pieTouch: A Direct Touch Gesture Interface for Interacting with In-Vehicle Information Systems.

Ronald Ecker[1] **Verena Broy**[1] **Andreas Butz**[2] **Alexander De Luca**[2]

[1]BMW Group Research and Technology
Hanauerstraße 46
Munich, Germany
+49 89 382 55362

{ronald.ecker, verena.broy}@bmw.de

[2]University of Munich
Amalienstraße 17
Munich, Germany

{andreas.butz, alexander.de.luca}@ifi.lmu.de

ABSTRACT

Touch-sensitive displays seem like a natural and promising option for dealing with the increasing complexity of current in-vehicle information systems (IVIS), but since they can hardly be used without visual attention conventional point touch systems are rarely considered in cars. To ensure road safety, the drivers' visual attention needs to be focused almost entirely to the road. In order to integrate touch screens successfully into cars, new concepts are needed to reduce visual demand. The adaptation of pie menus serving as a visualisation of gestures reduces the user's cognitive load, and we were able to achieve an almost blind interaction with the IVIS. We compared our design to a generic touch system using a dual task evaluation method (Lane Change Task [18][20]), and the results regarding total task completion time, lane deviation and subjective preferences confirm a higher usability and efficiency, as well as an added hedonic quality of pieTouch.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces –*Evaluation/methodology, Input devices and strategies, Interaction styles*; I.3.6 [**Computer Graphics**] Methodology and Techniques –*Interaction techniques.*

General Terms

Design, Performance, Experimentation.

Keywords

Automotive HCI, touch screens, in-vehicle information system (IVIS), pie menu, automotive user studies.

1. INTRODUCTION

In-vehicle information systems (IVIS) provide various applications to inform and entertain drivers during their ride. Examples include in-car navigation, communication and entertainment systems. Regarding interaction concepts for IVIS, at least two basic variants of input devices exist: interaction via haptic devices or via touch displays with simple point touch interaction concepts.

By taking a closer look at the evolution of human car interfaces, a change of interaction paradigms becomes apparent. When the first radio was integrated into the car 75 years ago, every function had its own button or control. Now that more and more functionality to inform and entertain drivers is integrated into cars, new interaction concepts are needed [13]. The concept of directly controlling functions with hardware buttons reached its limit. BMW currently deploys the iDrive system, a central control unit mounted in the center stack for interacting with the onboard computer [7], as a solution to control a large set of functionalities.

Figure 1. Pie sub menu for changing routing criteria of the navigation system. Appears when the user pulls his finger over the dedicated pie slice in the main menu and stops anywhere on the screen (location independent).

Besides handling the increased amount of functionalities, issues related to the mobile nature of the interaction have to be considered. All mobile input and interaction systems have to take mobility into account. That is, the users are not fixed to a specific location. Furthermore, mobile systems should be designed in a way to be robust against interruptions. Mostly, mobile interaction systems are only the users' low priority task, while their main focus is on something else. Talking about in-vehicle systems, this means that the drivers' attention is indispensable for traffic safety and interacting with IVIS is only secondary to the task of driving [11]. Therefore, designing IVIS imposes special requirements on interaction schemes. Common requirements and rules of interface design [26] are imperative and extended to avoid driver distraction during interaction. Criteria regarding usability, learnability, efficiency, memorability, error handling and satisfaction [23] are intensified compared to standalone systems. One important issue is to keep interaction interruptible and to enable the driver to switch back and forth between the IVIS and the driving task. Therefore, interaction tasks should be structured as sequences of small chunks and allows users to continue

MobileHCI'09, September 15 - 18, 2009, Bonn, Germany.
ACM 978-1-60558-281-8.

interaction at the same logical position after an interruption. Another issue is to reduce visual attention while interacting and to provide concepts which use mechanisms for "blind interaction". Several ISO standards [9][10] and negotiated agreements [11][12] state various compliance procedures for in-vehicle visual presentation and for principles of dialogue management.

As it has to be possible to use IVIS during the higher prioritized task of driving, it is crucial to understand the mechanisms of the driving task and its subtasks. Driving can be divided into stabilization, maneuvering and navigation [3]. Stabilization means to keep the car in the lane and the distance to the other traffic participants. Drivers have to consider the spatial relationships in their near environment. Complex acts, such as turning or passing are assigned to maneuvers. Navigation pertains to knowledge regarding the route to the destination. It requires large scale knowledge associating streets and routing information. Because of this, a plurality of cognitive processes is running. Especially visual attention is extremely important to ensure safety.

Haptic devices, such as multifunctional controllers, provide a number of advantages regarding the strong requirements of IVIS, particularly interruptibility and avoiding driver distraction. Compared to a multifunctional haptic device, touch screens have some drawbacks. Especially when interacting with point touch based screens, visual attention is required to press a button on the screen. Furthermore, state of the art touch displays in cars lack haptic feedback. Current research tries to simulate tactile impressions via vibration [32]. Another big issue is to locate the screen inside the car at a position that enables the driver to optimally read and reach it at the same time. General problems while interacting with a touch screen are the occlusion of displayed information with the finger and fatigue of the arm [7].

Despite all of these drawbacks, touch interaction is an interesting concept for IVIS as it is very efficient and intuitive especially for novices and non-technicians.

Many current mobile devices or smart homes are equipped with touch screens. Their interaction is not only realized with single point touch anymore. Touch gestures and multi touch input provide new dimensions for direct manipulation. We assume that touch gestures are able to reduce visual attention. It is not necessary to precisely hit a relatively small button on the screen. Instead, a larger screen area can be used for interacting with the application. The application of such touch gestures in automotive environments needs to be investigated to see whether they can meet the special requirements. Therefore, in this work we present pieTouch, a touch-based interaction concept for IVIS based on the pie menu idea. a user study was performed, which showed that after a short training, pieTouch (see Figure 1) can be used more efficient and with less visual demand than classical touch concepts.

2. RELATED WORK

State of the art touch interaction concepts used in cars are mostly point touch oriented. The mobile navigation system TomTom [29] offers its functionality in a matrix based selection menu. Jaguar and Toyota use similar touch concepts. In Porsches IVIS the map can be moved by pressing the finger on a direction symbol. VW research presented a concept where touchable buttons expand upon approach of the finger [33].

In automotive research, Bach et. al. [3] compared tactile, touch and touch gesture input and showed that touch gesture input could decrease significantly eye glances while interacting with secondary tasks. Gonzalez et. al. [14] integrated a TouchPad in to the steering wheel and compared methods for selecting items in long lists. They found out that gesture based text entry was the fastest technique.

Currently, more innovative products can be found in the mobile domain. Apples iPhone [2] was one of the first commercial products which offered manipulation via touch gestures within graphical metaphors. It is possible to pan 2D graphical information by moving the finger on the screen or to scroll in a list by moving the finger in the desired direction. Furthermore, the interface enables zooming via multi touch gestures. Microsofts surface [21] table uses similar mechanisms and allows users to rotate, move and manipulate visual objects with touch gestures on an interactive tabletop. The mobile device N2 from Neonode [22] realizes touch gestures in such a way, that the starting position of the gesture is the parameter for the desired command. To enable blind interaction, the borders of the screen offer haptic orientation.

One interesting research question is how to enhance usability of touch devices in mobile applications. The earPod [25] consists of a round touchpad and implements a reactive audio feedback. If the finger moves over a border between two menu items the list entry is read. Pirhonen [24] realized a mobile media player which combines simple gestures with an audio feedback for blind interaction.

An alternative way to select menu or list items is the pie menu. They display their options arranged in a circle around the mouse pointer [17]. Moving the pressed mouse pointer over one of the options and releasing it, causes the execution of a function. Further work enhanced pie menus to display submenus, scroll in longer menus, provide expert modes without display and show tooltips. Callahan could show in [8] that pie menus are faster and produce a lower error rate than list-based menus. After a training period users were able to use the pie menu almost blind. Furthermore pie menus possess the benefit that the finger does not occlude any content of the menu.

3. PieTouch DESIGN

A task analysis of the BMW iDrive system was carried out to specify the requirements. We considered not only concepts dedicated for automotive use, but also from the mobile, desktop and smart home domain.

Following an iterative design approach, the prototype was implemented in an early state to get fast feedback from users and experts. At the end the prototype was evaluated under automotive conditions.

3.1 Consideration of Different Approaches

The primary design goal was to reduce glance time when using a touch screen during driving. The high glance time necessary for the hand-eye-coordination is one reason why touch screens are currently rarely used in vehicles. Therefore, three different design approaches were considered.

The first deliberation was a library of symbolic direct touch gestures for using the main functions and navigating in common data structures of IVIS. For that reason existing touch gestures from other domains were analyzed. Such gestures could be used without focusing a specific location at the screen which constitutes the main advantage. Simple symbolic gestures for generic commands like scrolling (sweep up, sweep down), back and forward (sweep left, sweep right) or stop and play (tap) are used consistently for several products and are therefore known and very intuitive. More complex symbols are less self-explanatory and have to be learned and known before use especially when interacting with a big set of complex functions as in vehicles.

Second, drag and drop operations were considered. Based on lists and direct manipulation, an element of the list can be selected by putting the finger on it and dragged by moving it over certain symbols, which mark different actions for the selected list item. By releasing the element over a function symbol the action will be executed. This concept cannot fully be used without gazing to the screen but it is self-explanatory and easy to use. Because of the small number of functions, which can be displayed on a proper screen within the car, this concept was not considered further for touch interaction in the vehicle.

One problem of interacting via gestures is their lack of affordances. Functions are not displayed and have to be known or learned by novices. Pie menus, on the other hand, display the direction of a gesture and the assigned function, independent of position on the screen. In combination with touch, they offer a simple and intuitive method to support novices and experts simultaneously. Since all gestures are represented graphically, they can easily be learned by novices. For expert users, pie menus enable eyes-free interaction, because the direction of the gestures is known and the starting point of gestures is independent from the position of the finger on the screen. Often used gestures may even move from conscious actions into motor memory eventually. Thus, an extension of pie menus appeared to be the most promising concept for touch-based interaction with IVIS.

3.2 The pieTouch Prototype

The prototype was designed for a 7'' touch screen for finger interaction, which was assumed to be the maximum screen size for the adaptation in a car. The implementation started in a very early design state to receive quick and early feedback from experts and users. For answering critical design questions, expert interviews and user studies were carried out in an early design stage. In this way, even the first rudimentary implementation of a pie menu was tested in a driving simulator. All five consulted experts found that pie menus are a promising alternative to classical point touch concepts [7], and hence the decision was taken to investigate pie menus more closely for touch interaction while driving.

3.2.1 General Design

One problem, when realizing eyes-free touch screen interaction, is that screens do not provide haptic feedback like buttons, switches and knobs. Currently, a lot of research is done to enhance interactive mobile touch devices with haptic feedback [28][16][27][19][32] Until now a full imitation of haptical control elements was not achieved. The only touchable hardware elements of a screen are the borders. These borders were used for frequently used function supposed to be used without glance. These borders are especially suitable for slider-like finger motions. By considering the placement of the screen in the center stack of a car on the right hand side of the driver (except left-hand traffic), the screen is covered by the hand or arm, when interacting along the left side of the screen. Therefore, functions which are usable without looking at the screen are placed on this side, like the eye-free scrolling function. Functions which are not working without looking at the screen, like zooming a map, are arranged along the right edge of the screen.

For all context menus, pie menus were used. The pieTouch prototype implements aspects of two IVIS categories: the navigation and the communication system.

Due to the fact that besides context menus also panning (navigation system) and scrolling (contact list) occupy the screen real estate, a mode change between menu and function is required: One for the direct manipulation of lists or maps, the other for context menus. For changing the modes, dwelling was used. If users move their finger before a specified time threshold they are able to pan or scroll. After this threshold the mode for the pie menu is activated and the menu is displayed. Building on related work [7] and a user study in a driving simulator of the BMW Group, the time threshold was set to 300 ms. All six participants were experts from the MMI Department of the BMW Group Research and Technology. Five different prototypes with different time thresholds of 200, 250, 300, 400 and 500 ms were implemented. Each expert had to complete certain tasks. The captured objective dataset showed that the error rate (interaction in the wrong mode) between 300, 400 and 500 ms does not differ. The subjective opinion of the experts was that 300 ms appeared to be "*not too long or too short for changing the modes*".

Considering possible locations in the car raises the problem that the right index finger on the screen covers a few slices in the bottom right quarter (bottom left for left-hand traffic) of a 360° pie menu. Depending on the hand and finger posture, when interacting with the touch screen, different users cover different areas. Consequently, a second informal user study with eight participants was conducted. Six users covered an area from 120 to 150 degrees seen from the driver's perspective. The remaining two persons covered an area from 150 to 190 degrees. Adding a 10 degree tolerance, the section from 110 to 190 degrees was defined as unusable, because options in this section can not be seen easily. Therefore, the pie menu used in the prototype was not a closed circle around the users' finger.

With these results, the decision was made to use a threshold of 300 ms to let the pie menu appear around the touch point. A low frequency acoustic signal indicates the activation of the menu mode. When touching a screen, the finger covers more than a single pixel. Therefore, a 25 pixel tolerance around the initial pixel was granted. By dragging the finger into the direction of the desired option, the respective option is selected. By lifting the finger from the screen, the option or function is executed and a high frequency signal is played. This means that, executing a function can be split into three elementary steps:

- activation of the menu (touching the screen)
- selecting a function (dragging the finger into the direction)
- executing a function (lifting the finger)

Instead of executing the function directly after selecting, the operation can be canceled by dragging the finger back into the center. Shneiderman describes this behavior as "*un-touch screen*" [26] Using this, a positive effect on the error rate was assumed.

When the pie slice for the submenu is selected, a menu appears, when the users' finger does not move anymore. While moving, the sub pie follows the finger. In this way we made sure that also the sub menu is independent from the finger position on the screen and can also be used eyes-free. The pieTouch prototype provides audio feedback, but no haptic feedback.

3.2.2 *Main Menu*

The main menu is located at the bottom left corner of the screen. On the one hand, this is the nearest position to the driver, thus hand movement is minimized. On the other hand, the corner is ideal for touching, because the screen borders are on the bottom and the left side of the finger. Figure 2 illustrates the popped up main menu in context of the contact list.

Figure 2. Main menu in the contact list.

The menu consists of three application domains: navigation, entertainment and contacts. It is placed in a quadrant menu and does not require dwelling, because it only appears when touching the dedicated button, i.e. the corner of the screen. It is the only menu which depends on the position of the finger on the screen. When dragging the finger over the menu, the touched item is read. By exiting the menu entry the audio feedback stops, a click sounds and the next entry is read (see Figure 3), similar to [25].

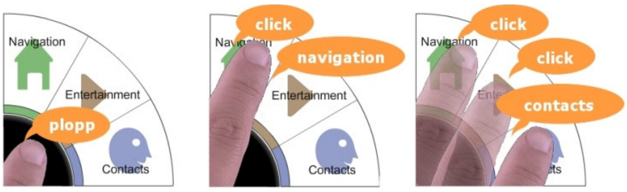


Figure 3. Acoustic feedback in the main menu.

3.2.3 *Communication System*

For the prototypical realization of the communication system, an address list was chosen. The functions which can be applied to the list items are similar to the functions in the iDrive system. The communication system is split into four functional screen areas. Along the left monitor border the scroll option for eyes-free usage is situated. For quick navigation through the list, an index is placed next to the right screen border. As mentioned above, the main menu is placed in the left bottom corner. The central screen area contains the list (see Figure 4).

Scrolling on the list follows the drag and drop concept. When sweeping the finger down, the list is moving upwards. The context menu is activated by tapping onto the designated list item and not moving the finger for 300 ms (see Figure 5).

The index can be used by tapping onto an index entry or sweeping over it. Due to the restricted screen size and the minimum font size for IVIS, letters are grouped according to the occurrence of the first letter of all names contained in the list. The pie menu appears by dwelling on a list entry for 300 ms on the upper side of the finger. When selecting one of the first three list items, the pie menu will be displayed underneath the user's finger, because on the upper side options can not be selected and displayed properly.

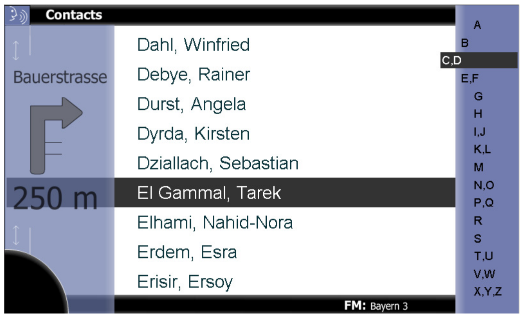


Figure 4. Contact list.

Figure 5. The contact list with the displayed pie menu for editing, calling and navigating to a contact.

3.2.4 *Navigation System*

The navigation system was based on the map view of the iDrive system. The context menu of the iDrive system contains seven route options for targeting the driver to the desired destination and five functions for manipulating the map. The following options were implemented in a pie menu: adjusting northward, enter point as target, mute targeting and change routing criteria.

The last menu item contains a sub pie menu with seven possibilities to change the routing criteria: shortest route, fastest route, route without traffic jams, toll free route, highway only, no highway and without ferry.

Figure 6. The navigation application with the main pie menu and the sub pie menu.

The navigation system has three functional areas. Along the right screen border the zooming bar is located, which can be used in a discrete or continuous way. The central map area contains the panning function and the pie menu as described above. The main menu is positioned in the left bottom border, as in every application domain of the pieTouch prototype (see Figure 6).

Zooming and panning the map was realized by direct manipulation. When the finger is moved immediately after putting it on the screen the panning mode is activated. Dwelling the finger on the screen for 300 ms activates the pie menu. As mentioned in [15], the most suitable number of entries in a pie menu is four or eight entries. We used a pie menu with seven options. In our prototype the size of pie menu slices is not stringently 90 or 45 degrees.

3.3 The Reference System

For evaluating the suitability of pie menus in automotive environments via a user study, as we will discuss in section 4 a reference system was indispensable.

The reference system, also called simpleTouch, completely matches the structure and functional extent of the pieTouch prototype. Also the number of interaction steps to reach an option is identical to the gesture based system. Its only difference is the interaction method, which is point touch based. By simply tapping on the desired option, figured as button or list item, this option will be executed. Audio feedback is restricted to a "click" sound, when touching an option and an adequate feedback, when executing a function.

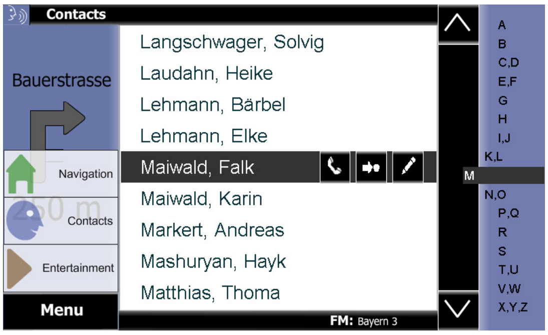


Figure 7. Contact list of the simpleTouch prototype with open main menu.

Navigating through the contact list can be performed by tapping onto the dedicated arrow buttons on the left side of the list or by touching a letter of the index to jump to the first corresponding list item. A sweeping gesture on the list or scrollbar is not provided. Dwelling the finger on these buttons, triggers automatic scrolling. When lifting the finger, the scrolling process is stopped. This way, users do not have to lift and tap on the screen to reach a list entry. Functions for the list item are located directly beside the name and can be executed by tapping on them (see Figure 7).

For zooming the map view of the navigation system, similar to the scrolling function of the contact list, dedicated "+" or "-"-buttons have to be touched. In analogy to the contact list, dwelling on the buttons triggers the automatic zoom process. A list based context menu contains the functions for manipulating the targeting options as described in 3.2. For displaying this menu a button is located on the bottom of the screen. Selecting a function also causes the menu to disappear (see Figure 8).

The higher interruptability and the direct function selection in the contact list are the main advantages of the simple touch prototype. The functionality is also not hidden in a first contact, which is a problem in the pie menu realization. Whether this implies a higher suitability to the driving task will be verified in the following sections.

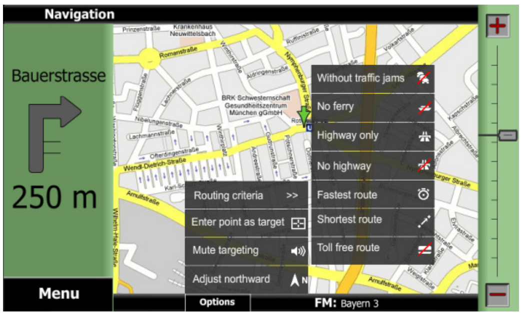


Figure 8. Open context menu in the navigation system of the simple touch prototype.

4. USER STUDY

In order to validate the suitability of the pieTouch concept a prototype was implemented in Flash and AS2. The concept was tested while the user was concerned with the Lane-Change-Task (LCT) [20], an established method for the evaluation of automotive interfaces. Because the LCT does not provide reference values for the quality of the evaluated system, a reference system was implemented in Flash. Quite few studies are comparing the central haptic control unit and a touch screen in an automotive environment [1][7]. Because of the distinct menu structure and number of interaction steps for reaching an option, the pieTouch system could not be compared with the iDrive system. Furthermore we were interested if it is possible to compensate negative characteristics of classical touch systems, like visual attention for the hand-eye-coordination, via touch gestures and pie menus. That is why this study compares a direct touch gesture (pieTouch) with a point touch (simpleTouch) interface.

4.1 Lane-Change-Task

The LCT is a dual-task-method where participants have to perform two tasks at the same time, the system going to be evaluated and the LCT driving simulation. The goal of this method is to measure the drivers' distraction from the driving task while interacting with a system. Therefore, participants have to accomplish sudden driving maneuvers, namely changing the lane as fast as possible with a constant speed of 60 km/h. For keeping this speed they just have to drive at full throttle. The lane change maneuvers are indicated by traffic signs. The distance between the signs averages 150 m. As the result, the mean deviation of the ideal driving (MDEV, see Figure 9) line admits to draw conclusions on how users performed the task.

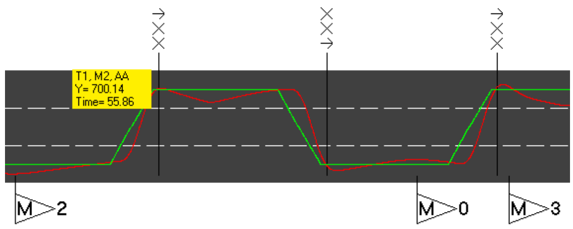


Figure 9. Example for deviation from the ideal line (output of the LCT analysis) [18].

The mean deviation is described as the average deviation from a normative model, which is the total area between the normative model and the actual driving course (**m^2**) divided by distance driven (**m**) [18]. The gap between the baseline (driving without interaction with a system) and the dual-task condition (driving and interacting) represents the degree of distraction. With the purpose to compare two systems the absolute MDEV values can be compared.

4.2 Experimental Setup

The experiment was realized in the usability lab of BMW Research and Technology GmbH in Munich. The setup comprises a steering wheel, pedals and one computer with a 19'' screen for the LCT simulation. The prototypes were installed on a separate computer with a 15'' Elo touch screen (see Figure 10).

To ensure that the touch screen was suitable for finger interaction, some pre-tests were carried out. Alternative screens were compared and the one that matched the requirements best was chosen. For the maximum screen size in the vehicle 800 x 480 pixel were assumed. Therefore, an acrylic glass plate was cut out and fitted over the screen, in order to still support screen borders, if not the original ones. For detailed information about the experimental setting for the LCT see ISO 26022 [18].

4.3 Participants

We recruited 16 participants between 26 and 42 years (average 32 years), each with a driving license. Four of them were women.

Figure 10. Experimental Setting.

4.4 Experimental Design

For this evaluation a within-subject design was chosen. All volunteers had to interact with both prototypes, while the order of the prototypes was counterbalanced to avoid learning effects. To guarantee the same experimental conditions, a protocol was created containing instructions and the exact workflow for the instructor.

At the beginning each user had the opportunity to explore and evaluate the first prototype in terms of the *think aloud technique*. Accordingly the systems were explained and different tasks were exercised. Afterwards the LCT was trained until a MDEV of less than one meter was achieved. Then the LCT was executed while simultaneously interacting with the one of the two systems and then with the other (**group 1**: simpleTouch, pieTouch; **group 2**: pieTouch, simpleTouch). In order to obtain subjective user opinions, three questionnaires (AttrakDiff [31], SUS [6] and a comparative questionnaire) were applied after interaction with each system. Finally, a questionnaire for comparing both systems was presented.

4.5 Tasks

Each participant had to perform three different *task categories* in a row with one prototype which was interrupted with a short break. The three tasks concerned are navigating through the contact list containing 151 entries to a specific name and selecting a menu item of the context menu (**scrolling**), selecting an item of the main context menu in the navigation system (**main menu**), choosing a routing criterion of the sub context menu in the navigation system (**sub menu**). Every single *task category* consisted of three tasks to obtain a measurable time period and minimize measurement errors. In order to deal with potential training effects, all three *task categories* were repeated three times with one prototype and measured separately. The following dependent variables were gathered: MDEV, error rate, operating time and training effect in terms of shorter operation time per repetition. The independent variable was the prototype, i.e., the way of interacting with the touch screen: point touch versus touch gestures.

4.6 Hypotheses

The pieTouch prototype was designed for nearly eyes-free interaction with IVIS. Therefore, we assumed less visual distraction than with the point touch based simpleTouch prototype. Since pie menus have to be learned and their full potential can not be shown in the initial interactions, a higher effect of training was expected. Because of the gesture interaction a higher hedonistic quality was anticipated. To verify these assumptions, the following hypotheses were worked out: (H1) The pieTouch prototype is more attractive than the simpleTouch. (H2) It takes more time to complete tasks with the simpleTouch than with the pieTouch prototype. (H3) When interacting with the simpleTouch more errors are made than with the pieTouch prototype. (H4) When using the pieTouch repeatedly, a greater reduction of operation time can be achieved. (H5) A smaller deviation from the ideal driving line can be accomplished with the pieTouch.

5. RESULTS

For each task category (**scrolling, main menu and sub menu**) the mean deviation from the ideal driving line and the overall operation time needed with the two prototypes was recorded using the LCT driving simulation. The error rate was recorded by the investigator.

5.1 Statistical Evaluation

To identify significant differences between the prototypes, the following statistical methods were used:

A Kolmogorov-Smirnov test [5] showed that most variables were not normally distributed. Thus, a Wilcoxon test for pair differences between dependent data was applied.

To compare group 1 (simpleTouch before pieTouch) and group 2 (pieTouch before simpleTouch), the Kolmogorov-Smirnov test for differences between two samples of dependent data was computed.

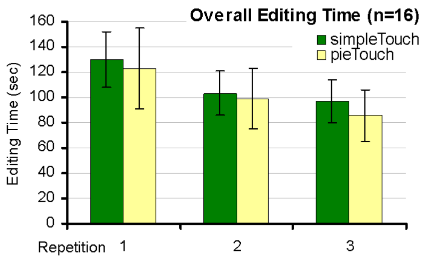
5.2 Objective Results

With objectively measured data, the hypotheses H2 to H5 were validated. H2 and H4 could be accepted, while H3 and H5 had to be rejected.

5.2.1 Editing Times

The *overall editing time* describes the time from the end of the instruction for the first task of the first *task category* (scrolling) until the last interaction step of the last task from the last *task category* (sub menu). The *category editing time* of a *task category* stands for the span between the end of the instruction for the first task until the last interaction step of the last task of this *task category*.

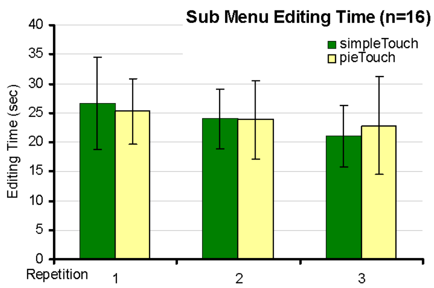
When looking at the overall editing time of all three categories and the three repetitions of these categories, a shorter completion time was achieved with the pieTouch prototype. The Wilcoxon test shows that the overall editing time at the third repetition is significantly lower with the pieTouch (p=0.023). Figure 11 illustrates the overall editing time.



Wilcoxon Test			
	Repetition 1 Pie – Simple	Repetition 2 Pie – Simple	Repetition 3 Pie – Simple
Z	-1.241(a)	-.982(a)	-2.275(a)
Significance	0.215	0.326	0.023

Figure 11. Overall editing time of the three task categories.

The category editing times for *scrolling* and *main menu* show similar characteristics as the overall editing time. All tasks were completed faster when interacting with the pieTouch prototype and at least one significantly shorter editing time in one repetition could be found by the Wilcoxon test.



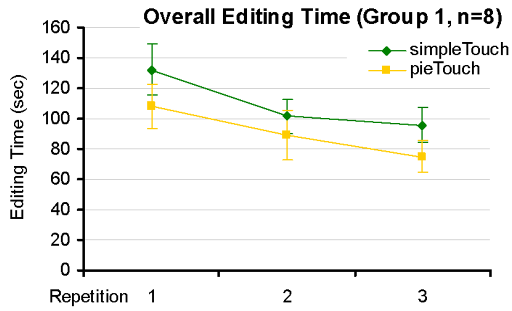
Wilcoxon Test			
	Repetition 1 Pie – Simple	Repetition 2 Pie – Simple	Repetition 3 Pie – Simple
Z	-0.259(a)	-0.879(a)	-0.052(b)
Significance	0.796	0.379	0.959

Figure 12. Editing time of the task category sub menu.

Only the task category *sub menu* differs from the overall achieved editing time distribution. In the third repetition of the task categories this category was performed insignificantly slower with the pieTouch prototype. The first two repetitions were completed faster with the pieTouch prototype (Figure 12). The assumption that tasks can be completed faster by using the pieTouch prototype (H2) was verified for scrolling in the list and the main pie menu. For selecting an option within the sub pie menu this hypothesis could not be supported.

5.2.2 Effect of Training

As mentioned above, the effect of training corresponds to the reduction of the editing time from one to the next repetition of the tasks. Figure 11 illustrates that for both systems the overall editing time was reduced in every repetition. An interesting evidence for the effect of training is the comparison of group 1 and group 2. Participants of group 1 could decrease the time with both prototypes. Noticeable is the fact that the difference between the first and second repetition is higher with the simpleTouch prototype. But with the pieTouch prototype a higher editing time reduction between the second and third repetition was achieved. The mean editing time for the first and third repetition was significantly smaller (p=0.012, p=0.025) when interaction with the pieTouch prototype (see Figure 13) took place.

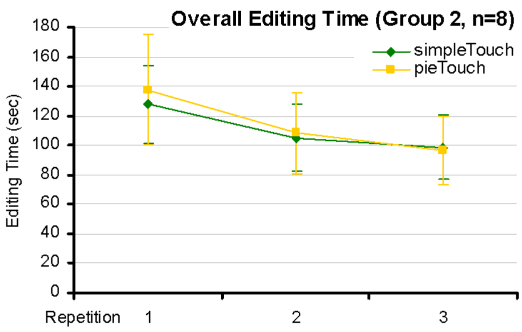


Wilcoxon Test			
	Repetition 1 Pie – Simple	Repetition 2 Pie – Simple	Repetition 3 Pie – Simple
Z	-2.521(a)	-1.680(a)	-2.240(a)
Significance	0.012	0.093	0.025

Figure 13. Overall editing time of group 1 (simpleTouch before pieTouch).

Vice versa this effect could not be replicated from group 2. No significant differences could be identified over all repetitions. In contrast to group 1 the last task repetition was performed faster with the pieTouch prototype although it was used before the simpleTouch (see Figure 14).

In addition both learning curves (see Figure 13 and Figure 14) for the editing time of the pieTouch prototype decline stronger than the curves of the simpleTouch Prototype. It is assumed that if a fourth repetition had been made, the pieTouch could achieve still better editing times whereas the learning curve of the simpleTouch is going to stagnate. To prove this statement, an additional evaluation would have to be done, but even now, the hypothesis that the training effect with the pieTouch is higher than the training effect with the simpleTouch (H4) tends to be true under these circumstances.



Wilcoxon Test			
	Repetition 1 Pie – Simple	Repetition 2 Pie – Simple	Repetition 3 Pie – Simple
Z	-1.120(a)	-0.700(a)	-0.560(b)
Significance	0.263	0.484	0.575

Figure 14. Overall editing time of group 2 (pieTouch before simpleTouch).

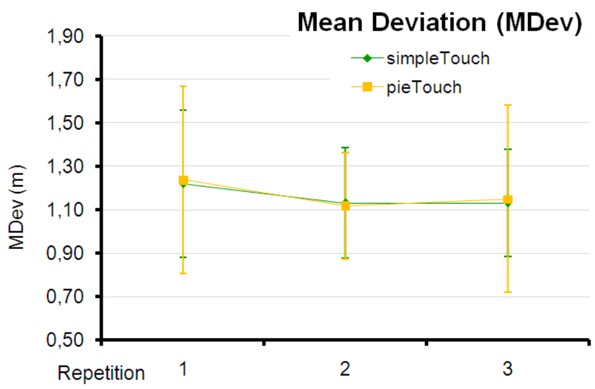


Figure 15. Mean Deviation of the driving task (n = 18).

5.2.3 Lane Deviation

The deviation from the ideal driving line does not show any differences. Hence, H5 could not be verified. All participants achieved the required lane deviation for the baseline at least in the third run. Figure 15 illustrates the mean deviation under the dual task condition for all three repetitions.

5.2.4 Error Rate

The assumption that using the pieTouch during driving causes fewer errors than the simpleTouch prototype (H3) could not be verified either. Participants performed eleven errors with the pieTouch and 17 errors with the simpleTouch, but regarding the 240 interaction steps in total, the difference was not statistically significant.

5.3 Subjective User Opinion

Three questionnaires were used to retrieve participants' subjective opinion concerning the prototypes and their interaction methods.

The **System Usability Scale** (SUS) comprises ten questions covering three different dimensions of usability: efficiency, effectiveness and learnability. The result of this score was 79 points for the pieTouch and 70 points for the simpleTouch. Users rated the dimensions of efficiency and effectiveness of the pieTouch prototype significantly higher ($p=0.001$, $p=0.007$; $p<0.01$). In contrast, users were less satisfied with the learnability of the pieTouch prototype ($p=0.033$; $p<0.05$).

The **AttrakDiff** [31] questionnaire is a semantic differential for evaluating a user's opinion about a product. Four different dimensions are considered:

- Pragmatic quality: Describes the Usability of a product.
- Hedonic quality – Simulation (HQ-S): Indicates to what extent the product can support novel, interesting and stimulating functions.
- Hedonic quality – Identity (HG-I): Indicates to what extent the product allows the user to identify with it.
- Attractiveness (ATT): Describes a global value of the product based on the perception of quality.

The confidence rectangle gives feedback about the reliability of the results. The smaller the rectangle is, the more reliable are the investigation results. Figure 16 shows the results of the AttrakDiff questionnaire where product A stands for the pieTouch and product B for the simpleTouch prototype.

Figure 16. AttrakDiff results [31].

The pieTouch was rated significantly better in all dimensions. Especially attractiveness and pragmatic quality was classified as "*ideal*". Also the hedonic quality is above the average. Due to the small confidence rectangle, users apparently agree and a high reliability of the results is given.

In order to find out, which prototype appears more appropriate to users for interacting with an IVIS, a **comparative questionnaire** was created. It consists of five questions about different aspects of the interface. Participants had to come to a decision between the prototypes. The questions focused on: scroll function, menu for changing the application domain (contacts, navigation, and entertainment), context menu (pie vs. list menu), prototype in general and the suitability for the driving task. Nearly everyone preferred the pieTouch prototype in all aspects. Because of the higher interruptability one person stated that the simpleTouch is more suitable for the driving task. One person preferred the simpleTouch menu for switching between application domains, because he was *more used to it* and two participants the scrolling via the arrow buttons because the scrolling direction was clearer. The strongest arguments for the pieTouch were: blind usage (20 answers for 5 questions and 16 participants), it's more fun (9 answers), the finger is always at the point of interest (4 answers).

5.4 Summary

The comparison of these two prototypes, one based on point touch and the other on gestures, illustrates that the gesture interface fits better to the driving task. Subjective user opinion as well as objective data captured with the Lane Change Task shows the advantage of this kind of interaction for short context menus and navigating through lists. Especially after training, both if carried out with a classical touch concept or the gesture interface, significant lower editing times could be achieved.

After an adaptation phase users performed the task in significantly less time with the pieTouch prototype. Furthermore the editing time declines faster after the third repetition in comparison to the simpleTouch. Nevertheless editing times were lower in every repetition with every task, except for the last repetition of the sub menu selection with the pieTouch. A higher learning effect as well as a better performance in initial interaction was monitored and verified. This statement was confirmed by subjective user opinions, where efficiency and effectiveness was rated higher for the pieTouch system. Participants evaluated the learnability worse, which corresponds to the greater training effect. Interacting with the pieTouch benefits from previously interacting with the simpleTouch. The captured editing times show that this effect could not be reproduced vice versa. Regarding the driving performance no difference could be measured in terms of lane deviation.

Because the time curve of the pieTouch in comparison to the simpleTouch remains constant, for further repetitions a further decrease is assumed. To prove this assumption, further experimental investigations will be necessary. Moreover the pieTouch prototype appears to be more attractive to users. Both prototypes are equal in layout design, hence the reason for this preference can only be found in the interaction method.

6. CONCLUSION

We presented an alternative approach to interaction with IVIS via direct touch gestures. The presented touch concept using pie menus combines the advantages of gestures and visually displayed menus. The visualisation of the gestures helped users during the initial contact with the prototype. For experts (after the third repetition) an almost blind interaction in the main pie menu of the navigation system was noticed by the investigator. This observance is backed up by the monitored driving data, which showed no differences but less editing time. Navigating through lists and context menus was performed significantly faster with the pieTouch prototype.

Basically the user study for automotive environments that was (LCT) carried out, concentrated on two aspects: Context menus and navigation techniques through lists via gestures. The comparison with a point touch based system shows the advantage of our approach when interacting with short context menus (e.g., the main context menu) and when scrolling through lists.

We were able to demonstrate that pie menus are more suitable for IVIS, especially for short menus as the main context pie menu and the menu for switching between application domains. For the context sub pie menu, no significantly better results could be measured. In consideration of the fact that the pie menu has a stronger training effect, it is assumed that more practice will influence the sub pie menu interaction in a positive way. The present experimental design was not able to prove this statement, and further investigation will be necessary. Beside the monitored data the results of the questionnaires support our findings.

Navigating through a list was significantly faster by interacting via gestures. Half of the participants moved the list in the wrong direction. It was not clear to all of them, which metaphor the pieTouch prototype implements, drag and drop or scrolling. To answer this question further investigations are indispensable.

Most frequently, the bad interruptability was criticized by participants. Because unforeseeable events occur while driving, the user's hands had to be available all the time. One demand of in-car system is to be able to stop interaction at every point without repeating any interaction steps. When selecting options in the sub pie menu, this requirement is not fulfilled. Alternative strategies like marking menus [15] could avoid this disadvantage. Few users called attention to the long dwelling time when interacting with the pieTouch. Under real circumstances, street unevenness could cause interaction errors. The dwelling can be reduced by alternative mode changes like multi touch as well as the deployment of marking menus. To prove this, field studies will have to be conducted.

In summary, we were able to demonstrate that the correct usage of gestures could enhance usability for touch screens in vehicles.

7. ACKNOWLEDGMENT

We thank Thorsten Bühring for giving us valuable input for the design process of PieTouch and the evaluation set up.

8. REFERENCES

[1] Ablaßmeier, M. Ackermann, C. Broy, V. Gründl, M. Lange, C. Libossek, M. Tönnis, M. & Winter, S. 2006 TUMMIC Abschlußbericht der Phase III: Mensch-Maschine-Interaktion im Kraftfahrzeug. Technische Universität München..

[2] Apple iPhone. URL: <http://www.apple.com/de/iphone/ >

[3] Bach, K., Jæger, M., Skov, M. B., and Thomassen, N. 2008. You can touch, but you can't look: interacting with in-vehicle systems. In Proceeding of CHI '08.

[4] Bernotat, R. 1970 Plenary Session: Operation Function in Vehicle Control. In Anthropotechnik in der Fahrzeugführung, Applied Ergonomics, Vol 13.

[5] Bortz, J. 2005 Statistik für Sozial- und Humanwissen-schaftler. 5. Auflage, Springer Medizin Verlag Heidelberg.

[6] Brooke, J. 1996 SUS: a quick and dirty usability scale. In: P. W. Jordan, B. Thomas, B. A. Weerdmeester, A. L. McClelland (eds.). Usability Evaluation in Industry. London, 189–194.

[7] Broy, Verena. 2008 Benutzerzentrierte, graphische Interaktionsmetaphern für Fahrerinformationssysteme. Doktorarbeit, Technische Universität München.

[8] Callahan, J., Hopkins, D., Weiser, M. & Shneiderman, B. 1988 An empirical comparision of pie vs. linear menus. In: Proceedings of CHI '88. 95-100.

[9] DIN Deutsches Institut für Normung (eds.). 2003 Road vehicles – Ergonomic aspects of transport information and control systems - Specifications and compliance procedures for in-vehicle visual presentation. DIN Deutsches Institut

für Normung, Oct. 2003. – Ref.No.: DIN EN ISO 15008:2003-10.

[10] DIN Deutsches Institut für Normung (eds.). 2003 Road vehicles – Ergonomic aspects of transport information and control systems - Dialogue management principles and compliance procedures. DIN Deutsches Institut für Normung, Mar. 2003. – Ref.No.: DIN EN ISO 15005:2003.

[11] Driver Focus-Telematics Working Group, Alliance of Automobile Manufacturers. 2003 Statement of Principles, Criteria and Verification Procedures on Driver Interaction with Advanced In-Vehicle Information and Communication Systems.

[12] European Commission Information Society and Media Directorate-General - G4 ICT for Transport (eds.). 2005 European Statement of Principles on the Design of Human Machine Interaction (ESoP 2005).

[13] Freymann, R. 2006. HMI: A Fascinating and Challenging Task. In Driver Assistance Technology to Enhance Traffic Safety. 71 – 81.

[14] González, I. E., Wobbrock, J. O., Chau, D. H., Faulring, A., and Myers, B. A. 2007. Eyes on the road, hands on the wheel: thumb-based interaction techniques for input on steering wheels. In Proceedings of Graphics interface 2007

[15] Kurtenbach, G. 1993 The Design and Evaluation of Marking Menus. PhD thesis, University of Toronto.

[16] Google Code. Iphone-haptics. University of Glasgow. URL: <http://code.google.com/p/iphone-haptics/>

[17] Hopkins, D. 1991. The design and implementation of pie menus. Dr. Dobb's J. 16, 12 (Dec. 1991), 16-26.

[18] International Organization For Standardization. ISO 26022 DRAFT. 2008 Road vehicles – Ergonomic aspects of transport information and control systems – Simulated lane change test to assess in vehicle secondary task demand.. – International Standard. Geneve.

[19] Leung, R., MacLean, K., Bertelsen, M. B., and Saubhasik, M. 2007 Evaluation of haptically augmented touchscreen gui elements under cognitive load. In: Proceedings of the 9th international Conference on Multimodal interfaces. Nagoya, Aichi, Japan. 374-381.

[20] Mattes, S. 2003 The lane change task as a tool for driver distraction evaluation. In H. Strasser, H. Rausch, & H. Bubb (Eds.), Quality of work and products in enterprises of the future. Stuttgart: Ergonomia Verlag.

[21] Microsoft Surface: <http://www.microsoft.com/SURFACE/index.html>

[22] Neonode Inc. N2. http://www.neonode.com/

[23] Nielsen, Jakob. 1993 Usability Engineering. Acad. Press, 1993. – 8–10, 49–70 S. – ISBN 0–12–518405–0

[24] Pirhonen, A., Brewster, S., and Holguin, C. 2002 Gestural and audio metaphors as a means of control for mobile devices. Changing Our World, Changing Ourselves. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems 2002. ACM Press, New York. 291-298.

[25] Shengdong Zhao, Pierre Dragicevic, Mark H. Chignell, Ravin Balakrishnan, Patrick Baudisch. 2007 earPod: Eyes-free Menu Selection with Touch Input and Reactive Audio Feedback. In: Proceedings of CHI `07. 1395-1404.

[26] Shneiderman, B., Plaisant, C. 2004 Designing the User Interface: Strategies for Effective Human-Computer Interaction (4th Edition). Pearson Addison Wesley.

[27] SoftNews NET SRL. Softpedia™. Nokia Chooses VibeTonz Tactile Feedback from Immersion. 2.7.2007. <http://news.softpedia.com/news/Nokia-Chooses-VibeTonz-Tactile-Feedback-from-Immersion-58833.shtml>

[28] Subramanian, Sriram, Gutwin, Carl, Sanchez, Miguel Nacenta, Power, Chris and Liu. 2005 Haptic and Tactile Feedback in Directed Movements. In: Proceedings of the Workshop on Guidelines for Tactile and Haptic Interfaces 2005. 6 pages.

[29] TomTom. URL: <http://www.tomtom.com/>

[30] Tönnis, Marcus ; Broy, Verena ; Klinker, Gudrun. 2006 A Survey of Challenges Related to the Design of 3D User Interfaces for Car Drivers. In: 3DUI '06: Proceedings of the 3D User Interfaces (3DUI'06). Washington, DC, USA: IEEE Computer Society. 127–134.

[31] User Interface Design GmbH. AttrakDiff™. Ein Service der User Interface Design GmbH. 22.2.2008. URL: <http://www.attrakdiff.de/ >

[32] Vilimek, R. Hempel, T. Zimmer, A. 2007 Effekte multimodaler Rückmeldung bei der Interaktion mit einem KfZ-Bordsystem per Touchpad. In: VDI-Berichte. 107–112

[33] Wäller, C., Bendewald, L., Oel, P. 2008 Optimierung der automotiven Touchscreen-Bedienung durch expandierende Ziele. In Useware 2008.