A Leap for Touch: Proximity Sensitive Touch Targets in Cars

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ABSTRACT

Combining touch screen technology with mid-air gestures into a unified input modality has potential to improve interaction with touch interfaces in cars. Moreover, target objects on a touch screen can be adapted to the proximity of a users' finger in mid-air. In this paper, we present an exploration of this design space based on two studies and various prototypical systems. First, results of a driving simulator study are reported, indicating that a driver's performance in acquiring a target object on a touch screen in a central console position increases with expanding targets, while altering the position of a target object on the screen leads to a decrease of performance. In a follow-up workshop with automotive experts, prototypes with multiple expanding targets were utilised to foster in-depth discussions on potential challenges and benefits with expanding targets in cars. Results of both studies indicate a high potential of expanding targets for in-car interaction scenarios.

Author Keywords

Fitts's law; touch; automotive; leap motion

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

While driving a car, it is important for touch interfaces to allow the driver's visual attention to stay focused on the road as much as possible. Thus, for driver interfaces touch targets need to be designed in a way that they can be acquired faster and more precise. Related research in target selection tasks on mobile devices during walking suggests that target selection times increase during walking and that the negative effect can be compensated by increasing target sizes [18]. Indeed, Fitts's law [7] states that increased target sizes or shrinked distances to a target improves targeting time. However, the potential for increasing target sizes or reducing the distance of targets to the user's finger is limited since touch screens often only offer a restricted space for targets.

In this paper, we focus on dynamic adaptation of size and position of target objects based on a driver's finger in mid-air before a touch target is actually acquired. Thus, an increase of size and reduction of distance at the time of touch is possible for all target objects compared to a static interface where all target objects are stable in size and position throughout the interaction. Target adaptation strategies are already well understood and altering size and position of elements based on the proximity of a driver's finger in mid-air should increase success in target acquisition. This is again expected to reduce the visual demand, since a lower accuracy of touch still leads to a successful input.

Although, target adaptation strategies have been studied in different contexts (e.g., [12, 20]), as far as we know, it has not been studied in a driving context. Thus, the following research questions are addressed in this paper:

- RQ1: Do target adaptation strategies (i.e., dynamically altering size and position of a touch target) improve targeting performance in a driving context?
- RQ2: How can we address challenges related with many closely positioned adaptive targets?

A driving simulator study and a follow-up workshop with experts in the automotive domain were conducted to address the research questions. Results show that adapting a target object's size does not only increase success rates but significantly improves task completion times, while (surprisingly) distance adaptation did not lead to improvements. In the following section, we describe related work. Afterwards, both studies are presented in detail, including descriptions of the prototypes. Based on the results of both studies, we conclude that there is a potential to change touch interaction in cars to the better by carefully applying target expansion strategies to support situatedness in in-car touch screen interactions.

BACKGROUND

A variety of designs exist that aim to improve target acquisition, referring to Fitts's law [7]. Fitts's law states that there is a trade-off between speed and accuracy in aimed movements [13], which depends on "distance to the target" and "size of the target". Targets are acquired (with success) faster when the target's size is increased. But the trade off is that accuracy in acquiring the target decreases.

An implication for graphical interface design is that depending on the context of interaction, designers need to decide to either use large target object sizes for good interaction performance or small target object sizes for displaying more targets and denser information. Consequently, researchers have studied compromises by proposing a multitude of methods to increase target sizes. For example, Albinson and Zhai [2] propose techniques for manually zooming in areas on the screen in order to perform subsequent pointing of a finer scale. Similar techniques to improve accuracy in acquiring small targets on touch screen have been proposed by Roudaut et al. [17]. However, those kinds of manually zooming techniques often require additional interactions, concluding in lower performance and undesired distraction of drivers in a driving context. The driving context is considered an eyes busy context [19], requiring that interaction with any visual interface in the car has good performance.

Another way to improve performance or decrease the level of required visual attention for drivers is to use multi-modal techniques. For example, automotive user-interface research has shown that touch screen interaction for the car can be improved by implementing haptic and audible feedback on touch screens [15] and that proximity sensing technology can reduce driver distraction for secondary tasks [16].

Related to multi-modal interaction are automatic target expansion techniques (e.g., [5, 12, 20]), which use additional sensors to compute context information (e.g., proximity to targets) and alter target sizes automatically, depending (solely) on the context information without requiring additional interactions. Arguably, automatic target expansion techniques are better suited for the automotive context, since these techniques require less direct interaction of drivers and thus demand less visual attention. McGuffin and Balakrishnan [12] have studied the relation between Fitts's law (which is based on static targets sizes) and expanding targets. In their studies targets (i.e., widgets on the screen) expanded depending on the proximity of a mouse pointer. They have shown that Fitts's law is applicable to expanding targets and that movement time depends (solely) on the final target width [12]. Thus, they argue that with multiple expanding targets there is no need to predict the pointer's trajectory for detailed anticipation of which widgets to expand and that it is sufficient to simply expand widgets that are near the pointer to significantly facilitate selection.

Yang et al. [20] have studied how expanding targets could be used to allow touch-based interaction with laptop user interfaces (i.e., how UI components could be transitioned based on off-screen movement of user's index finger for touch-based use). They implemented *TouchCuts* and *TouchZoom* as expansions techniques for single and multiple targets and showed that selection times could be reduced with expanding targets and touch touch-based input in comparison to a mouse. Many of the earlier work (e.g., [12, 20]) aimed to transfer through expansion techniques (established) interfaces for mouse-based interaction with small targets for optimised touch-based interaction. In comparison, Chen et al. [5] have recently studied mid-air movements of fingers before, after, and in-between touch events in one-handed touch based interaction. They have explored how touch and mid-air movement could be in general interwoven in order to create a unified input modality for mobiles, which already have interfaces designed for touch-based interaction.

While touch and mid-air gestures are complementary modalities, in the automotive context they have mainly been regarded as alternative interaction modalities. For example, May et al. [11] have compared multimodal air gestures with a conventional direct touch system for navigating menus in the vehicle. Their findings suggest that multimodal air gestures exhibited safer secondary task dwell patterns, but lead to longer task completion times and a higher workload compared to direct touch. A benefit of mid-air gestures is that they offer a way to interact with distant targets, which can not be reached and thus physically touched by users (e.g., [4, 14]). Thus, mid-air gestures have been used to interact with an infotainment system visualized in as a head-up display [10].

In this paper, we explore adaptation strategies for proximity sensitive touch targets in the car context. This design space is a result of the combination of touch and mid-air finger movement before touch. We argue that the combination not only results in various benefits of both modalities (e.g., gaze-reduced interaction and tactile sensation), but it may also improve the interaction performance for in-car interactions. A related approach to ours, which combines touch and mid-air gestures for interaction in cars has been proposed recently by Ahmad et al. [1]. Their approach is complementary to ours, since they did not investigate adaptation strategies of targets on the touch screen but studied probabilistic Bayesian prediction algorithms to predict a target object on the screen early in a mid-air pointing gesture. Their technique is especially relevant when in-car interaction takes place during difficult driving situations (e.g., when roads have uneven surfaces).

EXPLORATIVE DRIVING SIMULATOR STUDY

In the previous section, we summarised related work, including proximity-sensitive strategies for dynamically altering a target object's position and size. Related work suggests that users should be faster in successfully acquiring a target object when the object's size is expanded or the distance to the object is shrinked. However, it is unclear if the assumption holds in a driving context: e.g., if dynamically altering size and position of a touch target improves targeting performance for drivers in a driving context.

In order to explore this research question, we conducted a lab study in a driving simulator setup, placing the participants in the context of a car and providing them the experience of driving the car. Figure 2 presents the setup for the study, including a tablet device (i.e., a second generation iPad) attached to the middle console of our car simulator. A Leap Motion (LM) controller[1] was positioned right below the tablet, ensuring that mid-air finger movements before a touch event could be recognised and utilised to adapt target objects. The distance about when the touch screen content should adapt to an approaching finger was set to a range of 7 inches from the center of the touch screen. The distance from the steering wheel to the center of the touch screen was 14 inches.

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[1] https://www.leapmotion.com

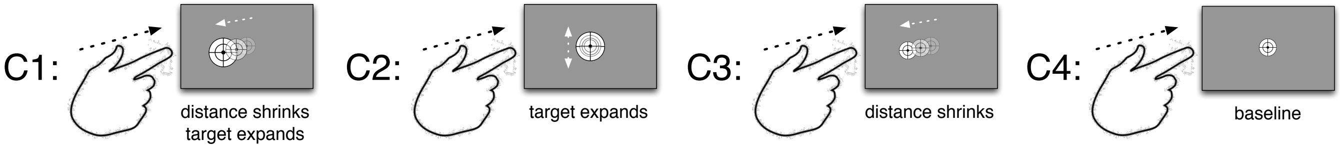

Figure 1. Abstract presentation of the adaptation strategies.

Figure 2. Physical setup of the interaction. Participants were asked to acquire the target object repeatedly during driving in a car simulator. The 3D sensor was positioned in a way that would allow to sense mid-air finger movement before participants touched a target on the screen.

Target Adaptation Strategies

There are many ways to adapt over time visual characteristics (e.g., size, position, and color) of a target object on a screen. When it comes to improving performance in aimed movements, Fitts's law suggests to either shrink the distance to a target object, expand the target object, or both shrink the distance to the target object and simultaneously expand the target object. Thus, there are the following three general ways of adapting a target object based on changing size or distance (see Figure 1), which we refer to as adaptation strategies:

- C1: In the first strategy the touch target moves towards the prediction point and expands depending on the proximity to the fingertip in 3D.
- C2: In the second strategy the touch target expands depending on the fingertips proximity but the target center stays at the same position.
- C3: The third strategy moves the target towards the prediction point but the size of target stays the same.

A concrete implementation of each of these three adaptation strategies was used in the user study as a separate condition under which target acquisition tasks were completed. In addition, we implemented a fourth condition (C4) in which the target object's size and its position stays the same as a baseline condition (i.e., no adaptation strategies are applied).

All adaptations happen on the 2D touchscreen based on the 3D position of the forefinger in mid-air, the 3D coordinates of the center of target on the screen, and a prediction point on the 2D screen. The prediction point was calculated based on the orthogonal projection of the 3D position of the forefinger onto the 2D screen. This point was used for predicting the 2D coordinates where the forefinger was expected to touch the screen. Both expansion and movement were limited to allow the creation of an interface with multiple elements and prevent them from overlaying each other. The size of the target was 48px (9-10mm) and it expanded up to 128px (24-25mm) and/or moved towards the fingertip up to 48px (9-10mm) .

The target sizes we used are within recommended sizes for icons and interactive elements on touch screens. For example, guidelines for Android developers propose that touch targets should have a size between 7 and 10mm. Similar values are recommended by other companies and operating systems arguing that this size allows users to accurately target objects on a touch screen. The movements and expansion limits were chosen in a range small enough to allow the creation of an interface with multiple similar elements.

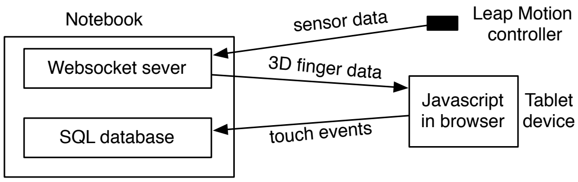

Figure 3. System architecture used at the driving simulator study for synchronising touch and mid-air finger data.

The interfaces were developed in Javascript and the official Leap Motion Javascript library. Thus, synchronising touch events and Leap Motion data happened on the tablet device in Javascript. Touch events and touch positions were logged to a mySQL database for post-hoc analysis (see Figure 3).

Participants and Procedure

Seven volunteers (4f, 3m) with a mean age of 33 (SD=3.8) participated. All participants were right-handed, had driving licenses, and owned a touch-screen device. Participants were invited to make themselves comfortable in the driver's seat and asked to (virtually) drive until they felt comfortable in using the car simulator. Thereafter, participants were asked to perform target acquisition tasks repeatedly on the iPad device, which was attached to the middle console of the car (see Figure 2). Participants were requested to drive as careful as they would drive in real live. They could take as much time as they needed to complete all tasks; however, all participants completed the study within 20 minutes. A researcher was seated at the co-driver seat and made notes on the driving performance and documented participant's comments. Furthermore, the researcher acted similar to a co-driver concerned about the driving performance, reminding the driver to keep at the track and drive at proper speed.

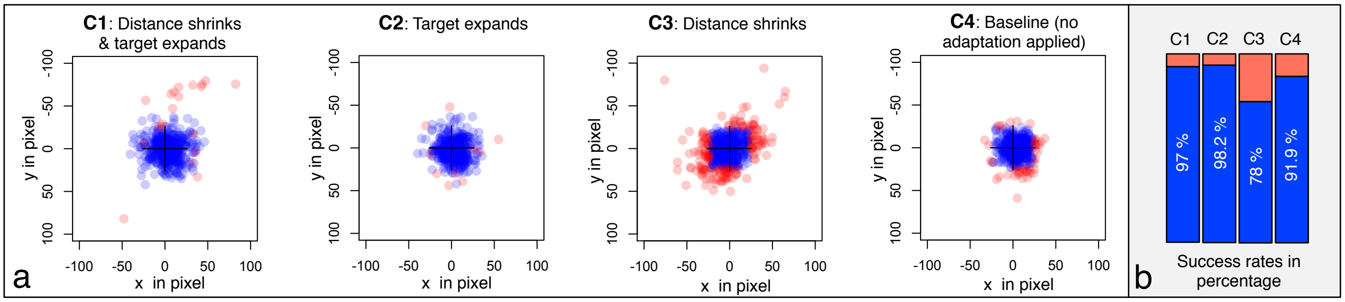

Figure 4. Overview of accuracy in target acquisition for all conditions. Positions of touch are presented in relation to the center of the target.

The target acquisition tasks had to be completed in 4 conditions (i.e., C1, C2, C3, and C4 in Figure 1). The order of conditions was randomized to reduce bias. In each of the four conditions, participants had to successfully acquire the target 50 times in order to make sure that we have a large balanced number of successful trials for each condition for the subsequent data analysis. In addition to the 50 trials in which targets where successfully acquired, we also logged the number of failures produced by each participant, for each condition. Furthermore, participants were asked to use only their forefinger to tap the target (i.e., a crosshair) that was presented at the center of the screen as precise as possible and as fast as they felt comfortable with. Similar approaches that investigate touch behaviour have been used in related work (e.g., [8]). Participants were instructed to start each target acquisition task by grasping the steering wheel and to return to this position after each acquisition of a touch target.

Analysis and Results

In the following, we first present general trends based on observations of participants' behaviour during the study and graphical representations of the collected touch data. Then, the results will be interpreted based on fitting a statistical model to the collected data.

Generell trends and observations

Figure 4a presents an overview how target objects were acquired on the touch screen for each condition, highlighting success (e.g., blue dots) and failure (e.g. red dots) in acquiring targets.

In condition three, participants produced the most failures (i.e., missed the target on the touchscreen), which we also observed in-person during the driving simulator study. Participants were either overshooting or undershooting the target object, due to the fact that the target object was moving. The typical behaviour observed was that participants performed corrective movements, freezing the initial aimed movement mid-air (in order to check the road once more) before finally touching the target with a corrected movement. Most of the participants' comments in condition three were related to frustration about the fact that the target did not stay on a static position. One participant described her experiences as if the target was trying to fool her.

In contrast to condition three, in condition two, participants seem to have produced the least amount of failures and as expected even less than in the baseline condition. During the study, when participants were completing tasks in condition two, participants made appreciating comments, for example that it felt like one can not miss the target.The performance in condition one seems to be better than in the baseline condition, but there are a few failures that could be due to overshooting the target. In both condition one and condition two, there are a few red dots (failures) between the blue dots (successes), which indicates that the Leap Motion sensor was a few times not precise enough to detect the real proximity of the fingertip to the touch target's center position.

When we asked participants at the end of the study about their subjective preferences and to rank the different conditions. All seven participants preferred condition two (i.e., the condition in which only target size is adapted) and all seven participants ranked condition three (i.e., the condition in which only target distance is adapted) as least preferred. User preferences towards condition one (i.e., the condition in which target size and target distance are adapted) and condition four (i.e. the baseline condition without any adaptation) were similar. Participants did not prefer condition one over the baseline condition and vice versa.

Success rates and task completion times

Figure 4b presents the success rates in percentage computed for each condition. It seems that expanding targets (C2 vs. C4) strongly improves success rates. Shrinking the distance causes errors (C3 vs. C4) and additionally expanding targets counterbalances many of the errors (C1 vs. C3).

Success rates are very important for driver interfaces, because they mean that the driver does not have to make corrections, which can cause additional distraction. Of related importance for driver interfaces are task completion times. We computed task completion times for successful tasks by measuring the difference between two successful subsequent trials. Based on the resulting data we computed a repeated measures ANOVA to investigate, if there was a significant influence of adaptation strategy on task completion times. As expected (see Figure 5a) we found that task condition had a main effect on task completion times; $F(1, 6) = 13.7$, $p<0.001$. This means that completion times were significantly different between conditions.

In order to identify significant difference that are not clearly visible in Figure 5a (i.e., differences between C1, C2, and C4), we conducted post hoc comparisons using pairwise t-tests with adjusted p-values. As expected, participants were significantly slower in C3 (M=3160ms, SD=2116ms) than in all the other conditions, i.e., C1 (M=2265ms, SD=818ms), p=<0.001; C2 (M=2011ms, SD=1061ms), p=<0.001; C4 (M=2171ms, SD=1174ms), p=<0.001.

Interestingly, participants were also significantly slower in C1 (M=2265ms, SD=818ms) than in C2 (M=2011ms, SD=1061ms), p=<0.001 as well as in C4 (M=2171ms, SD=1174ms); p<0.005. Furthermore, participants were significantly faster in C2 (M=2011ms, SD=1061ms) than in C4 (M=2171ms, SD=1174ms), p=0.04.

The analysis supports our initial observations considering condition three; i.e., participants completed tasks significantly slower than in the other conditions. Furthermore, the data shows that expanding the target (i.e., C2) results in significantly improved task completion times compared to tasks completed in the baseline condition (i.e., C4). Interestingly, additionally shrinking the distance (i.e., C4) causes task completion times to be significantly worse compared to the baseline.

We found statistical differences in the numbers, which mean based on our method (repeated measurements) that there are significant within subject differences, which may not be visible to the same extend in Figure 5a, since this figure presents cumulated results over all par-ticipants for each condition. Independently, the numbers need to be interpreted considering a driving context; that is, a mean difference over all participants between C2 and C4, which is about 150ms might be not worth mentioning in a desk environment but in a driving context it can not be ignored. When having to choose between C1 and C4, with C1 producing better success rates and C4 better task completion times, one has to take into account what penalties there are for non-successful interaction in a real interface implementation.

Accuracy in target acquisition

Success rates were specific to the concrete target object sizes that were used in the study. In order to measure touch accuracy in more detail, we computed the absolute distance of touch (including touches that produced failures) to the center position of the target. The resulting data (see Figure 5b for an overview) was used to compute a repeated measures ANOVA, which revealed significant differences between the study conditions F(1, 6) = 9.6, p<0.001. Again, seven post hoc comparisons using pairwise t-tests with adjusted p-values were conducted, which identified significant difference between C1 (M=20.3px, SD=14.4px) and C2 (M=16.5, SD=9.3), p=<0.001; between C1 (M=20.3px, SD=14.4px) and C4 (M=14.3px, SD=8.4px),p=<0.001; between C2 (M=16.5, SD=9.3) and C3 (M=20.9px, SD=8.4px), p=<0.001; and interestingly between C2 (M=16.5, SD=9.3) and C4(M=14.3px, SD=8.4px), p=<0.001. No significant effect was observed between C1 and C3 (see Figure5b).

Surprisingly, accuracy was proven best in the baseline condition (i.e., C4). With the accuracy data one has to keep in mind that while we observed statistical differences in the numbers, their practical relevance for human interaction is minimal to obsolete. For example, the mean difference between C2 and C4 is 2.3px (approximately 0.4mm). That said, the data shows the expected speed accuracy trade-off for expanding targets. That data shows that participants were significantly faster with expanding targets (i.e., C4) compared to the baseline condition (i.e., C4), but the accuracy achieved in C2 decreased significantly compared to C4.

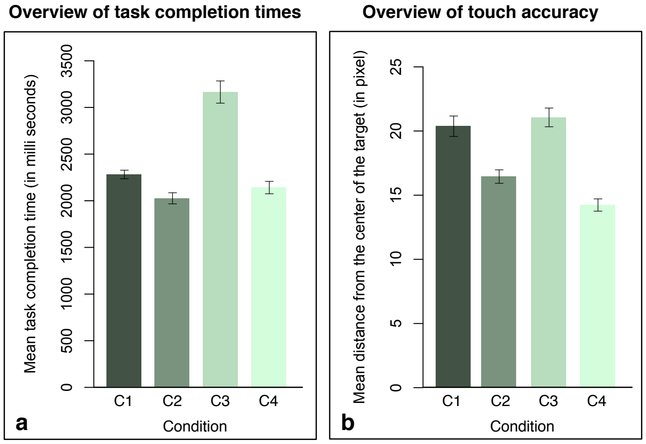

Figure 5. a) Mean task completion times for each condition. b) Overview of accuracy in target acquisition for all conditions. Error bars denote standard error of the mean.

Reflections and Initial Design Implications

We conducted the explorative driving simulator study in order to "replicate" results associated with dynamically adapting targets, which were gained in different contexts (e.g., desktop context) but were not yet explored in a driving context. In summary, we found that expanding targets based on the proximity of the driver's forefinger significantly improves (as expected) targeting for touch screens in the car. Surprisingly, shrinking the distance to a target object resulted in significantly worse performance (i.e., success rates, task completion times, and accuracy). The results is surprising since Fitts's law suggests that shrinking the distance to a target object would result in better performance during aimed movements.

On one hand, it could be that when driving a car, drivers have reduced visual resources to spare and, consequently, drivers are not able to keep focus on the target object during an aimed movement. In order to touch a moving target on a screen, the initial movement might require subsequent corrective movements and cause undershooting or overshooting the target. We have witnessed this behaviour in-person when participants were completing tasks in condition three. On the other hand, while in condition three the distance to target objects was shrinked, it was shrinked not according to a predicted movement trajectory in 3D. That is, while the finger movement trajectory is in 3D, the adaptation happens on the the 2D screen, requiring subsequent corrective movements, which might cost more time in a driving context. If it were possible to shrink the distance to the target in 3D space (e.g., physically moving the screen itself towards the driver's finger) driver's might not need to perform corrective movements, resulting in better outcome.

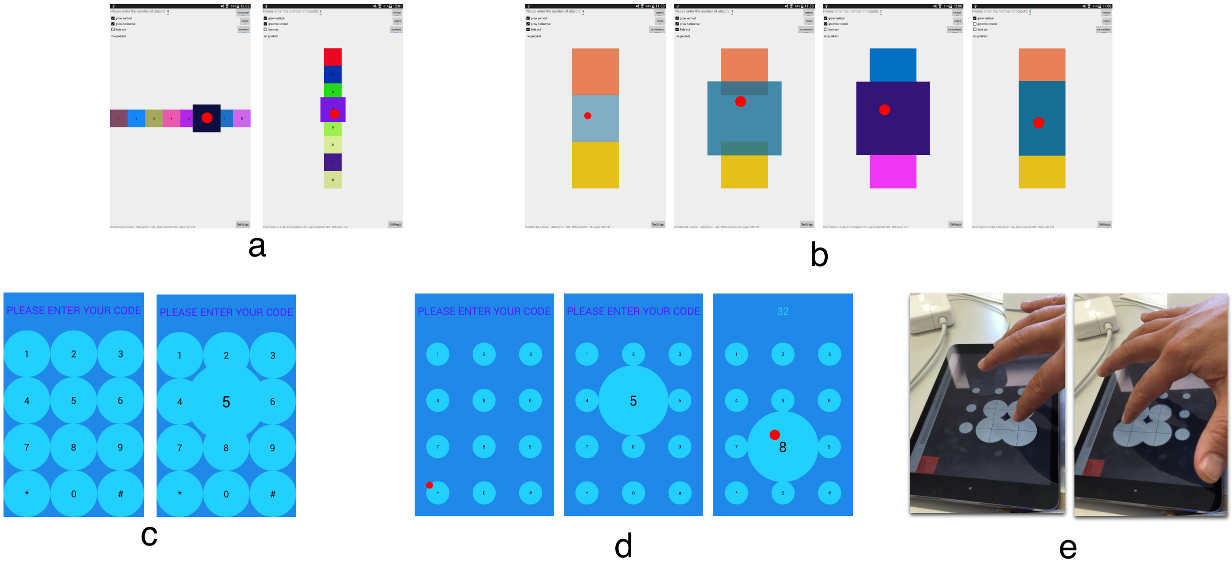

Figure 6. **Exemplary screenshots of the two applications (i.e., a and b *LayoutExplorer*, and c and d *Numpad*++), showing variations of interfaces with expanding targets a) Horizontal and vertical menu layouts b) Varying strategies to visually adapt a target, c) Number pad interface with initially larger target objects, and d) Number pad interface with initially smaller target objects e) Demonstration of proximity sensitive target expansion with multiple expanding targets.**

In conclusion, when there is no way to move the target object in 3D, target expansion strategies should be used to improve touch screen interaction in the car. Target positions should not be altered even if the change results in reduced distances to target objects. We investigated our "solutions" using a single target. There are some issues when multiple targets are used. Since the display space is restricted, the question arises which targets should be expanded and which not. McGuffin and Balakrisnan [12] show that only the final expanded target sizes matters and not the original size of the target. Consequently, there is some freedom for the designer to design the initial layout. When finalizing touch interface designs (e.g., choosing icons that represented meaningful objects), one has to be aware that there are additional semantic measures to target size and position, which may also influence performance when interacting with touch targets [3].

The outcomes of the driving simulator study were used to guide follow-up prototyping activities. Resulting prototypes were thereafter utilised to foster discussion in a workshop with experts. In the following section we describe our activities in detail, providing further insights on issues identified but not addressed in the driving simulator study.

WORKSHOP WITH EXPERTS

The workshop was set-up together with five automotive experts having various backgrounds (i.e., HCI, computer sciences, psychology) and an expert in interaction design (i.e., touch interaction) who was organizing the workshop. An additional researcher was responsible for the data collection (i.e., making observational notes) during the session. Overall, the workshop lasted for 1,5 hours and took place at our research institute. Main goal of the workshop was to explore the potential of different adaptation strategies for in-car use in order to identify future design spaces in the car. In particular, the workshop aimed to address issues that are related to the design of such adaptation strategies, such as target location on the screen as well as issues related to many closely placed targets.

Prototypes

Following up the results of the driving simulator study two applications with expanding touch targets were implemented. The applications were implemented as native Android applications, allowing the design of "richer" graphical interactions on the mobile device and potential improvement of performance (compared to the Javascript implementation that was used in the previous study).

We refer to the first application as *LayoutExplorer*. The aim of this application is to allow rapid exploration of different kinds of menu layouts (e.g., horizontal, vertical) with adjustable numbers of expanding targets. Furthermore, this applications allows to explore targets that visually behave in different ways by adjusting (using a control menu) scaling factor, scaling orientation (horizontal, vertical, or both), transparency of the target, and background type (icon or color). Figure 6a presents exemplary horizontal and vertical menus with expanding targets. Figure 6b shows examples for different visual behaviours of target objects.

The second application, which we refer to as *Numpad*++ is an implementation of a number pad, typically used in cars, for example to input zip codes . The *Numpad*++ application was implemented in two versions (i.e., with initially large targets and initially small targets inspired by suggestions of McGuffin and Balakrisnan [12]) in order to explore "worst case" scenarios where the screen is filled with expanding targets. Furthermore, in both applications it is possible to show a red dot, indicating feedback during mid-air finger movement for the prediction point of touch on the 2D screen.

Workshop Procedure

As a first step within the workshop, the automotive experts had the opportunity to use the *LayoutExplorer* and *Numpad++* applications for experiencing interaction with expanding targets in different interfaces. By using the "think allowed" technique [6] the experts were asked to verbally articulate their experiences when interacting with the prototypes. On basis of the presented prototypes, as a second step, a feedback round with the workshop participants has been conducted. To ease the discussion on future design spaces, four potential usage scenarios (i.e., the driver, the co-driver, shared use and semi-autonomous driving) have been developed for the workshop and were used to structure the discussion. For each of those scenarios, the participants were asked to make notes and comment on the screen/target location and position of targets on the screen. Furthermore, participants were asked to provide one potential/weakness of using such adaptation strategies in each of the presented scenarios. Each note was discussed with the entire workshop group.

In a third step, the workshop organizer triggered the discussion about how context parameter may be combined with such adaptation strategies (i.e., expanding targets) to gather further insights about future application areas and interaction potentials. The workshop then closed with a general discussion in the group about open issues concerning the presented adaptation strategies and how they may be addressed in future designs. On basis of the responses, feedback and ideas we gathered throughout these different steps (collected with notes), a content analysis [9] has been conducted. The relating findings are presented in the following.

Workshop Results and Discussion

Experiencing interfaces with multiple expanding targets

The main responses from the interactive session at the beginning of the workshop are centered around concerns the experts have and potentials they see when interacting with expanding targets in the car. For example, one concern dealt with the interaction accuracy for left-handed co-drivers and how this may already be addressed with expanding targets. Another open issue dealt with the affordance of touch-screens with expanding targets; does the affordance of a touch screen remain (i.e., is touch still needed) or will "uni-modal" mid-air gestures and mid-air pointing for selection be preferred in future. Further, the experts articulated that expanding a target could not only be used to improve performance in acquiring the target, but to zoom-in a target (e.g., a map) and select an area within the target object (e.g., a point of interest on a map). Experts also mentioned that by adjusting the transparency of expanding targets a feeling of static positions of targets was established in spite of some overlaps associated with expanding targets.

Driver interaction

Considering driver interactions, the experts were in general agreement that expanding targets on a screen has potential for drivers as it may improve performance and reduce distraction significantly while driving. Surprisingly, many closely placed expanding targets were not seen as an issue. One expert even noted that with touch screens as large as tablets and them becoming even larger (e.g., in Tesla model cars) one might not need to expand targets at all in the future, with issues then relating to reachability of targets. The main critical aspect outlined is performance and reliability in recognising mid-air finger movement. The data gathered from 3D sensors needs to be (always) reliable and performant before expanding targets can be used in real cars for drivers.

Passengers, collaboration, and semi-autonomous cars

With regard to the interaction spaces of passengers and in semi-autonomous cars, the experts noted that these two scenarios were in terms of interaction context rather similar. The only difference being that in semi-autonomous cars "drivers" can take part in collaborating activities with passengers (e.g., play a game) which brings us to the last scenario: shared use of touch screens in the car. For example, touch screens attached to the middle console, which can be used by drivers and front-seat passengers. It was articulated that intentions to touch a target could be used to foster collaboration between driver and front-seat passenger. For example, a passenger could point to a target (but not touch it) to communicate the driver which target to acquire. Target expansion could be used to highlight which target was pointed to by the co-driver. Using different visualisations for different persons in the car (e.g., through color coding) the same technique could be used when two persons interaction at the same with the same touch screen. It was also noted that seat-detection technology may allow identifying the number of persons in the car and potential make use of identifying the person closest to the touch screen.

Integrating driving context and expanding targets

In a last discussion round, the experts discussed about how context parameter (i.e., physical and social parameter) may be combined with adaptation strategies. Here, the experts noted that, for example, the size of the targets enhances in relation to the drivers or passengers eye-sight (i.e., enlarging targets when being short sighted). The experts also discussed that the representation of the items on the screen (e.g., size and shape) can change according to changes in the driving style (e.g., items enlarge when driving faster). Using larger scales for expanding targets when driving faster can also support driving security through higher interaction performance and accuracy. Furthermore, the experts also emphasized the possibility of driving profiles (e.g., age of the driver, seating position) that allow for personalized adaptation strategies and screens. Also external context factors, such as for example weather, fluidness or density of traffic, long or shorter driving distances as well as the physical and mental state of the driver might be parameters to be thought of, when designing for interaction with expanding targets in the car. Besides these topics, the experts also discussed about open issues that need to be thought of. They, for example, consider sound/auditory input as complementary to pure visual input especially in hazardous driving situations.

CONCLUSION

In this paper we explored two research questions. First, if dynamically altering size and position of a touch target improves targeting performance in a driving context; and second, how challenges related with many closely positioned (expanding) targets can be addressed. In order to answer the first research question we conducted a driving simulator study. Our aim was to confirm in a driving context the positive effect of target adaptation strategies (reported in previous related research) on performance. We implemented three strategies where the targeted object dynamically adapts its visual design on the screen (i.e., size, position, and both size and position) to the proximity of a driver's finger in mid-air when approaching the touch screen. Results show that adapting the target size on touchscreens does not only increase success rates but significantly improves task completion times, while (surprisingly) distance adaptation did not lead to improvements but significant worsening.

In order to address the second research question, we implemented two prototypes (based on the results of the first study) for exploring interfaces with multiple expanding targets. In a workshop with experts, prototypes were used as probes to foster discussions on the results of the driving simulator study, issues related with many closely positioned targets, and challenges in relevant future design spaces (e.g., semi-autonomous driving). We conclude that by combining mid-air gestures with touch, not only is it possible to improve in-car touch-based interaction, but that through the combination a design space is spanned with high potential to address situations in the car which demand visual attention (e.g., collaboration between passengers and drivers, critical driving conditions). In our future work, we aim to continue our exploration of this design space towards creating embodied interaction with automotive interfaces.

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