestures.

A novel opportunity for the interaction design lies in the flexibility of the visual representations of virtual buttons or interactive areas, as they can be displayed on the steering wheel. It has to be found out whether drivers prefer a rotation stable projection, a rotation following projection or flexible visual output that follows the

a)



b)

Figure 3. The multi-touch steering wheel hardware. a) General overview on the setting. B) Detailed screenshot of the foot well.

hands, so that buttons could always appear next to the hands on the steering wheel. This is a significant difference compared to traditional buttons attached to the wheel (see figure 2).

The flexibility of a multi-touch display also allows reacting to contextual information. Contextual controls could be designed that discriminate driving and standing and allow implicit and explicit interaction. Furthermore personalization of the steering wheel space might be also an option. The described design questions above deal with input opportunities. Another challenge can be seen in the new output options. Beside the input areas there might be enough space on the steering wheel for graphical output like representing navigation instructions or indicating the position in a list of songs while searching for a music title. It needs to be investigated what kind of visual output on the steering wheel is useful or if the steering wheel should be only used for input and a visual output should be presented in a head-up display. Further design options include the integration of additional modalities like speech or haptics as proposed by Harrison and Hudson [5] to provide direct feedback while interacting with the system.

Prototype

To explore the design space we implemented a fully functional prototype (see figure 3). A 11mm thick round acrylic glass with a radius of 35 cm (standard steering wheel size) was used as the steering wheel "*body*". The FTIR [10] principle was applied to allow multi-touch input. The infrared LEDs were protected with a steering wheel cover. Simple tracing paper was attached as diffuser on top to allow projection. The whole setup was mounted on a rotatable stand. Both, camera and projector (used for the multi-touch tracking) can be attached that they rotate with the steering wheel. Alternatively, it is possible to fix the projector in one position so that the projection does not rotate with the steering wheel. A WiiRemote was used to detect the rotation angle of the steering wheel and realized the communication with the driving simulator CARS[2]. tBeta[3] was used for image processing. It comes with a module to stream the touch events into the TUIO protocol [6] to connect it to the Flash application responsible for the visual representation of interactive elements on the wheel.

User Study and Preliminary Findings

The main goal of our initial study was to explore thumb-based gestures on the steering wheel. Similar to Wobbrock [12] we want to establish a set of standard gestures for multi-touch input on the steering wheel that is intuitive to the users. In a first step we focus on interacting with a music player and a navigation system. We conducted a user study with 12 participants (12 male, aged 23 to 30; mean age = 25). Differently to Wobbrock the participants had to drive while doing the gestures. Furthermore we did not present any graphical output relating to interaction tasks.

Tasks & Procedure

The participants were seated on a car seat in front of the multi-touch steering wheel (see figure 4) and were

[2] CARS is an open source PC-based driving simulator. Configurable Automotive Research Simulator http://cars.pcuie.uni-due.de/.

[3] tBeta is open source software solution for computer vision. Its successor version is called "Community Core Vision" and is available at: http://ccv.nuigroup.com/.

Figure 4. Particpant performing gesture input while driving in a virtual driving environment.

Figure 5. A user interacting with the multi-touch steering wheel.

asked to find 19 different commands for interacting with a music player and a navigation system. The experimenter presented instruction like "play a song", "forward to the next song" or "open a navigation map" on file cards in random order and asked "What kind of gesture would you use to perform this task?". The participant had to invent different gestures and perform them on the multi-touch enabled steering wheel. They were asked to keep their hands at the wheel and perform gestures with one or both thumbs on a predefined interaction area on the steering wheel (see figure 5) while driving in the simulator. The fingertrails were tracked and captured and we also videotaped the hands from above. We asked the users to apply the "think-aloud-technique" and recorded their utterances. An additional driving task was used to give participants the impression that they are driving while performing the gesture input. We projected a virtual driving environment on a wall (see figure 3, 4). The participants maneuvered the car with constant speed of 30km/h on a straight road with partial roadblocks where they had to drive around by switching lanes. Driving performance was not measured in this first study but it is planned to investigate how gesture-based input influences driving performance in future studies.

Results & Findings

As the data and videos are not completely analyzed yet we present qualitative results of this first user study in this paper. First of all the participants liked the gesture interaction on the steering wheel and found it straightforward to use. They valued that fact that there is no need to look for the button and hence interaction is possible anywhere. Some of them worried that it might be hard to remember the gestures. This demonstrates the need to invent intuitive gestures. To support already existing mental models it makes sense to look into symbols that are already well known by the users from other domains and that are connected to specific commands. Participants often drew an arrow or a triangle when they were asked for a "play song"-gesture because they know it from other music players. It could be observed that participants also transfer gestures they know from interacting with the iPhone, e.g. for zooming in or out of a map. For the zooming task participants often used both thumbs on the opposite sides of the steering wheel while for nearly all other tasks they prefer to perform gestures with one thumb only. None of the participants thought about gestures that where side depended, e.g. interaction with the right thumb might have a different meaning than performing the gesture with the left thumb. The participants reported problems by finding gestures for selecting/starting specific applications (e.g. starting the navigation system). A few simply used the first letter "N" to start the system. It might be reasonable to look more into handwriting as an additional option, so that an application can be started by a single gesture or by writing the name or the initial letters in case the driver forgot the single gesture. In that case a combination between gesture interaction and another modality like speech might be also an option.

Discussion and Future Work

Overall the initial results are promising and show the utility of the approach. Nevertheless there are still a lot of open questions that are not investigated so far. Findings how the gestures differ compared to multi-touch gestures on a screen or a table would be an interesting. If we can use the same gestures or the same mental models it would be easier for the user to remember gestures. It may be useful to investigate the combination of gesture interaction and additional physical button. In addition a comparison to other input modalities is in our area of interest for future studies. Another main focus of next user studies are related to the safety issues created by the visual feedback, presented on the steering wheel or head-up display. Another opportunity that arises from the use of a multi-touch display as steering wheel is personalization. Drivers could take along their own interface to different cars and users could create their personalized interface, e.g. with personalized buttons at certain locations and specific gestures. Even the gesture set could be designed by the users themselves and applied in different cars. When combining input via buttons and visualizations like a speed indicator together on a steering wheel the question arises which parts of the display should be turning around with the steering wheel. On one hand it is hard to look on the speed indicator in curves when it is upside down but it makes sense that buttons are always next to the hands. Following this idea, it is interesting to investigate if input from the back and front of the steering wheel could improve the interaction. With our current setup it is possible to sense touch input from both sides, e.g. when installing a camera on the head rest.

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