HapTouch and the 2+1 State Model: Potentials of Haptic Feedback on Touch Based In-Vehicle Information Systems

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ABSTRACT

Haptic feedback on touch-sensitive displays provides significant benefits in terms of reducing error rates, increasing interaction speed and minimizing visual distraction. This particularly holds true for multitasking situations such as the interaction with mobile devices or touch-based in-vehicle systems. In this paper, we explore how the interaction with tactile touchscreens can be modeled and enriched using a 2+1 state transition model. The model expands an approach presented by Buxton. We present *HapTouch* – a force-sensitive touchscreen device with haptic feedback that allows the user to explore and manipulate interactive elements using the sense of touch. We describe the results of a preliminary quantitative study to investigate the effects of tactile feedback on the driver's visual attention, driving performance and operating error rate. In particular, we focus on how active tactile feedback allows the accurate interaction with small on-screen elements during driving. Our results show significantly reduced error rates and input time when haptic feedback is given.

Categories and Subject Descriptors

H5.2 **[Information interfaces and presentation]**: User Interfaces. - *Haptic I/O, Auditory (non-speech) feedback, Input devices and strategies (e.g., mouse, touchscreen)*

General Terms

Performance, Human Factors

Keywords

Haptics, Tactile Feedback, Exploration, In-Vehicle Information Systems, Multitasking, Touchscreen

1. INTRODUCTION

It is possible and safe to turn the knob of an in car-stereo system or to open the car-window using a slider-button without an eye glance away from the road. Mechanical in-car interface elements such as buttons, faders or dials communicate tactile and kinesthetic cues about their position, orientation and state to the user and can therefore often be used blind.

However, in-vehicle information systems (IVIS) nowadays provide manifold functionalities, i.e. navigation, entertainment or vehicle control [5] almost exclusively in the visual channel. The concept of directly controlling functions with hardware buttons has reached its limits concerning space and number of controls.

The use of haptically enabled controllers as used by Audi[1] and BMW[2] is common, but has some disadvantages in terms of usability [7] and increased, but interruptible interaction times [6]. While touchscreens are advantageous in terms of usability or flexibility of GUI-design, the interaction with touchscreens highly depends on visual attention. Visual attention in turn is the most important attention property when driving vehicles. Studies such as [10], [11], [12], have shown significantly less eye-on-the-road time when drivers interact with visually highly demanding in-car systems. Burnett [8] states that touchscreens require significant visual attention of the driver, due to the lack of tactile feedback. Standard touchscreen systems present a flat surface to the user's fingers or hands, regardless of what is presented visually. Interface elements can only be seen, but not felt. The loss of tactile feedback inhibits exploration of virtual elements on the screen. Target acquisition or pointing is solely visual until the finger contacts the screen and activates a function. Visual output to the driver may be missed or may constitute a potentially dangerous source of distraction.

Figure 1: The HapTouch system is a force-sensitive touchscreen device with tactile feedback.

In this paper, we present *HapTouch*, a touch-based in-vehicle information system with tactile feedback. The touch-screen is force-sensitive, i.e., touching and palpating the screen is possible without unintentional activation. The user may explore the screen using his fingertip, and tactile characteristics of interactive elements (i.e. edges, surface) are conveyed using different types of vibrotactile signals. By further pressing the screen, the user may activate or drag virtual elements. Tactile sensations such as the "snap" of a button or the "ripples" of a fader are provided. The screen is vibrating, shaking or pushing in z-direction (against

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[1] Audi MMI, http://www.audi.com

[2] BMW iDrive, http://www.bmw.com

the user's finger) through linear bearings and a voice coil actuator. We implemented a set of signal generators based an additive wave synthesis, in order to produce complex tactile impressions.

The continual variance of pressure on the screen is used as a continuous input signal. In order to model interaction and resulting feedback, we expanded Buxton's three-state-model of graphical input by adding an additional state. We implemented our resulting 2+1 state model and utilized it as the foundation of interaction and haptic management on *HapTouch*.

In order to validate the effects of *HapTouch* on driving performance and visual distraction, we conducted a quantitative comparison pre-study based on the Lane-Change-Test [13]. The results show positive effects on error rate and driving performance (mean deviation) when tactile feedback is given. Additionally, we conducted a qualitative survey based on the System Usability Scale (SUS) method [20].

2. Direct Interaction and Multitasking

Direct interaction was found to be advantageous for a number of reasons [18]. In particular, it reduces the semantic and articulatory distance between the user and what is manipulated. In a car, we are used to very direct form of interaction, since the buttons and knobs we manipulate also directly communicate their state and hence the result of our manipulation.

If the concept of direct interaction is used with more complex information appliances, such as kiosks, vending machines or mobile phones, touchscreens are usually chosen for input and output, because they spatially and temporally unite input and output. They normally lack, however, tactile output capabilities, and even if they provide this communication channel, their interface concepts usually don't support tactile exploration, but just augment the visual output by tactile sensations. Non-visual feedback has great potential when interacting with reduced screen visibility or in multitasking scenarios.

2.1 Mobile Devices

Touchscreen-equipped mobile devices are becoming more powerful and follow the user wherever she or he goes. Small size and weight let us use these devices in dynamic contexts. Due to the small size and in order to maximize the usable screen-size, often no physical keyboards are implemented. Text-input is accomplished using soft-button touchscreen keyboards. In multitasking scenarios such as walking the streets while writing a short message, the user's visual attention is divided between the mobile device's screen and the environment. High demands on visual attention result in high cognitive load. In [17] Oulasvirta et al. explain that the use of mobile devices diverts our physical and attentional capabilities from other tasks like driving a car. The interaction with a mobile device competes for the same limited resources that we need for the task of driving. Hence, the requirements for interacting with a mobile device in multitasking scenarios and while driving a car can be seen as equivalent. Of course, avoiding distraction and attention deficits in the driving task is the primary challenge; a demanding interaction with in-vehicle systems is a safety risk for the driver, passengers and other road users.

2.2 In-Car Systems

In general the users' interaction tasks in automotive environments can be divided into the primary, secondary and tertiary task. The primary task comprises the maneuvering the vehicle in terms of accelerating and decelerating, as well as steering. This task is the most important for road safety and should therefore have the major part of the operators' attention. Secondary tasks are, for example, the interaction with the windshield wiper and direction indicator, as well as the advanced driver assistance systems (ADAS) and they are also essential for roadworthiness. All other, non-safety-related functions are tertiary interaction tasks. Many of these functions, such as entertainment, communication and information applications, are implemented in the in-vehicle information system (IVIS). A main requirement for the IVIS is to not distract the driver from the primary task. Therefore the IVIS must not only fulfill common usability criteria, but also be suitable for the driving task. The IVIS must always be interruptible and avoid cognitive and visual driver distraction. Several standards, guidelines and negotiated agreements exist to ensure a safe interaction with the IVIS during driving.

Beside centrally mounted multi-functional controllers and hardware buttons, one valuable and well established solution to handle the big amount of in-car functionality is touch. Due to the lack of tactile objects touch interaction requires a lot of visual attention.

2.3 Benefits of Tactile Feedback

Research in the field of non-visual feedback on mobile devices shows that computer-controlled haptic feedback improves usability and user experience [14] [1]: Brewster et al. [15] equipped a PDA with a vibrotactile actuator. Their study shows that tactile feedback provides significant benefits for keyboard interactions on touch-screens, both in static and dynamic situations. They also suggest that sonic enhancement of buttons could improve performance, but could be intrusive or not heard in noisy environments. Leung et al. [1] examined haptic feedback on touchscreen devices under cognitive load. They observed that haptically augmented GUI elements might be more useful in terms of reduced time scores and perceived performance than their-non augmented counterparts. Hoggan et al. demonstrate in [16] that tactile feedback can significantly improve fingertip interaction and the performance (speed, error-rate) with virtual keyboards on touchscreen mobile devices. Added tactile feedback brings the performance of touchscreen keyboards close to the level of physical keyboards.

As stated above, the interaction with mobile devices can be compared to the interaction with in-vehicle systems concerning visual and cognitive load. Considering safety reasons, it seems important to assay the potential of haptic feedback on touch-based in-vehicle systems.

2.4 Tactile Feedback and Automotive Touchscreens

To this date, several commercial in-vehicle systems based on touchscreens with tactile feedback exist. The companies Alpine[3] and Immersion[4] are producing tactile touch-screen solutions for

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[3] http://www.alpine-usa.com/

[4] http://www.immersion.com/

in-vehicle multimedia systems. The basic principle of their systems PulsTouch and TouchSense is the movement of the touch-sensitive screen as a whole under the user's finger.

Lee et al. [22] assessed the benefits of multimodal feedback on dual-task performance under demanding conditions such as a driving scenario. In their work, they compared the effects of unimodal and multimodal feedback during touchscreen interaction in multitasking scenarios. The results of the experiments showed that participants were able to perform both a virtual car avoidance and a mobile phone task more rapidly when they were given trimodal sensory feedback (including auditory, tactile, and visual stimulation). The effect increased with higher stimulus rate.

Pitts et al. [23] describe the initial outcomes of a study to investigate subjective user responses to haptic touchscreens during a simulated driving scenario based on the Lane Change Test. The participants were presented with a series of use-case trials which had to be performed on the in-car touchscreen system. Several combinations of multimodal feedback were evaluated. Results indicated a subjective preference for multimodal feedback over visual feedback only. Respondents expressed that haptic feedback makes the interface more pleasurable and easier to use.

Other research focuses on novel interaction techniques for in-vehicle touchscreens in order to reduce visual distraction. Gesture input is performed with a finger that does not simply touch the screen, but remains in contact and moves along predefined paths. In [24], touch interaction was identified as the fastest and easiest interaction technique. In combination with gesture input, the participants used significantly fewer eye glances and no long duration eye glances, which have a devastating effect on driving performance. Papers like [25] propose the use of direct touch gestures like pie menus for reducing the user's cognitive load. The use of on-screen gestures results in higher usability and efficiency, as well as an added hedonic quality.

Therefore, the combination of direct touch input and tactile feedback might seems very promising in terms of reducing visual and cognitive load. Regular touchscreens don't support tactile exploration, because touching an interface element immediately activates it. In order to enable exploration, we therefore designed a system which can discriminate different pressure levels. In order to adequately describe interaction with such a system, we defined a 2+1 state model based on state machines for it.

3. The 2+1 State Model

Interactive systems like computers with input devices can be described using state models. Reaching a state depends on the input that is executed until then. A state transition is possible when logic conditions are fulfilled. Possible transition properties could be the contact of the finger with the screen or a button press.

The approach to define states of devices and interactions was presented first by Mackinlay [3]. State models can be visualized using statecharts. Statecharts are a graphical representation of finite-state machines [4]. Based on this, Buxton [2] described state models as a means for modeling and describing graphical interaction. Buxton's state 0 is named *Out-Of-Range*. An interaction has no effect on the system. State 1 is named *active tracking*. An example is the mouse pointer that is moved by the user. An additional signal like depressing a mouse button shifts the system into state 2 (*activating, dragging*). During mouse-interaction, state 0 (the *Out-Of-Range* condition) is undefined, because no interaction technique can be built that depends on this action (i.e. lifting the mouse from the table).

We propose an extension to Buxton's model, which we call the 2+1 state model. The user's interactions with the *HapTouch* system are tracked and translated into states of our model.

3.1 Single Touch Screen: 2 States

An interactive single touch screen system can be described using two states (see Figure 2). In State 0, the finger is the tracking symbol. Target acquisition is done without touching the screen's surface; hence the system is not aware of the finger's position. The tracking is passive and based on continuous visual attention. Due to the fact that there is no exploration phase with the moving finger on the screen (State 1), the possible conveyance of tactile characteristics of interactive elements is reduced to the short moment when the finger touches the screen.

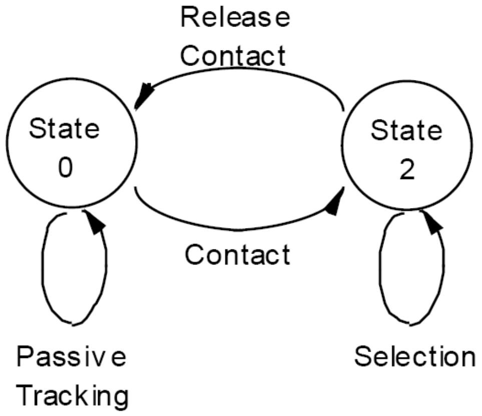

Figure 2: Classic touchscreen interactions can be described using two states. When an interactive element on the screen is touched, an activation of this element is conducted. Passive tracking is happening with the finger "in-the air". Hence, State 1 is bypassed (from [2]).

3.2 Separation of Tracking & Activation: 3 States

In order to provide the user with tactile feedback during the exploration of a touch-sensitive surface, a separation between tracking (State 1) and activation (State 2) is necessary. Assume using a touch tablet with a stylus. When the stylus is in range of the tablet-area, the tracking symbol follows the stylus' motion (State 1). Extra pressure on the stylus activates the tip switch; the system is moved into State 2 (Activation, Dragging). An additional signal like the activation of a stylus results in an additional state in the model.

3.3 Continuous Force Sensing: the 2+1 State Model

The *HapTouch* system separates tracking from activation by using an additional signal, the force of pressure. The technical modifications of the *HapTouch* system to sense force values are described in part 4.1.

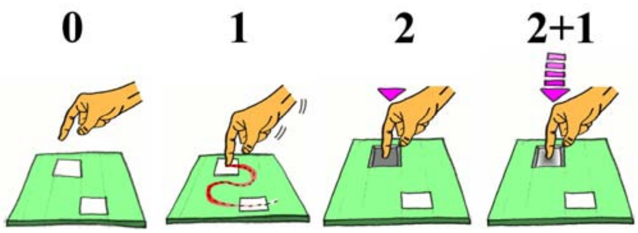

Figure 3: Our implemented 2+1 state model coordinates the user's input and the resulting tactile feedback.

As described in Figure 3, the 2+1 State Model consists of 4 states: the *HapTouch* system is in State 0 when the finger does not touch the screen, the system is not aware of the finger's position. When the finger touches the screen (on or next to an interactive element), the system shifts to State 1. The finger can be moved over the screen, the position is tracked, tactile information on edges, surfaces or functionality of virtual elements can be given. By pressing an interactive element on the screen with additional force (greater than a certain threshold), the system shifts to State 2. In this activation state, virtual buttons change their visual appearance and objects may be tracked. The mechanical "snap" of the button or edges of dragging targets are perceived. When the screen is pressed with even greater force, the *HapTouch* system is switched to State 2+1. The continuous variance in the applied force of pressure is mapped to parameters of tactile signals like frequency or amplitude. Novel touchscreen interactions like zooming or resizing can be accomplished based on the force of pressure in State 2+1.

4. Implementing HapTouch

Based on our 2+1 state model, we designed and implemented the *HapTouch* system. This system generates vibrotactile signals in response to a user's interaction on a force-sensitive touchscreen. Resulting tactile signals are generated by additive signal synthesizers. The system consists of both hardware and software components (see Figure 4).

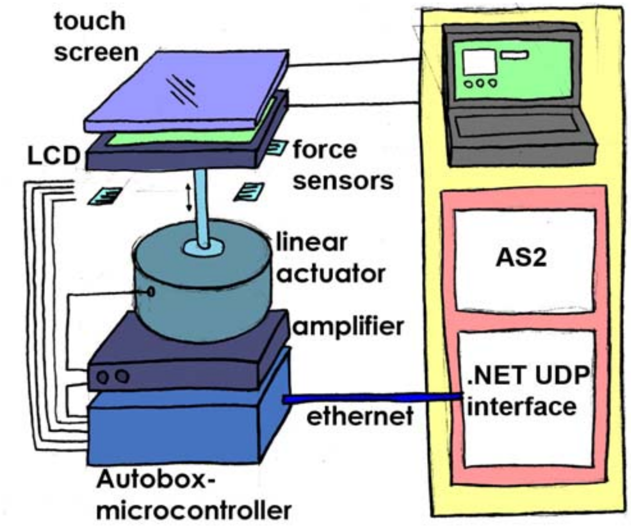

Figure 4: Schematic overview of the *HapTouch* system's hardware

The *HapTouch* system handles and manages user input position and degree of pressure force. These dynamic events are matched to a state model on a controlling PC. The resulting haptic pattern description is passed on to a real time system. The signal is generated using two additive oscillators and passed on to the voice coil actuator. As a result, tactile information is communicated to the user.

4.1 Mechatronics and Hardware

The used system was schematically shown in Figure 4. The touch system is built up with an 8.4" color TFT Display and a surface capacitive touchscreen that was chosen to get a rigid touch surface. The entire touch system, i.e., touch input and graphic output, is controlled by a PC. To add the ability of force measurement in order to enable activation and modulation by force input, four FSR sensor elements are mounted between the corners of the display and the casing of the touch system.

The touch system is movable in z-direction on linear bearings and connected to a voice coil actuator. The actuator dimension was set to cover a wide range of amplitudes for frequencies below 300 Hz and also to reach high accelerations for short pulses. The actuator is driven by a microcontroller that provides analog input to an amplifier that sets the appropriate actuator current. On the software side digital signal-generators are implemented on the microcontroller that can be controlled by the PC. The microcontroller also gets the signals from force sensors and provides a physical force signal to the PC.

To get information of the effective actuated way to z-direction a laser triangulation sensor is integrated to the system.

4.2 Receiving and managing user input

The central controlling PC manages the screen content and input on the touch sensitive display. When the user touches the sensor area, the position of the finger is permanently passed on to the controlling PC. The finger's contact with the screen is sensed as an activation of the left mouse button. The user is interacting with virtual elements depicted on the touchscreen. Every interactive element is created with a set of haptic patterns for every state of that object. Up to 9 different sub-states with associated tactile characteristics can be reached based on the implemented 2+1 state model.

During an interaction, events (e.g. RollOverChange, current pressure value, current pressure threshold) are broadcasted. A ButtonHapticsListener object manages the 2+1 state model of an assigned interactive element. Changes of element status or pressure values are received and the state model is updated. The ButtonHapticsListener object also receives global events (e.g. finger on/off screen). Subsequently, tuples of haptic signals are passed on to the UDP-socket and from there to the rapid prototyping system Autobox.

4.3 Generating haptic signals

The dSpace Autobox[5] is the central unit of mediation between soft- and hardware. The Autobox is a modular micro controller with PowerPC architecture. To meet the requirements of communication with the controlling PC, a UDP/IP board was

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[5] http://www.dspace.de/ww/de/gmb/home/products/hw/accessories/autobox.cfm.

embedded. Using MATLAB/ SIMULINK[6], we implemented a dynamic real time system on the Autobox.

Based on the principles of modular and analogue synthesizers, the real time system generates a sum of harmonic oscillations. The controlling PC sends tuples of signal descriptions into the Autobox system. Two signal generators process the following attributes (see Figure 5 for an example):

- Type of oscillation: sine, rectangle, sawtooth
- Frequency: up to 20000Hz, a dynamic modulation is possible
- Amplitude: max. stroke of actuator is approx. 28 mm
- Starting direction of actuator: +z / -z direction
- Signal duration

Two signals can be added together and are passed on to the D/A-converter and from there to the amplifier system. The touch system communicates tactile signals to the interacting user.

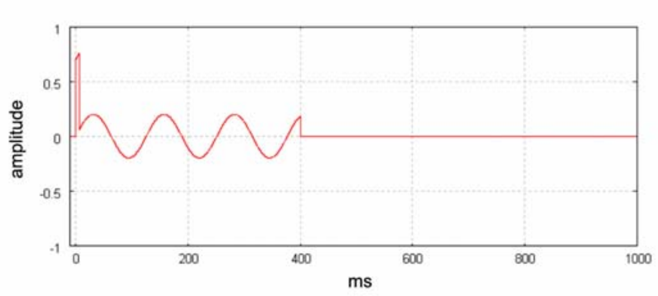

Figure 5: An example for additive signal mixing: a sine wave (frequency: 50 Hz, amplitude: 20%, starting-direction: positive, duration: 400 ms) is added to a rectangle wave (frequency: 10Hz, amplitude: 70%, starting-direction: positive, duration: 6 ms). The interacting user perceives a sharp click followed by a short buzz.

5. Evaluation of HapTouch

In order to get a first impression whether the developed 2+1 state model supports users in interacting with a touchscreen a pretest was conducted. Pretests in general allow identifying whether the experimental setup is appropriate in order to answer a research question before executing the final experiment. Furthermore the effects of the evaluated system can be estimated. During the development phase of *HapTouch,* several human-machine-interfaces were implemented. On the one hand, the 2+1 state model was realized and provided a basis of the augmentation of user interactions with tactile feedback. On the other hand, we evaluated subjective user experience using expert evaluations.

5.1 Research Questions and Hypotheses

We already named promising results of studies evaluating the potentials of tactile feedback on touch based interfaces in multitasking scenarios. Based on these findings, we designed a study in order to assay the effects of separating tactile exploration and tactile interaction feedback (i.e. *HapTouch* and the implemented 2+1 state model). We had the assumption that the use of *HapTouch* provides benefits in terms of error rate and driving performance when compared to non pressure-sensitive in-vehicle systems without non-visual feedback. We were also interested in the effects of tactile feedback on the usability of small interactive GUI-elements.

Based on these considerations, our hypotheses for the pretest were as follows:

H1: The tactile display of an interactive element's **position** on the screen helps to reduce visual distraction when using the in-vehicle system.

H2: The tactile communication of an interactive element's **function** helps to reduce error rate during interaction and improves driving performance.

H3: Providing a tactile **acknowledgement** after a(n) (un)successful activation helps to reduce the error rate during interaction and improves driving performance.

H4: Tactile feedback helps to make interactions more exact, smaller interactive GUI-elements are possible without increasing error rates and operating-time.

5.2 Evaluation Techniques

For evaluating in-car systems usually dual task methods are applied. Therefore participants not only have to operate with the system to be tested. They also have to fulfill another task where the task prioritization can be defined dependent from the research question which should be answered. In the case in-car systems the system to be tested is the secondary task and the other the primary task. The quality of the primary task allows drawing conclusions about the degree of distraction of the evaluated interface.

Our study is based on the standardized Lane Change Test (LCT). The LCT simulates a road with three lanes on which participants had to drive with a constant speed of 60 km/h. Frequently appearing traffic signs prompt the user to change the lane immediately and as fast as possible. Test persons are instructed to priories the driving task. As a result the deviation of the ideal driving line gives feedback about the distraction of the evaluated system from the driving task. To ensure that all participants are familiar with the driving simulation of the LCT a baseline has to be absolved until a mean lane deviation (MDEV) of smaller one meter is achieved. The difference of the MDEV of the baseline and the dual condition where the driving task has carried out while interacting with the system shows the degree of distraction.

5.3 Experimental Set-Up

The experimental setup was assembled according to the ISO standard for the LCT [19]. A 19'' TFT monitor displayed the driving simulation. A steering wheel and pedals for braking and accelerating were mounted in front of the simulated driving scene in order to control the simulation. The touchscreen installation was placed on the left side of the driver and optimized for driving. For reducing the auditory noise produced by the actuator of *HapTouch* participants had to wear head phones. This was necessary because the created noise can serve as auditory feedback and an additional not controllable variable would have been added to the experimental design. The experimental setup is illustrated in Figure 6.

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[6] http://www.mathworks.com/

Figure 6: Experimental setup for the LCT.

The independent variables are the system variation (*HapTouch* small, *HapTouch* large, ClassicTouch small and ClassicTouch large). The objective dependent variables are total task time, error rate and MDEV. Furthermore the subjective users preferences in terms of the SUS where captured as a dependent variable.

5.3.1 Tasks

Participants had to enter a sequence of numbers into a standard number pad (Figure 7). Therefore four different interfaces were implemented. On the one hand the size was changed and on the other tactile feedback was added. The goal was to enter the number 9332715. This number was chosen to cover following path of motions: horizontal, vertical and diagonal motions, shift in the directions of 90 and 45 degrees, repeated entering and different distances of the key field (0, 1, 2).

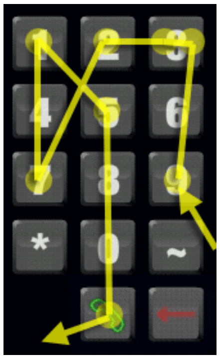

Figure 7:
Number pad and entering order of the numbers during the experiment.

5.3.2 Test Procedure

At the beginning participants had the opportunity to explore the *HapTouch* and ClassicTouch system. Afterwards, the prototypes were explained and a training had to be absolved until the test persons felt secure in interacting. Then the LCT driving simulation was explained and explored until a baseline of smaller than 1.2 meters MDEV was driven by every volunteer. Afterwards the dual task condition was carried out where the order of the systems was counterbalanced according to latin square to avoid training effects. For each system three task repetitions had to be absolved in order to reveal potential training effects. At the end participants had to answer the SUS questionnaire.

5.3.3 Participants

Five volunteers, between 23 and 48 years old, were recruited. Four male and one female person attended the pretest. All participants had an academic degree and a driving license.

5.4 Results

The first objective dependent variable is the error rate during number input. The second dependent variable is the total task time needed for the input of the seven digits (including ENTER and possibly UNDO). The third dependent variable is the mean lane deviation (MDEV) in the lane change path.

5.4.1 Error rate

Analogous to Potter et al. [21], we defined two errors during digit input:

- **Misplaced activations:** ClassicTouch: activation/ touch next to an interactive element, *HapTouch*: pressure next to an interactive element
- **Wrong digits in number after completion:** missed, added or false digits

Corrections of the entered number are possible and result in increased total input time.

On average, participants misplaced of 0.2 activations on ClassicTouch small and 3.87 on ClassicTouch large. On average, 0.2 activations were misplaced using the *HapTouch* large and 0.8 with *HapTouch* small. On average, 0.13 numbers were entered wrong with the ClassicTouch large as well as ClassicTouch small. On average, 0.07 digits were entered wrong on *HapTouch* large and 0.4 on *HapTouch* small. This results in the arithmetic mean values of all errors per input illustrated in Figure 8.

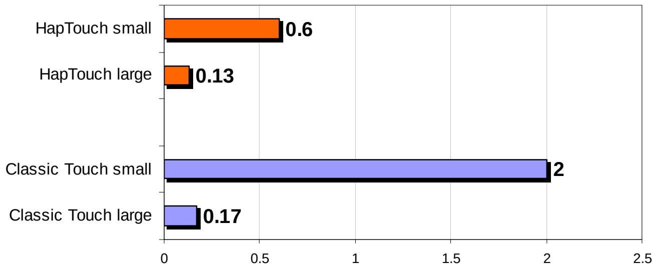

Figure 8: Arithmetic mean values of errors per input (n=5).

5.4.2 Total Task Time

The time needed for completion of the digit input task was measured automatically. Measurement started after completion of the first target acquisition or pointing phase. With the system ClassicTouch, the first pointing is over after the user touches the screen. With *HapTouch*, the first pointing phase is over when the defined pressure threshold is exceeded by the push of the user's finger. Total Task Time values are illustrated in Figure 9.

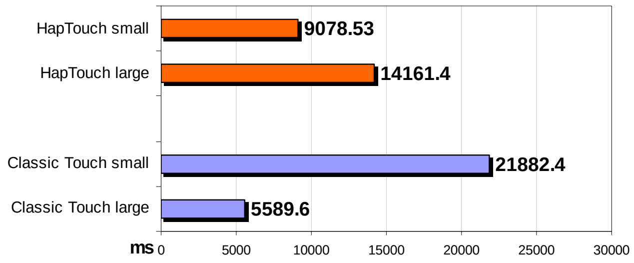

Figure 9: Average Total Task Time values (n=5). The noticeable difference between the large system's values presumably results from a flaw in our study design. We carried out redesigned follow-up studies to eliminate artifacts. The results showed smaller MDEV and TTT values for *HapTouch* large. See part 5.5.

5.4.3 MDEV

The average MDEV values are illustrated in Figure 10. Measurements took place in parts of the Lane Change Track, in which interactions took place. The starting points of the tracks were isochronous with the start of time measurement.

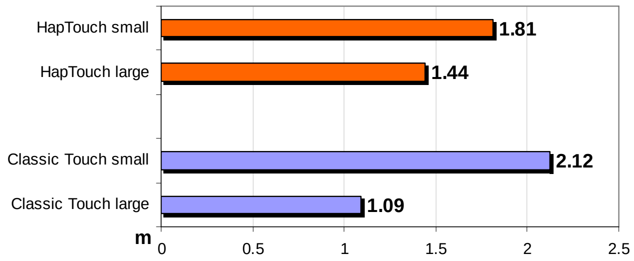

Figure 10: Average Mean Deviation (MDEV) Values (n=5).

5.4.4 Subjective User Opinion

On average, the 5 participants evaluated the *HapTouch* prototype as a whole with 74 points and the ClassicTouch system with 78.5 points. Figure 11 shows the evaluation of each dimension. Over the usability dimension *Satisfaction*, users preferred the *HapTouch* system.

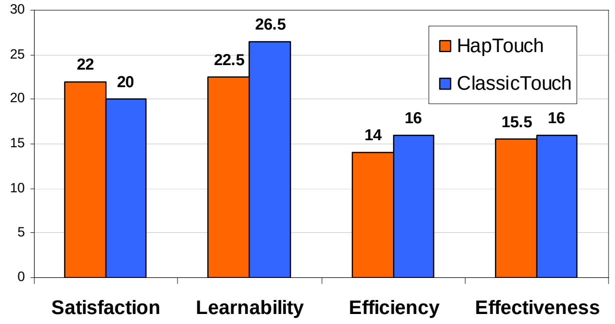

Figure 11: Result of the SUS questionnaire (n=5).

5.5 Discussion

Due to the limited number of participants, no statistically significant statement or result can be given. This was not our intention when carrying out the pretest. The primary intention was to identify whether the experimental setup is appropriate before executing the final experiment.

The *HapTouch* system represents a novel interaction technique with touch sensitive screens – the separation of exploration and activation. We assume that the training phase for each participant with the novel system may be too short to establish usage strategies. This corresponds with the subjective results of the SUS values for *Learnability* for the *HapTouch* system. Two participants reflected on the possibility to leave the finger on the tactile screen when replacing it on another input element. This strategy offers the possibility to perceive element's edges and in-between areas. By using these tactile cues, the non-visual interaction can be supported. In order to gain a deeper understanding of learning and usage strategies, further studies involving video observations must be executed.

By all means, we identified promising trends in our results. First of all, when using tactile feedback during the exploration and interaction with small screen elements, *HapTouch* resulted in 80% less misplaced activations. Tactile exploration and interaction feedback seems to make smaller GUI-elements usable.

This trend is extending towards total task time. On the one hand, the tactile exploration of the large *HapTouch* buttons takes more time than touching the ClassicTouch elements. On the other hand, participants were faster with the small *HapTouch* elements, due to not needed corrections of their input.

The same correlation may exist for the MDEV values: the MDEV when using large *HapTouch* buttons was 23.4% higher than the values for large ClassicTouch buttons. On the contrary, the MDEV for the small *HapTouch* elements was 15% less than for small ClassicTouch.

Despite these promising trends, we identified a major flaw in our study design: participants who made fewer errors (e.g. using *HapTouch*) had to make fewer corrections. So they completed their input task in a shorter amount of time. As a result, they were not forced to do many Lane Changes. Accordingly, their MDEV values will be better than the values of participants with error-prone input systems (like ClassicTouch). This effect may be avoided in future experiments with *HapTouch* by using evaluation techniques with constant, but reduced cognitive load for the primary task of driving. On the one hand, this scenario would be more similar to real life usage of in-vehicle information systems. On the other hand, the distinct influence of the number of errors on the Total Task Time and MDEV values would be reduced.

6. CONCLUSIONS AND FUTURE WORK

Our explorative pretest of the *HapTouch* system and its novel interaction technique evaluated effects on error rate, task completion time, driving performance and user satisfaction. Based on our results we can assume that tactile feedback on touch-based in-vehicle systems considerably reduces the errors made during number input tasks. This especially holds true for very small interactive elements. In our opinion, the possibility to explore edges, areas and functionality of elements using exclusively the sense of touch is of particular importance. This may be beneficial for eyes-on-the-road time and, as a result, traffic security. Additional tactile feedback when activating elements by finger press may support this trend.

In the future, we intend to improve our understanding of the value of tactile feedback on in-vehicle systems by more formal evaluations. We are in the process of improving the hardware design of the *HapTouch* system. For example, smaller actuators with the same performance are tested at the moment. The improvement of the force sensor unit based on mechanical and physiological threshold values is another subject-matter. Continuing focus of our work lies on the development of tactile signals that are easily perceived in a car environment and communicate functional and physical characteristics of interactive elements. We already evaluated effects of cross modal (visual/tactile) congruencies on user perception and performance during the interaction with touch sensitive screens. Results showed distinct effects of matching visual and tactile appearance on the affordance of the element. The presented pretest is providing a basis for follow-up studies.

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