Improving the Tactility of Touch Interfaces

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Before the dominance of digital tools, most interface designs used to have a physical surface that users could touch and feel. This physical interaction was a great way to communicate certain affordances to the user. Now, the rise of touchscreens in devices in the last decade and the increasing dependency on such devices has made the interaction between a person and a digital interface important. One of the drawbacks of using digital interfaces is that they rely a lot on the vision of the user. Take, for example, the media system of a modern car. Most controls are embedded inside the touch interface that the driver has to look at to interact with. Operating the vehicle without visual attention becomes essential to decrease potential distractions when engaging in a secondary activity that requires focusing on the center console. This paper aims to address the problem by exploring existing literature to find solutions to improve the tactile experience of current touchscreen technology. This paper concludes with the importance of tactile feedback in touch interfaces and brings forth important factors for creating an effective tactile feedback system. It also explores alternative solutions to provide feedback through external devices, which further enhances interaction by making use of the device's specific features to provide multi-modal input.

CCS CONCEPTS • Human-centered computing • Human-computer interaction • Interaction Devices

Additional Keywords and Phrases: tactility, touchscreens, affordance, surface haptics, accessibility

1. INTRODUCTION AND BACKGROUND

Nowadays, for most people, interacting with touch interfaces is a daily occurrence. An example of this is the prevalence of smartphones in people's lives. Touchscreens have become ubiquitous in modern life, revolutionizing the way we interact with technology [4]. Touch interfaces have permeated our personal and commercial spaces, from smartphones and tablets to self-service kiosks and vending machines. This widespread adoption can be attributed to the numerous advantages touchscreens offer over traditional physical interfaces.

One of the key benefits of touchscreens is their ability to maximize space and enhance efficiency. By eliminating physical buttons and controls, touchscreens allow for more compact and streamlined designs, enabling the integration of a wider range of features and options within a limited area [4]. For instance, a smartphone screen can accommodate a multitude of applications and functions, whereas a traditional phone with physical buttons would require a larger form factor to accommodate the same level of functionality [3]. Furthermore, touchscreens provide a more intuitive and user-friendly interaction experience compared to physical interfaces. The direct manipulation of on-screen elements using natural hand gestures creates a sense of immediacy and connection, making it easier for users to navigate and interact with devices [1]. Additionally, touchscreens often employ graphical user interfaces (GUIs) that utilize familiar visual cues and symbols, further enhancing usability and accessibility [11].

However, despite their widespread adoption, touchscreens also present certain drawbacks compared to traditional physical interfaces. One of the primary concerns is the overreliance on visual feedback, which can pose challenges for visually impaired users [7]. The absence of tactile feedback, such as the sensation of pressing a button or turning a dial, can make it difficult for users to confirm their actions or receive contextual information through touch alone [1]. Moreover, the lack of physical buttons and dials can hinder user interaction by eliminating affordances, which are visual or tactile cues that suggest the appropriate way to use an interface element. Without these affordances, users may experience frustration and confusion as they attempt to navigate and interact with the device [2]. This paper aims to explore ways to address these drawbacks and improve the tactility of current touchscreen technology. The primary approach taken to improve the tactile experience is to investigate different types of feedback that can be integrated with touchscreens today and also examine contemporary technology that supports this goal, such as Above-Device Interaction [10]. This paper also explores the idea of moving the location of tactile feedback outside the glass of a standard touch interface through external devices and enhancing existing interaction through multi-modal input.

2. LITERATURE REVIEW

This section presents details of the systematic search performed and the synthesis of the findings. Based on the scope of this study, a total of about 17 papers were considered for analysis. Out of these 17, 12 papers were finalized after removing papers that did not fit with the specific research goal. Below, the methods of the literature review are presented, and the results are categorized into themes.

2.1. Methods

2.1.1. Literature Search

The ACM Digital Library was selected as the primary source for finding papers for this report. The goal of searching papers was to systematically search and focus specifically on the touch interfaces and their tactility. Initially, the search started with generic terms for material, such as *touchscreens*, *tactile feedback*, and *touch interfaces*. After reviewing some articles, we discovered more specific terms such as *surface haptics*, *haptic devices*, and *above-screen interaction,* which improved the search quality and was key to finding more relevant articles.

2.1.2. Scope, Screening, and Study Selection

This study aimed to examine the drawbacks of using touch interfaces, explore ideas to improve tactile feedback, and assess the effectiveness of alternative feedback types, such as audio and visual feedback. While searching for articles in the ACM digital library, The relevant articles were decided on by reading the title and following up by reading the abstract. If the paper fell into what we were looking for, we read the conclusion to determine if the result helped inform the overarching goal of this report.

2.2. Results

2.2.1. Effectiveness of Tactile Feedback for touch-interfaces

The study by Koskinen E. et al. concluded that tactile feedback significantly elevates finger-based text entry and user performance on touch screens, resulting in increased usability and pleasantness in the experience [11]. The experiment used 12 participants, and each participant was asked to do a task using various tactile feedback conditions. The results also conveyed that the user experience can be improved further by the customization options of feedback intensity and the incorporation of optional audio feedback to cater to diverse user preferences. The addition of tactile feedback can benefit all interactions with touchscreen buttons, not just text entry, and can benefit both stylus and fingertip interaction [6]. Tactile feedback was also noted to significantly improve virtual button interaction, reduce error rates, and improve performance, particularly in noisy environments in the study by Kaaresoja T. et al. [12]. The experiment with 24 participants also resulted in a suggested latency range for each type of feedback. Their guidelines stated that tactile feedback latency should be between 5 and 50 ms, audio feedback latency between 20 and 70 ms, and visual feedback latency between 30 and 85 ms in capacitive touchscreen virtual button interaction. These values help add a practical dimension to calculate the effectiveness of each type of feedback. These guidelines are essential to inform that hardware and software engineers do not need to optimize the latency between touch and feedback towards 0ms when working towards improving user experience. To assess whether the advantages of tactile feedback translate into a real-world scenario, Brewster S. et al. conducted an experiment where six participants interacted with a device providing tactile feedback on a moving train in Glasgow City underground [6]. They found that the number of lines entered into the device and errors made were the same as in a lab setting. The only variable affected by the real-world context was the number of uncorrected errors resolved by the participants. This experiment also was a great way to test the effectiveness of tactile feedback in an environment where auditory feedback cannot be relied on.

Tactile feedback can also be improved in terms of precision by using specialized actuators, as Hoggan E. et al. explored in their study [1]. Specialized actuators provide localized feedback to the hand holding the device, incorporating spatial location into the feedback to indicate which button is pressed. They experimented with nine male and three female participants to find that using multiple actuators to provide spatial cues has improved text entry on touchscreens. Additionally, specialized actuators can produce a wide range of frequencies, unlike many basic mobile phone actuators with a limited frequency range. Another interesting technology that takes tactile feedback to the next level was used in a study done by Mullenbach J. et al., where the experiment involving 24 participants explored haptic communication between pairs of couples and strangers using a haptic virtual touch application to provide a sense of co-presence and intimacy [9]. The application was hosted on the *TPad* Tablet, which improves upon tactile feedback by incorporating a haptic surface above a touchscreen tablet, allowing for the variation of friction coefficient and resistance force as the fingertip slides across the screen, creating perceptions of shape and texture. The *TPad* Tablet allows for the creation of haptic patterns that can be used to communicate literal texture, convey emotional information, highlight content, engage in physical playfulness, and provide one's partner with an experience or sensation. Considering the existing technology and specialized technology available, good tactile feedback can significantly improve the usability of touch screens by enhancing performance, reducing errors, and providing users with valuable information in various interaction settings.

2.2.2. Tactile Feedback away from the Screen

Alternative types of interaction can be useful in certain situations where touching the touch interface may not be appropriate. Gestures offer advantages over touch interaction, including the ability to interact in a larger space above the device, especially on small wearables like smartwatches. Additionally, gestures enable users to interact with devices when touching them would be inconvenient, such as when cooking and needing to navigate a recipe without touching a tablet with messy hands [10]. In order to make use of gestures while still retaining the advantages of tactile feedback, Freeman E. et al. performed a study to add tactility to gestures by proving feedback through ultrasound haptics and wearable technology. Their experiment was conducted with 16 participants testing various distal types of feedback, such as an ultrasound array to provide feedback on top of a phone, a wearable ring to provide feedback on the user's finger, and a wearable watch to provide feedback on a user's wrist. The experiment concluded that tactile feedback was key to improving user experience – dynamic tactile feedback, in particular, was found to provide subtle changes in feedback that make users more aware of how the interface responds to their actions. Gestures also help in reducing screen occlusion by not requiring input elements on the screen. Occlusion affects touch input interfaces' effectiveness by reducing the input area on the touchscreen [5]. This reduction in input area can impact the accuracy and speed of touch input, potentially leading to decreased performance and user satisfaction. Therefore, minimizing occlusion is crucial for improving the usability and performance of touch input interfaces. User input through gestures can be further improved by using the ideas from Azenkot S. et al.'s work, where they devised a unique way of number-entry input where each number is encoded by a gesture relating to the digit's semantics [7]. Six blind and ten sighted participants were asked to input numbers on a device using this method. This resulted in realizing that entering numbers through Digitaps was faster but less accurate when audio feedback was removed.

Adding onto the external nature of the above technology, an external device such as *Conté* can also help improve interaction with a touch interface [8]. *Conté* is a prototype made by Vogel D. and Casiez G., a versatile input device inspired by artists' manipulation of an actual Conté crayon. It can switch between different interaction modes using a single hand by changing the contact point on the device. The device has the potential for mode switching based on grip sensing and leveraging different contacts for diverse affordances. The operator can switch interaction modes using a single hand by changing which corner, edge, end, or side is contacting the display. *Conté's* rectangular prism shape enables precise pen-like input and tangible handle interaction. The features of this technology, along with tactile feedback, can be helpful with a wearable device like the ones mentioned above to interact with a touch interface.

3. DISCUSSION

The common takeaway from all the papers is the importance and effectiveness of tactile feedback in improving interactions with touch-screen devices. Tactile feedback has been shown to enhance text entry, reduce errors, and increase user satisfaction, particularly in mobile settings [1, 6, 12, 11]. Tactile feedback can also be combined with other types of feedback to enhance user experience and improve interaction with touch-screen devices [6, 12]. The work done by Kaaresoja T. et al. shows that tactile feedback, when combined with visual and audio feedback, can improve performance and lower the workload in touchscreen button interaction. Additionally, multimodal feedback, including tactile feedback, has improved users' awareness of the interface state and made interaction easier, suggesting that combining tactile feedback with other modalities can significantly benefit user experience [8, 10].

Some papers also provided insights into improving the quality of the tactile feedback itself. The work done by Koskien E. et al. concluded that using piezo actuators was better than using vibration motors to provide tactile feedback for touch screen virtual buttons [11]. The results indicated that piezo feedback was the fastest to use and had the most negligible errors, suggesting that it may be a better option for providing tactile feedback for touch screen virtual buttons. The study suggests that customization of feedback intensity is necessary because different individuals may have varying preferences for tactile feedback. Another takeaway from their study suggests that user customization of feedback intensity is necessary, especially considering that strong haptic patterns can be associated with anger [9]. The study indicated that some users preferred more potent stimuli while others liked weaker ones, highlighting the importance of customizable feedback intensity [11]. A suggested latency for tactile feedback is also derived to be between 5 and 50 ms to ensure touch-feedback simultaneity for users [12]. The tactile feedback can also be localized using special actuators such as the C2 Tactor from Engineering Acoustics Inc., a small wearable linear vibrotactile actuator designed to provide localized feedback. This device was used in experiments by Hoggan E. et al., who noticed increased performance as participants could use spatial cues when interacting with a touch interface. Combining all these standards helps create a quality tactile feedback system that can ensure recruiting all the advantages of tactile feedback, as discussed in the previous paragraph.

Tactile feedback can also improve accessibility to visually impaired users by providing additional sensory information. For blind people using touchscreens, audio feedback through screen readers like Apple's *VoiceOver* is essential for navigating the interface [7]. However, when auditory feedback cannot be relied on, such as in noisy environments, tactile feedback can provide physical sensations to mimic physical buttons on touchscreens. Combining the number-entry method taken from the work done by Azenkot S. et al. [7] with the above-device tactile feedback using gestures [10] can be an effective way for visually impaired users to input information onto their devices. Information from the device can also be communicated back to visually impaired users by making use of variable friction and localized feedback technology [1, 9], especially through wearable devices or ultrasound haptics [10]. Even for individuals with sight, having another channel for passing information to the user can be a great way to improve the quality of interactions with existing information on screen or can also be used to communicate indirect information not visible to the user.

The papers included in this report also explore providing tactile feedback through external devices instead of directly through the glass of a standard touch interface. The work done by Freeman E. et al. explored the preference for wearable locations [10]. Participants liked tactile feedback on their fingers because it was close to the point of interaction, and fingertip position controlled the cursor, making it logical to receive feedback. Additionally, feedback on the wrist was found to be helpful, and participants indicated a willingness to wear a watch on the opposite wrist if it provided a purpose, such as feedback during gesturing [10]. Combining wearables with the takeaways from the Conté prototype, a wearable can also be a great way to provide multi-modal input to a touch-interface device [8]. For instance, each gesture done by a user's finger, such as touching, pinching, sliding, etc., can be updated to have multiple outputs based on the orientation of a wearable ring on the user's finger.

Tactile stimulation also opens up a pathway to communicate effectively using just touch. The experiment by Mullenbach J. Et al. involved exploring haptic communication between couples and strangers using a haptic virtual touch application to provide a sense of co-presence and intimacy [9]. One of the drawbacks of this study was the limited area of the *TPad* tablet used. Introducing technology such as ultrasound haptics allows the use of a larger area above the device while retaining the tactile aspect of communication [10].

This type of communication can play a significant role, especially with new virtual reality and augmented reality experiences.

4. CONCLUSION

This report explores the critical role of tactile feedback in improving touch-interface interaction. The studies included in this paper confirm that tactile feedback enhances usability, reduces errors, and increases user satisfaction, particularly in mobile settings. Beyond these practical benefits, tactile feedback also allows the possibility of improved accessibility and non-verbal communication for visually impaired users. Creating an effective tactile feedback system requires accounting for multiple factors. The choice of actuators for the pleasantness of vibrations, the user-customizable feedback intensity, and the optimal latency between touch and feedback ensure seamless synchronicity to enhance user perception.

External devices like wearables and ultrasound haptics allow tactile feedback to move outside the screen. Alternative interaction, such as gestural interaction for non-touch input, is ideal for situations where direct screen contact is inconvenient or undesirable. Wearables like rings and watches can become feedback hubs that deliver dynamic stimuli in response to user actions when using gestures. These devices can also facilitate a multi-modal input and enrich the interaction experience.

In the future, cost-effectiveness, technical complexity, and user acceptance of these technologies require careful consideration. Additionally, exploring novel applications, particularly in virtual and augmented reality settings, unlocks the potential for tactile feedback to redefine how we interact with the digital world. By embracing these advancements, we can not only enhance usability and accessibility but also look forward to a future where tactile stimulation can be used as an effective way to communicate with each other.

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