Touchscreens as the De facto Interface to Complex Systems

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Touchscreens as the De facto Interface to Complex Systems

Touchscreens have become the de facto interface for mobile devices, and are now rapidly becoming the standard way to interact with complex systems across a variety of domains. Today, car dashboards, medical machinery in hospitals, and factory production line control systems, are commonly controlled through touchscreens. Whilst touchscreen interfaces generally perform well in controlled indoor environments, their use in-the-wild brings a variety of new challenges and requirements, ranging from eyes-free usage, use whilst encumbered with other equipment, environmental issues such as rain, parallax error due to the use of protective and vandalism-proof touchscreens, use whilst wearing gloves and secondary use whilst engaged in a primary task. In this chapter, we bring together work addressing in-the-wild applications of touchscreens, highlighting challenges relevant for designers of complex touchscreen-controlled systems. We discuss the accuracy with which users interact with touchscreens, problems caused by parallax errors and the propensity of touchscreens for accidental input. Finally, we present a case study, exploring novel touchscreen input mechanisms in a car dashboard context.

Keywords: touchscreens; interaction; complex systems

Touchscreens as the de facto human-computer interface

Touchscreens are one reason for the success of mobile devices such as smartphone and tablets. Their success carried over to other device domains including cars, vending machines, and complex systems, as touchscreens enable intuitive input and manipulation of data. Whilst using keyboard and mouse to control graphical user interfaces is still common in office environments, outside of such optimised environs the touchscreen became the dominant input device. Annually, it is estimated that almost 2 billion touchscreen panels are delivered, finding a huge variety of applications in all areas of human endeavour (Touch panel market tracker). The original driver for the development of touchscreen interfaces was their ability to support *direct manipulation*, i.e. users can manipulate visual user interface (UI) elements shown on the display directly using their fingers or a stylus. However, their wider adoption has been fuelled by a multitude of other factors, such as their flexibility, low cost and speed of interface development. Further, the level of de facto standardization of touchscreen interactions, initially driven by Apple's iPhones, also reduces the learning curve for systems with touchscreens. Once users internalized interactions, such as *pinch-zoom*, the input technique can be directly adopted when taking a new system into use. A testament to this is the commonly reported case of young children, raised with tablet computing devices, being disappointed when they are unable to *pinch-zoom* an image in a printed magazine.

At some point in their evolution, as well as controlling purely on-screen interactions, touchscreen UIs began to be used to control real-world physical systems. In such applications, touchscreens often replaced mechanical input mechanisms, placing additional requirements on the interface to produce satisfactory interaction. In many of these usage contexts, users interact with touchscreens in challenging conditions, either caused by environmental factors, e.g. cold and rain, or by other limitations such as the user wearing gloves or being encumbered with other equipment (Ng, Brewster, & Williamson, 2014). Further, often operators need to interact with touchscreen interfaces whilst focusing their gaze elsewhere, resulting in the need for eyes-free usage of the interface. Examples of such cases range from factory production lines to large forestry machines, hospital operating theatres and juice dispensers in hotels (Figure 1).

Figure 1. Left: A touchscreen juice dispenser in a hotel provides an example of the ubiquity of touchscreen interfaces. Right: "This is not a touchscreen" - a warning on an interactive non-touchscreen display in a toy store illustrates children's expectation of touchscreen functionality.

Whilst touchscreen interaction provides advantages such as flexibility to cost efficiently optimize the interface for each use case, it also brings challenges that must be addressed by the UI designer. Many factors including touch target size and location, ergonomic factors and the resilience of the attached functionality to accidental activation must be considered to design successful interfaces. Additionally, touchscreens lack the haptic benefits of physical knobs and buttons. Interfaces with physical push buttons, physical knobs that can be rotated and sliders that can be physically moved provide a far more tangible experience than touchscreen UIs, and as a consequence reduce the requirement on the visual sense for operation.

To provide guidance for UI designers, we firstly discuss the challenges related to the accuracy with which users can interact with touchscreens. Secondly, we describe the issue of the reliability of touchscreens as an interaction medium, focusing on the accidental activation of touchscreen functions. Finally, as an example of touchscreen interaction with a complex system in-the-wild, we present the design of a novel interface for an automotive dashboard. This chapter then concludes with a summary of the challenges to be addressed in the design of touchscreen interfaces for complex systems.

Touchscreen accuracy

Background

A large body of research investigated the accuracy of finger based touchscreen input. For example, research has reported an optimum target size of 9.6 mm for acceptable error rates for thumb based interaction on a handheld touchscreen device (Parhi, Karlson, & Bederson, 2006). The work by Holz & Baudisch, (2011) provides perhaps the best overview of finger-based touchscreen interaction and why users' accuracy is limited. Here, the *fat finger*, problem is described, where the thickness of the user's finger causes perception errors due to parallax differences between the visible upper surface of the finger and the underlying pad of the finger that is in contact with the device's screen.

In the following we present two aspects affecting the accuracy of interacting with touchscreens in the wild – touchscreen targeting accuracy and errors due to parallax effects.

Compensating Systematic Errors

Touchscreens come in a variety of sizes and users interact with them in truly diverse environmental conditions. To study the diversity of touch interaction with a large number of subjects in realistic and diverse contexts, we followed what has been called an in-the-wild approach (Henze, Poppinga, & Boll, 2010). We published multiple mobile games to the Google Play store (formerly called Android Market), *Hit it!*, *Tap it!*, and *Type it!*, that present controlled touch tasks and recorded the player's touch behaviour (Henze, Pielot, Poppinga, Schinke, & Boll, 2011; Henze, Rukzio, & Boll, 2011, 2012). In these games, players have to select targets or control keyboard while we systematically control the properties of the targets and the features of the keyboards (Figure 2). Altogether, the games were installed more than 100,000 times and produced a combined data set containing more than 135 million individual touch events.

From the results, we, for example, identified that the position of the previous target affects the error rate and speed with which targets are selected, and the average touch position is skewed towards the previous target. The large data set enabled us to identify that users make systematic errors, with taps being offset towards a point at the lower right middle of the screen. As the errors are systematic we could show that it can be compensated to improve users' accuracy. Later research extended the work and showed how to further improve users' accuracy using machine learning (Weir, Rogers, Murray-Smith, & Löchtefeld, 2012), and considering the individual user (Buschek, Rogers, & Murray-Smith, 2013).

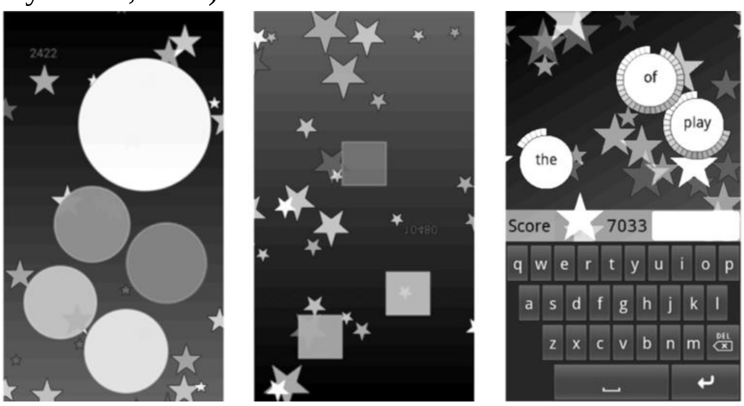

Figure 2. Screenshots from our applications investigating touchscreen accuracy. Left: Hit it! Center: Tap it! Right: Type it!

Correcting Parallax Errors

Using mobile devices, touch accuracy is already affected by perception errors. Touchscreens used in public settings and industrial installations are typically equipped with a protective glass layer on top of the display, creating a gap between the front of the touchscreen glass and the actual display. As illustrated in Figure 3, this gap results in a parallax error, i.e., a displacement between the perceived and the detected touch point on touch interfaces (Khamis, Buschek, Thieron, Alt, & Bulling, 2018). This problem is further amplified as the angle between the display and user's eyes increases. For example, in industrial environments, the parallax error is potentially exacerbated by the location and usage modes of touchscreen displays, which often result in the user's viewpoint being at severe angle to the display. To reduce the angle relative to the user's view, many ATMs and ticket vending machines feature inclined displays. However, inclining the display is not always feasible, and hence parallax continues to hinder the user's experience in many present-day touchscreens (see Figure 3).

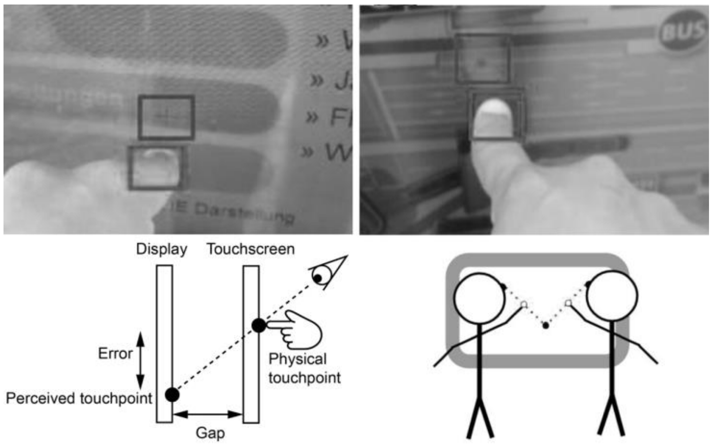

Figure 3: Top Row: In these real-world examples, the lower boxes illustrate where the user intends to touch; the uppeer ones show where the system thinks the user is touching due to parallax error. Bottom Row: Parallax errors are caused by the gap between the display and the touchscreen. EyePACT reduces the parallax error significantly by leveraging the user's eye position to estimate the intended touch point (figures adapted from Khamis et al. (2018)).

In our project *EyePACT*, we propose a simple yet effective Eye-based Parallax Correction method for Touchscreens. We first cast a gaze vector that intersects the user's touch point to estimate where the user intends to touch, and then trigger the touch event at the point where the gaze vector intersects the display. We presented the first evaluation of eye-based parallax correction. Results show that EyePACT significantly improves accuracy, and adapts to varying levels of parallax even with gap distances as large as 6.8 cm. We also found that it significantly improves multi-user interactions.

Namely, it allows for maintaining a large distance between the fingers of the different users while they interact with the same target, thereby preventing finger interference. We further experimented with a regression model that corrects for parallax without the need for a camera. We found that it significantly improves accuracy, and that combining it with EyePACT significantly improves accuracy further.

Accidental and controlled interaction with touchscreens

False negatives and false positives

In any interaction that takes place in an in-the-wild context there is a potential for failure. For example, when aiming to switch on a room light with a traditional mechanical light switch, there is a chance that the user's finger slips on the switch, or does not press quite hard enough to activate the switch. In this case, when aiming for a positive interaction, switching a light on, the user has unintentionally created a negative unintended result, termed a *false negative*. Whilst such occurrences are rare when using mechanical light switches, and are easily corrected with users typically blaming themselves for the error, touchscreen interfaces provide higher potential for such errors. The reciprocal error of the *false negative*, the *false positive,* is familiar to the majority of smartphone users. Here, a functionality is activated by accident, e.g. continuing our light switch analogy, by accidentally leaning against a wall mounted light switch and unintentionally switching the light on, creating a *false positive*. Using smartphones a common problem is to unintentionally touching the screen with the palm, see e.g. Le, Kosch, Bader, Mayer, & Henze (2018), which can result in e.g. hanging up an ongoing phone call by accident.

For each design case, the user interface designer must consider the balance between ease of activation, i.e. reducing *false negatives* and the consequence of false activation through a *false positive*. For example, a fire alarm requires a high resilience to false positives, which is reflected in the common design of such interfaces, with the user having to first break a glass cover before pressing the activation button. Whilst such design approaches have become de facto standards for physical interfaces, the same is not yet the case for touchscreen interfaces. In the touchscreen domain, the challenge is further exacerbated by the lack of haptic feedback from touchscreens and the lack of the immediate and natural *undo* mechanism naturally present in mechanical switches. Thus, the error tolerance of touchscreen interfaces requires particular attention from the designer, see (ISO 9241-110:2006 - Ergonomics of human-system interaction -- Part 110: Dialogue principles).

Unintentional touchscreen interactions

To quantify unintentional touches on touchscreens we studied the accidental touches that occur when users perform typical smartphone handling tasks. We compared the accidental touches with a baseline where participants purposefully interacted with touch targets on a smartphone screen. Further details of this study are found in Matero &

Colley (2012). For example, we show that not only the location on the touchscreen where the input happens but also the duration the user's finger is in contact with the touchscreen is an important factor to identify accidental touches (see Figure 4). Here, the majority of intentional touches having contact times between approximately 100ms and 300ms, with contact times outside this window being more likely to be accidental in nature. We provide a filter function that, based on the collected data set, can reject 80% of unintentional touches, whilst having minimal effect on the intentional touch performance, reducing it by less than 1%.

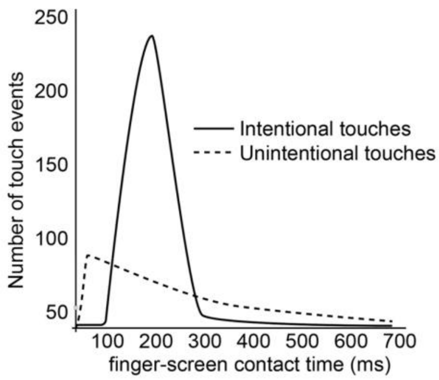

Figure 4. Intentional touchscreen interactions result in finger-screen contact times between 100 and 300ms. Touches that are briefer or longer than this range are more likely to be unintentional.

Controlled interaction with touchscreens

Traditionally, complex control systems, e.g. in factories and industrial vehicles have utilised custom control panels containing arrays of physical buttons, levers, rotary knobs, and linear sliders. When such control systems are replaced with touchscreens, the natural tactile and kinaesthetic feedback provided by such controls is lost. This is particularly relevant in use cases where the user is multitasking, or has to operate the controls whilst looking at another part of the system, e.g. an industrial excavator operator's focus should be primarily to the outside of their cab. This reduction in usability can result in an increase in errors, and in the case of many complex systems, requires a costly rectification process.

Whilst a wide variety of different technologies have been studied to artificially enhance touchscreens with haptic sensations, e.g., vibration (Kaaresoja, 2006) and electrostatics (Bau, Poupyrev, Israr, & Harrison, 2010) these do not approach the level of tangibility provided by actual physical controls. Physically morphing touchscreens, e.g. using embedded air or liquid pockets, have been studied e.g. (Harrison & Hudson, 2009) and are commercially available from Tactus (Tactus Technology White Paper)

To combine some of the benefits of physical controls with those of touchscreen interaction, we created a *guided touch* concept where touchscreen interaction is guided by an overlaid transparent acrylic sheet that enables only interaction with areas of the screen where holes are cut out in the overlay (Colley, Virtanen, Ojala, & Häkkilä, 2016). We evaluated the interface in a study simulating the split visual attention that may occur when operating an industrial system, the user having to manipulate items at a distance via a locally situated control panel (Figure 5). Users found the guided touch solution improved the task usability and were able to move more quickly between operation of different controls (although the overall interaction time was not reduced). This type of *guided touch* solution may be of benefit in applications where the functionalities provided by the touchscreen are fixed, or change based on usage mode, e.g. agricultural equipment used for different tasks.

Figure 5. Eyes-free use of the touchscreen enhanced by the addition of a Perspex guiding layer

Case example: Touchscreen car dashboard

The car dashboard is an example of a domain that has previously been dominated by carefully designed physical interfaces, that is now migrating to use touchscreen interfaces. Manufacturers such as Tesla Inc. started to prominently integrate touchscreens into their vehicles. Tesla's Model S offers a 17” capacitive touchscreen to provide an intuitive and extensible way to interact with the car. With the recent trend towards autonomous driving, a wide range of further use cases are envisioned for in-vehicle touchscreens, see e.g. Pfleging, Rang, & Broy, (2016). As with many other domains for complex interactions, the dashboard interface requires that the user is able to operate it whilst primarily paying attention to another task, in this case safely driving the vehicle. Standard touchscreen UIs require the user to locate individual touchscreen controls on the touchscreen, which due to the lack of tangibility, is difficult to achieve without frequent glances to the touchscreen and away from the primary task.

To enable users to activate functions without necessarily looking at the screen, we studied *finger specific interaction,* whereby each of the user’s fingers triggers a different function when touching the touchscreen (Colley & Häkkilä, 2014). To explore this in the car dashboard domain, we developed a prototypical system and compared normal button based interaction with finger specific interaction, where the user is able to touch anywhere on the touchscreen to activate the desired functionality (Colley, Väyrynen, & Häkkilä, 2015). Our system allows to control a range of functions including the navigation system, the air condition and multimedia functions (Figure 6). We integrated the system into a car and show that finger specific interaction requires less visual attention than using touchscreen buttons. On the negative side, the new interaction approach required users to memorise the functionality attached to each finger and some participants reported dexterity limitations with their little finger.

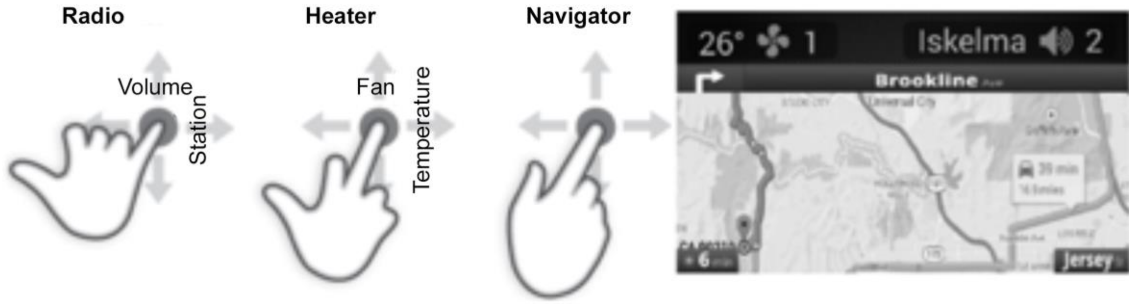

Figure 6. Finger specific interaction to enable eyes-free touchscreen interaction with a car dashboard (adapted from Colley et al. (2015)).

Conclusion

Touchscreens will continue to be a primary way for humans to interact with complex computer-based systems for the foreseeable future. As we have highlighted, touchscreens do not necessarily lead to improved user experience and overall system performance. In this chapter, we have described some of the primary challenges that should be considered by the designers of complex systems integrating touchscreens, ranging from managing their propensity for accidental input, errors due to viewing angle and the parallax effect, and challenges to utilise them eyes-free. Improving interaction with touchscreens has been a particular focus area in the human-computer interaction research community for some years, and continues to be so. In this chapter, we have presented four of our research contributions aiming to improve touchscreen usage in-the-wild, *compensating systematic errors*, *parallax correction, guided touchscreen interaction*, and *finger specific interaction.*

Future research directions

Multimodal interfaces

Touch interfaces can greatly benefit from the inclusion of additional modalities. For example, in our work on parallax correction, we demonstrated how implicitly leveraging the user’s eye gaze significantly improves the accuracy of touchscreen input. Multimodal interfaces have been long investigated in research and industry. However, the recent advances in sensing technologies make a myriad of modalities ubiquitously available for in-the-wild application. For example, Google’s project Tango and Apple’s iPhone X feature depth cameras that can be used for accurate gaze estimation, and situated displays in public (e.g., ATMs) are increasingly adopting cameras for interaction and security purposes. Eye trackers, proximity sensors, and depth cameras can be used to detect eye movements, bodily and mid-air gestures, body posture, body height, and more; all of which can support and enhance touch-based interactions. This presents an opportunity for wide-scale multimodal interfaces that are used in the wild.

Mirroring familiar interactions

Many users of touchscreens come from a background where their first interaction with computing devices was through desktop computers. Touchscreen still lack basic features that come with the traditional keyboard and mouse. For example, a mouse comes with at least two buttons, thereby offering two modes of input, while direct touch lacks an equivalent to allow further modes of input. While research has investigated solutions using dwell time, touch gestures and force touch, to allow further modes of input, none of these approaches has yet made it to wide scale usage, which implies that further research is needed to take these concept to the wild.

Providing additional input modes

A major challenge for touchscreens is providing different input modes. For desktop computers, the mouse provides a second input mode through the right mouse button. Further input modes can be realized through modifier keys on the keyboard. Current touchscreens realize additional input modes through long presses or by distinguishing different force levels. Both approaches are limited in the number of additional input modes that can be provided and are either slow or imprecise. Our work on finger-specific input can be used to provide additional input modes (Colley & Häkkilä, 2014). Further directions to enrich touchscreen interaction include recognizing the angle of finger touching the screen (Mayer, Le, & Henze, 2017) and using other body, such as the palm to activate additional functions (Le et al., 2018).

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