Cite as:
Pfleging, Bastian, Dagmar Kern, Tanja Döring, and Albrecht Schmidt. "Reducing Non-Primary Task Distraction in Cars Through Multi-Modal Interaction." it-Information Technology 54, no. 4 (2012): 179-187.

Reducing non-primary task distraction in cars through multi-modal interaction

Multimodale Interaktion zur Reduktion der Fahrerablenkung beim Ausüben nicht-primärer Fahraufgaben im Auto

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Abstract

To offer access to a multitude of driving and more often non-driving related functions in the car including infotainment, entertainment, comfort, and assistance systems, automotive user interfaces have become more complex in the last decade and this trend will probably continue in the future. Interaction with these systems inevitably leads to driver distraction and consequently to an increased risk for the drivers as well as for their environment. Hence, for some functions interacting while driving is prohibited (like entering an address into the navigation system) whereas other functions are allowed or even need to be operated while driving (like setting speed limit for cruise control).
In our research we investigate how interaction styles in automotive user interfaces can be designed in order to limit driver distraction to a minimum. There are two major areas we discuss in this paper: (1) the support for switching attention between interactive systems in the car and the road, and (2) interface technologies in the car that minimize the need for (visual) attention. We describe technological solutions for both areas, explain their implementations and discuss the impact on driving performance, based on results obtained by several simulator studies. The main findings are that multimodality, especially including implicit and explicit interaction, can speed up attention switching and that gestural interaction provides a way to reduce visual demand.

Zusammenfassung

Die Anzahl an Funktionen für Infotainment, Entertainment, Komfort- und Assistenzsysteme im Fahrzeug hat im letzten Jahrzehnt dazu geführt, dass die Bedienung dieser System komplexer wurde. Dieser Trend wird wahrscheinlich auch in der Zukunft anhalten. Dies führt unweigerlich dazu, dass der Fahrer von der eigentlichen Fahraufgabe abgelenkt wird und dass somit das Risiko für sich selber und für sein Umfeld steigt, in einen Unfall verwickelt zu werden. Aus diesem Grund ist die Bedienung einiger Funktionen verboten, wie die Zieleingabe ins Navigationssystem während der Fahrt. Andere Funktionen hingegen dürfen oder müssen gar während der Fahrt bedient werden, wie z. B. das Einstellen der Geschwindigkeit für den Tempomat.
In unserer Forschung untersuchen wir, wie Benutzungsschnittstellen im Fahrzeug so gestaltet werden können, dass die Fahrerablenkung auf ein Minimum begrenzt ist. In diesem Artikel stellen wir die folgenden zwei Möglichkeiten vor: 1) eine Unterstützung

beim Wechsel zwischen der Bedienung des interaktiven Systems und der primären Fahraufgabe bezogen auf die Aufmerksamkeit und 2) verschiedene Interaktionstechniken im Fahrzeug, welche die (visuelle) Ablenkung von der Straße reduzieren. Wir beschreiben technische Lösungen für beide Bereiche, erklären ihre Implementierungen und diskutieren ihren Einfluss auf die Fahrausführung basierend auf Ergebnissen aus verschiedenen Fahrsimulatorstudien. Die Haupterkenntnisse sind, dass Multimodalität besonders in Verbindung mit impliziter und expliziter Interaktion den Wechsel zwischen der Bedienung des Systems und der primären Fahraufgabe bezogen auf die Aufmerksamkeit beschleunigen kann und dass Gesteneingabe eine Möglichkeit darstellt, die visuelle Ablenkung zu reduzieren.

Introduction

Looking at modern cars, interaction in the car becomes more and more demanding. While driving a car, the driver can use an ever-increasing number of functions and applications – from operating a radio to browsing the Internet and beyond. Even today, the primary task of driving a car requires the largest part of a driver's (visual) attention, which is a very limited resource. Thus, interacting with user interfaces to fulfill secondary and tertiary driving tasks [Geiser 1985] poses a potential risk on driving safety if they require larger parts of driver's attention. Therefore, interaction design for automotive user interfaces shall keep the demands on the driver as low as possible – at least as long as the driver is in charge of driving the car.

As we can see today, drivers already use a lot of functions (including nomadic devices) like, e.g., navigation services, messaging, Internet, social networking etc. Drivers even use some of these actions (e.g., entering an address into the navigation system, writing text messages, calling somebody on the phone) although law prohibits them. Therefore, we see a need for a safety-conform support for interaction instead of prohibiting this interaction. Especially the everyday commuter wants to use the time in the car for (social) messaging and communication. Therefore, automotive user interfaces should support these tasks accordingly while maintaining driving safety at the same time.

The rise of assistance functions in the car might as well lead to more autonomous driving modes. During these autonomous driving phases, driving might be less demanding and enables the driver to do different tasks compared to current driving. Depending on the driving conditions of traditional or (semi-) autonomous driving, interactive systems in the car might need to serve different purposes. Therefore, interfaces are necessary that support these different driving modes.

In the remainder of this article, we want to look at different options of how to reduce driver distraction caused by secondary and tertiary driving tasks. We show, how implicit interaction (e.g., based on eye-gaze or body posture) can help automotive UIs to better support attention switching and interaction. Additionally, we illustrate how multimodality, in particular (touch) gestures and other modalities, might help to reduce drivers' visual demand.

Trends & constants

Looking at the car as well as at domains of consumer devices, a lot of changes can be noticed with respect to the user interface. Especially driven by the sector of consumer electronics, several trends can be identified that influence the domain of automotive UIs. As the number of people that own mobile devices such as smart phones or tablets is increasing rapidly, many of them also expect their cars to have features and modalities similar to these devices. They see the car as another lifestyle space. This leads for

example to an increased desire for connectivity (Phone, E-Mail, Internet) in the car. This causes in turn an increased demand for text input (messaging, browsing, searching). These trends were also caused by and supported from a technological perspective: A greater availability of interactive multimedia content and of other information (car-to-car, car-to-infrastructure, etc.) allows providing rich information to the driver. At the same time, we see that costs for computational power decrease. Technological advances in output devices (e.g., head-up display, central information display, fully programmable dashboard) facilitate provisioning of data as well as a multitude of new sensors for data input (e.g., Kinect, Eye Gaze Tracking, etc.) is available.
While these trends with regard to hardware and user's needs drastically change the requirements of automotive user interfaces, we still observe some persisting constants. The main constant with regard to automotive user interfaces is here the need for driving safety. Similarly, the shape of the interior car is only changing very slowly. Thus, space for new technology and devices is scarce.

Case study 1: Supporting Attention Switches

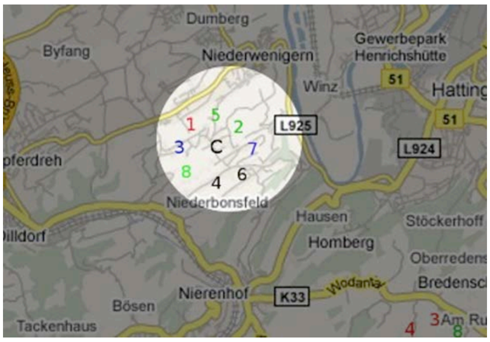


Image: Gazemarks_spotlight.jpg

Figure 1: A spotlight is used to visualize the last conscious gaze position

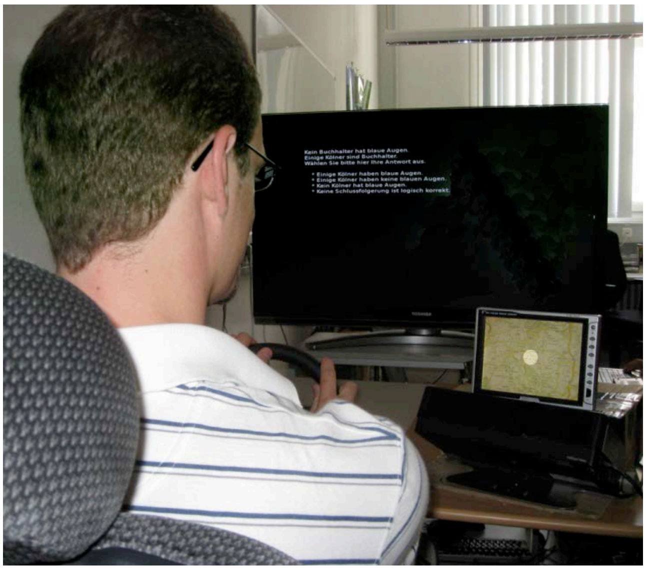


Image: Gazemarks_setup.jpg

Figure 2: Setup of the simulator study: A Gazemark highlights the last gaze position on a 8" screen. The driving scene is replaced by questions presented on a 42" screen to simulate the attention necessary to drive a car. An eye tracker is mounted underneath the small sceen to record the driver's last conscious gaze position on the map display

Using interactive systems while driving requires drivers to switch attention between the road and the interactive system very often and frequently. For example, drivers might interact with a navigation device while driving and gaze alternately at the device and the forward roadway. With information printed on paper, we see that people often use their fingers or other objects as placeholders to keep remember their last gaze position before looking away. With these placeholders they can faster resume the interrupted task after looking back at the paper. Kirsh [Kirsh 2001] and Dix et al. [Dix et al. 2002] present concepts that help to structure the environment to be able to keep track of multiple activities over different timescales. With using simple aids, the process of switching attention between displays can be simplified and sped up.

In contrast, in the car placeholders for the last gaze position on the screen are needed to speed up the task-resuming time. However, screens are typically positioned at a distance from the user in a landscape orientation. In this context, we predict that people will be less likely to use physical props or their hands as placeholders. Furthermore, digital visual placeholders like using the cursor for marking a line on the screen are not common in automotive user interfaces.

We propose the concept of *Gazemarks*, a new eye-tracking technique that automatically provides visual placeholders to the user [Kern et al. 2010]. The basic idea is to make use of the user's gaze behavior to determine where a placeholder could be beneficial. Gazemarks supports the need for interruptability of tasks that is stressed by automotive guidelines [AAM, ESoP]: A driver should always be able to interrupt and to continue a task whenever he wants to. He should never be forced to complete task. One guideline even suggests that after 2 seconds the driver should redirect his view to the road [AAM]. In a user study (described later) we found that resuming a task (in our case finding a location on map again) after an interruption without any placeholder consumes almost these two seconds (Mdn 1999.50ms). Thus, doing any additional task implies violating the "2-seconds-rule".

To overcome this problem we propose the Gazemarks concept. Gaze*marks* don't require active manipulation and can therefore be controlled implicitly by the driver. The usage of an eye tracker allows us to implement a system that remembers the last gaze position on a screen after visual attention has been switched away. Upon switching attention back to the screen, the system highlights the last gaze position.

To be able to implement such a system it is important to consider five essential aspects that play an important role for the gaze position: (1) What is the definition of a gaze fixation? (2) How long is the last conscious gaze fixation? (3) How can showing a visual placeholder be avoided after a blink? (4) How should the last gaze position be highlighted? (5) When should the visual placeholder disappear again?

(1) Definition of gaze fixation:

The human eyes are permanently in at least slight motion, and therefore a gaze cannot be determined as a fixation at a single pixel on a screen. Instead, a gaze on a screen is defined as a set of glances at a region with a specific radius around the first glance. That means the number of glances at this region is counted and after reaching a set threshold these glances are said to form a gaze.

(2) Last conscious gaze fixation

There are two different kinds of gazes: on the one hand, gazes which are consciously at a specific location and on the other, unconscious gazes which are too short for the user to really recognize the content at the position. The latter kind of gaze occurs, for example, when the attention switches from one task to another and the user looks away from the display, which shows the task he is currently working on. We performed a user study with 13 participants, and we found that the last conscious gaze position has to be focused longer than 0.13 seconds. More information about this study can be found in [Kern et al. 2010].

(3) Blinking

Blinking is defined as the rapid closing and opening of the eyelid. On average, a blink takes approximately 0.3 to 0.4 seconds [Moses 1981]. Humans are typically unaware of their own blinking and therefore it is necessary that blinks are ignored in the Gazemarks concept. Otherwise, after each blink the last gaze position would be marked. To achieve this, a Gazemark is only shown with a delay of 0.6 seconds after the last gaze position has been detected on the screen.

(4) Representation of the visual placeholder

There are many options to mark the last gaze position on the screen. The optimal representation is probably dependent upon the task that the user is performing. In a pilot study with 6 participants [Kern et al. 2010] we found that for searching on an arbitrary graphical user interface (e.g., digital map) marking the region around the last gaze position similar to a Spotlight (see Figure 1) is promising. Therefore, a circle is drawn around the last gaze position and the outer area is grayed out. The last gaze position is easy to find and the users perceive this technique to be accurate, since it is robust against minor deviations caused by the eye tracker. We decided to select the spotlight representation in our prototype implementation.

(5) Disappearing of the visual placeholder

Based on comments retrieved in our pilot study we decided that the visual placeholder should be only visible for 3 seconds at most and should disappear directly after finding and fixating the last gaze position again.

We ran a user study with 16 participants to compare two conditions: a control condition of performing a search task on a screen without any visual placeholders and performing a search task with *Gazemarks*. The experimental setup is shown in Figure 2. In this study we used no actual driving task. The attention to the road was simulated by questions presented on the large screen. We asked participants to perform an attention-switching task with a visual map-searching task implemented on the small screen and the textual reasoning task presented on the large screen. On the small screen, a map was shown with six letters randomly placed on the screen. Around each letter, eight numbers were equally spaced in a circle (see Figure 1). Two different maps were prepared to assign them in counterbalanced order for the two conditions. The participant was initially told to find one of the letters on the small screen and tell the experimenter upon finding the letter. The participant should then direct the view to the 42" display where two questions were shown, one after the other. After answering both questions, an arrow appeared indicating one of eight directions. The subject had to look back at the small display, find the same letter again and tell the experimenter which number is shown in the indicated direction. This procedure was then repeated for each of the six letters before switching to the other condition.

The hypothesis that we tested was that users would be able to perform a simple visual search task faster when the last gaze position is highlighted. The results showed as predicted, participants were found to be considerably faster in searching for letters on the map with Gazemarks (Mdn=625.75 ms) than without (Mdn=1999.50 ms), $T=1$, $p<0.001$, $r=-0.87$ [Kern et al. 2010]. This allows continuing with a task without breaking the 2-seconds-rule. In summary, the Gazemarks concept shows high potential to reduce the time needed to reorient on a screen and therefore reduce the time looking away from the road.

Case study 2: A Multi-Touch Steering Wheel

One major question of automotive user interfaces is the location of input elements (ranging from buttons to interactive surfaces) and displays as output devices. Depending on the position, the effort to locate an input element or to direct the view to the screen differs. Potential locations with in driver's reach are the dashboard, the center stack, the windscreen (head-up display) as well as the steering wheel itself [Kern et al. 2009]. Similarly, touch interaction can take place at different locations, like the steering wheel [Doering et al. 2011, Gonzales et al. 2007, Pfleging et al. 2011] and the center console. While traditional controls are mainly located around the steering wheel (center stack) and on the center stack, the steering wheel gained more importance within the last couple of years. Today, it is mainly used for a couple of buttons, but of course the potential number of buttons on the steering wheel is limited by the size of the wheel itself. In this section, we therefore explore possibilities, how to use the steering wheel as a touch-enabled input and output space.

Text Input on the Steering Wheel

In order to use features like navigation services, writing text messages, looking up names in the phonebook, and other info- and entertainment features, text input is one major requirement. Although text input while driving is discouraged, people use their phones to write messages and enter their navigation destinations after they have started driving [PrivilegeInsurance]. Currently, text input in the car is mainly done by using the following technologies: (1) touch-based direct input with on-screen keyboards, (2) tangible controls (i.e., turn and push controllers, sliders, buttons) with an on-screen keyboard, (3) voice recognition, or (4) handwriting recognition on the center console. In a recent study, we looked at using handwriting recognition for text input. We address the following central questions that arise when designing a handwriting recognition system for use while driving: (1) Where should the input surface be located? (2) Where should the visual feedback be presented? (3) How does text input impact driving behavior?

Encouraged by the results in [Burnett et al. 2005] which suggest that handwritten input is faster than interaction with an on-screen keyboard, we designed a user study to explore potential setups in a car cockpit. For this study, we created functional prototypes that allow text input on the steering wheel or on the central console and provide visual output on the steering wheel, the dashboard, or the central console. We conducted a user study to explore the implications of these conditions and in particular their impact on driving behavior.

Keeping Burnett et al.'s [Burnett et al. 2005] concerns regarding text input on a steering wheel in mind, we nevertheless decided to pick up their idea of having a text input interface mounted on a steering wheel, because it is the most independent position for left-handed and right-handed drivers in both right-hand and left-hand drive cars. Nowadays it is very common to have a multifunction controller knob input device in a car's center console, like BMW's iDrive controller or Mercedes MMI controller. In [Graf et al. 2008] as well as in some current cars[1], the center console has already been used for handwriting recognition for search interfaces in cars. Thus, we decided to compare the steering wheel to the center console as text input interfaces under different feedback conditions (feedback on the active input interface vs. feedback in the dashboard display). Both input locations were easily reachable from the driver's seat. We chose a within-subject design with two independent variables: the position of the input surface

[1] http://www.audiusa.com/us/brand/en/models/a8/explore/a8_mmi.html

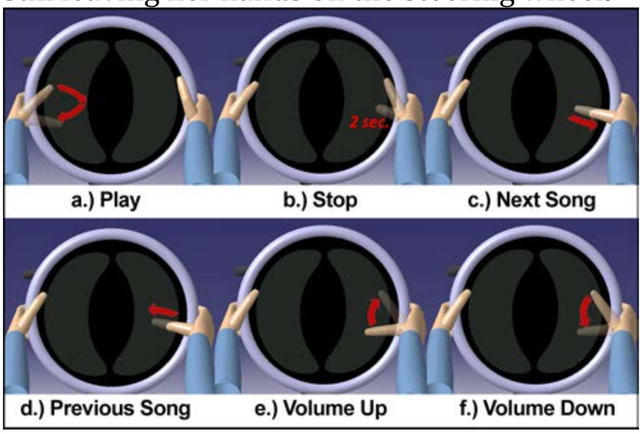
and the position of the visual feedback. We explored four different conditions (input surface/visual feedback): (a) steering wheel/steering wheel (sw/sw), (b) steering wheel/dashboard (sw/db), (c) central console/central console (cc/cc), and (d) central console/dashboard (cc/db). The results of our study show that handwritten text input using fingers on a touchscreen mounted on the steering wheel is well accepted by users and leads to 25% fewer corrections and remaining errors compared to text input in the center console. This suggests a design where the input surface is on the steering wheel and the visual feedback is presented in the dashboard. The advantage of this design is that it could suit both left- and right-handed people, regardless of which side the steering wheel is. Although text input while driving will inevitably impact driving performance. the performance measures from our driving simulator study show no indication that entering text on the steering wheel hinders drivers' abilities in steering.

Touch Gestures as an Input Modality on the Steering Wheel


multitouch_steeringwheel_01.jpg

Figure 3: The simulator setup includes the first prototype of a multi-touch steering wheel. The steering wheel allows multi-touch gestural input and graphical output on the whole surface of the steering wheel.

Most of the locations to input data or to show visual output in the car require the driver to move his hands away from the steering wheel or to look away from the road. We developed a working prototype of a multi-touch enabled steering wheel [Doering et al. 2011] that allows multi-touch gestural input as well as graphical output on the whole steering wheel surface. We integrated it into a driving simulation setup (see Figure 3). With this first version of the prototype, we conducted two user studies. In the first study, we developed a user-defined steering wheel gesture set, and in the second, we applied the identified gestures and compared their application to conventional user interaction with infotainment systems in terms of visual distraction. In order to identify suitable gesture interactions with the steering wheel as part of the first study we chose two exemplary applications, a music player and a navigation system, and proposed 20 associated commands (e.g., play, stop, next song; zoom map in, move map left) that could be useful to perform directly on the steering wheel. The study design followed the explanation of Wobbrock et al. on studies on user defined-gesture sets [Wobbrock 2009], in which users are asked to come up with a gesture for a certain command. In our setup, the users had to perform the gestures while driving in the driving simulator. In this setting, many participants chose to use only the thumbs for interaction. This allowed the drivers to leave their hands at the steering wheel while interacting. We collected a total of 240 gestures (12 users conducted 20 gestures each) and identified the gesture with the highest agreement for each command. We found that agreement on gestures differed, depending on whether gestures could be transferred from other devices (e.g. zooming a map) or had to be invented by the users (e.g. stopping the music player). The resulting gesture set contained a range of gestures embracing symbolic, physical, metaphorical and abstract gestures (see Figure 4 for the identified gesture set for music player interaction). Overall, the participants felt comfortable with performing gestural interactions on the steering wheel while driving. In order to gain further insights into the visual demand of gestural steering wheel interaction, we conducted a second study, adding an eye tracker to the setup that captured the drivers' glances at the interface. In this study, we compared the interaction with a conventional center stack radio and navigation system to the interaction with our steering wheel music player and map application. We designed a within-subject study where participants had to conduct two runs in each of the four conditions ("gesture music player", "gesture map", "console music player", and "console map"). Regarding visual demand, we measured the number of glances at the interface as well as the time spent looking at the interface per interface condition. Our results showed that the overall visual demand for gestural interaction on the steering wheel was much lower than the visual demand for conventional center console devices. Participants looked at the gestural interface 58% to 77% less often than they looked at the console and spent on average 59% to 67% less time looking at the interface when using the gestural interface (depending on the task). The results of our studies suggest that multi-touch steering wheels are well suited for driving as users where able to remember and conduct gestures while driving and that they help to reduce visual attention. Using a multi-touch steering wheel, the driver can interact while still leaving her hands on the steering wheel.



multitouch_steeringwheel_05.png

Figure 4: Our identified gesture set for music player interaction on a multi-touch steering wheel.

Combining Speech and Touch Gestures on the Steering Wheel to Facilitate Gesture Input

One aspect we did not focus on in the explained studies is the scalability of command sets. Our gesture set worked well for the set of commands we proposed, but as the number of infotainment systems and comfort functions in cars increase, we also need to address larger command sets. Nevertheless, the memorability of larger gesture sets is difficult and the design of intuitive and simple gestures would lead to conflicts or the need for modes. This challenge can be addressed by combining different modalities to extend the interaction space. Speech input for example, is one potential expressive candidate, which is already integrated into several cars but seldomly used due to a higher learning curve of remembering available commands [Pickering et al. 2007]. In order to facilitate speech input and to extend (touch) gesture interaction, we conducted a study [Pfleging et al. 2011] where participants could (1) address visible interaction objects by saying their name/description (e.g., “left external mirror”) and (2) interact using a suitable gesture on the multi-touch steering wheel. We chose a scenario of controlling 26 secondary and tertiary functions in a car (i.e., safety and comfort functions). All selected functions were simple one-step functions, mapping a single command onto a single interaction object. The selection of tasks also concentrated around well-know functions that should be common for the average driver as well as they should somehow be visible to the driver. Interestingly, for 86.7% of all executed tasks, the set of user-defined gestures was very similar and could be reduced to directional touch gestures (moving a finger up/left/right/down, see Figure 6). At the same time, remembering the speech commands (just saying the name of the interaction object) is easy in many cases as the objects are in the driver's field of view. Using directional gestures like moving a finger up/down to close/open a window also allows an easy undo of an action as the finger just has to be moved to the other direction to revert the action just done. We conducted a simulator study with 16 participants comparing the proposed multi-modal approach and a setup using traditional controls. The results show that the mean distance to baseline measured during an LCT test [Mattes 2003] was slightly but not significantly higher. A DALI questionnaire revealed that the drivers perceive a lower visual demand when using the multimodal interface. A next step will be to evaluate driving performance and gaze behavior in detail. Additionally, we plan to investigate if additional modalities can facilitate this approach even more. One idea is to use body posture estimation (e.g., head posture) in order to detect towards which the objects the driver's commands are aimed at.


speech_gestures_setup.jpg

Figure 5: A second prototype of a multi-touch enabled steering wheel was used to test the multimodal combination of gestures and speech.

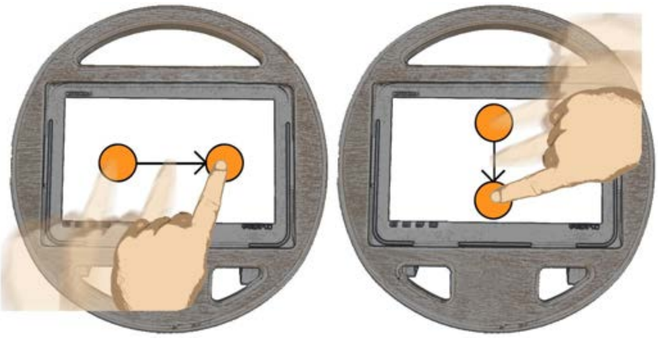

gesture.jpg

Figure 6: When combining speech and touch gestures, the complexity of many touch gestures is reduced to directional finger movements on the screen.

Conclusion & Future work

Latest figures [US Traffic 2010] show that the percentage of accidents caused by distracted drivers increased between 2000 (10%) and 2009 (16%). As interactive systems in the car are one of the potential reasons for driver distraction, it is worth

finding solutions that reduce distraction while using automotive user interfaces. In order to keep the advantages of current interfaces at the same time, we presented two technologies in this paper that might help to reduce driver distraction. By using eye tracking, our Gazemarks concept allows to highlight the last conscious gaze position on a screen. Thus, the time to re-orient one's view to a screen can be reduced which in turn can reduce the time before the driver moves his view to the road again. By using a multi-touch steering wheel, we see that text entry can be improved compared to text-entry on the center console. Similarly, executing gestures on a multi-touch steering wheel helps to reduce the visual demand of the driver compared to traditional controls. The number of available commands also controls the complexity of gestures. Using an additional modality like speech input, the complexity of these gestures can be reduced as shown in our multimodal prototype. Also, the visual demand is reported to be lower.
In future work, we would like to see how the combination of gestures and speech can be extended to control abstract objects, like, e.g., radio station or volume. Additionally, we would like to investigate how additional modalities might even allow easing the interaction process further.

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